Architecture of Shipborne Automatic Identification System (AIS) via Space Wireless Communication System and Networks

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Abstract: The Wireless Communication System (WCS) is one of the fastest-growing sectors of the communications industry for fixed and mobile applications especially for maritime communications. The current Automatic Identification System (AIS), according to the International Maritime Organization (IMO) and Safety of Life at Sea (SOLAS) regulations and recommendations, is established to work at VHF frequency bands for Safety and Security (SAS) purposes and collision avoidance at sea. In fact, AIS is also developed for commercial purposes to provide positions for all ships worldwide. New AIS technologies and solutions are already proposed via Geostationary Earth Orbit (GEO) and Non-GEO or Low Orbit Satellite (LEO) and othet satellite systems including via Stratospheric Platform Systems (SPS). In this paper will be introduced current Radio and new Satellite AIS for maritime applications and the possibility of their integration with SPS networks. Economical and practical efficient methods to provide communication via SPS instead of several AIS Base Stations are presented.

Key Words: WCS, IMO, SOLAS, SPS, AIS, VDL, CNS, GEO, LEO, TCS, RSAS, GNSS, SOTDMA, IMS

1. Introduction

In accordance with IMO requirements all SOLAS registered seagoing ships in international traffic above 300 BRT must have radio VHF AIS equipment installed onboard. The AIS systems are designed to provide communication and determination including enhanced SAS for all ships engaged in the sailing over open sea, approaching to the anchorages and to complain stringent to port security requirements. The AIS transponder fully exceeds all specifications for SOLAS AIS onboard ships as outlined by IMO and by the ITU-R M. 1371-3 Regulations as well.

The AIS network is an automatic tracking system used on ships and by Vessel Traffic Service (VTS) to identify and locate vessels movements electronically just by exchanging ship's position and certain data with other nearby vessels and AIS Base Stations or Gateway. The communication in AIS system occurred through two VHF radio channel links, which links have to be in Line-of-Sight (LOS) only. A ship equipped by AIS transmits data to each other and onshore AIS Gateways as well. Depending on landscape configuration AIS Gateways should be installed on shore as many as necessary to cover close water surface area to keep LOS with every AIS unit onboard ship in the certain coverage area.

Because of limited propagation problems and LOS transmission of the VHF AIS, the new AIS via satellite is developed by Orbcomm satellite operator using Little Leo Earth Orbit (LEO) satellite constellation. However, the AIS satellite network can be also developed via GEO constellation and Non-GEO satellite networks, such as Big LEO Iridium and Globalstar or Nano satellite systems. Because of expensive satellite AIS solutions recently are proposed cost effective AIS via SPS networks. The SPS solution is a station located at an altitude of 20-50 Km as a fixed geostationary point relative to the Earth,

Today there are established Satellite Communication Systems (SCS) and Terrestrial Communication Systems (TCS), while SPS as an alternative has attracted the attention of the communication industries. The new SPS networks employ unmanned or manned, solar or fuel energy airships or aircraft carrying payloads with transponders and antennas. The SPS technologies can be considered as novel solutions for providing Communications, Navigation and Surveillance (CNS) applications and services for maritime and other mobile applications, which are integrated with Regional Satellite Augmentation Systems (RSAS) of the Global Navigation Satellite Systems (GNSS).

2. Radio AIS or VHF Data Link (VDS) Configurations and Classes

More adequate designation for AIS can be Very High Frequency (VHF) Radio AIS (R-AIS), because recently is developed Satellite AIS (S-AIS) with similar service for ships and aircraft, which integrated network is illustrated in **Figure 1**. Some producers determined an additional nomination for AIS known as VHF Data Link (VDL). The R-AIS and S-AIS are maritime surveillance system that uses VHF-band to exchange information (data) between ships and shore stations, including positions, identification, course and speed. This system is mainly aims at avoiding collisions between ships.

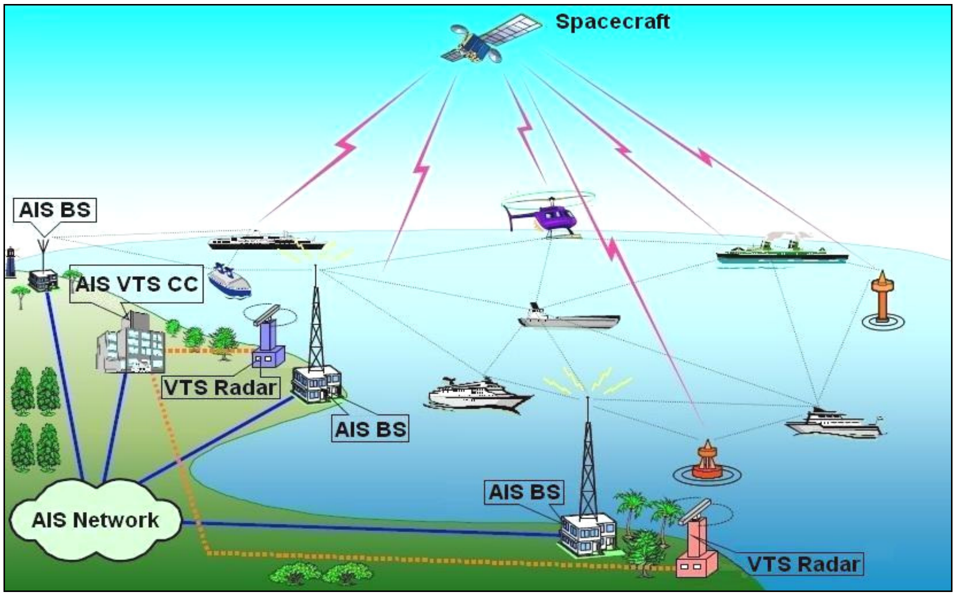

Figure 1. Maritime Integrated AIS Network – Source: IMO **[1]**

The link budgets allow receiving transmitted VHF AIS signals from space, and consequently a global maritime surveillance can be considered.

However, some special challenges arise in AIS system, such as so call message collisions due to the use of SO-TDMA protocols (not designed for satellite detection), so advanced signal processing for separation of received signals is needed. According to IMO regulations each oceangoing vessel has to install AIS transponders onboard, which automatically broadcast regularly to the coast station its ship name, call sign and navigation data. This data is programmed when the equipment is installing onboard vessels and also all this information is transmitted regularly.

Some special challenges arise in AIS system, such as so call message collisions due to the use of SO-TDMA protocols (not designed for satellite detection), so advanced signal processing for separation of received signals is needed. According to IMO regulations each oceangoing vessel has to install AIS transponders onboard, which automatically broadcast messages to the coast station its ship name, call sign and navigation Created by Admintransmitted regularly board. The signals are received by AIS transponders fitted on other ships or on land based systems, such as AIS-VTS Control Centres, VTS Radars and Base Stations (GES), shown in **Figure 1.** The received information can be displayed on a screen or chart plotter, showing the other vessel's positions in much the same manner as a radar display. The AIS standard comprises several substandards 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 AIS system, within which the entire product types must operate. Namely, there are two types of R-AIS Transceivers (transmit and receive) "Class A" and "Class B"

1. AIS Class A – Vessel with onboard mounted AIS operates using Self Organized Time Division Multiple Access (SOTDMA). Targeted at large commercial vessels, SOTDMA requires a transceiver to maintain a constantly updated slot map in its memory, such that it has prior knowledge of slots that are available for it to transmit. The SOTDMA transceivers will then pre-announce their transmission, effectively reserving theirs transmit slot through 2 receivers (Rx) in continuous operation. It has an integrated display, interfaces capability with multiple ship and transmits data every few seconds using power of 12 W. In **Figure 2 (Left)** is illustrated interface of CNS Systems VDL 6000 R-AIS Secure Class A, which provides tracking control of vessel including vehicles inside ports. This unit can include transmission of secure text messages and reception of encrypted range and bearing. The Secure Class A System for naval operation can be configured in standard mode, silent mode or secure mode. The VDL6000 system is easy to install onboard any ship by connecting it to a GPS and VHF antenna. The mandatory installation is complete after connecting it to the navigation GPS, gyro and installing the Pilot Plug interface. The optional installation can be delivered with an interface to the chart system and/or ARPA radar.

Figure 2. Classs A and B Maritime R-AIS – Source: Ilcev **[1]**

2. AIS Class B – This transceiver is not required to have an integrated display and it can use Carrier Sense TDMA (SCTDMA) or Self-Organizing TDMA (SOTDMA) with transmitter (Tx) power of 2 W. It can be connected to most display systems, which received messages, will be displayed in, listed or overlaid on charts. The vessels information will automatically be transmitted at fixed intervals or under Base Station control. It receives both Class A and B AIS data messages via dual AIS channels (Ch. 87B and 88B) simultaneously.

The 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. The Plotter looks like a marine radar display. North up, course-up and range zoom from 0.125 NM to 24 NM is 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, which can be sorted by CPA or TCPA order.

The Detail screen shows various information about the selected AIS targets, such as CPA and TCPA for collision-risk management. In this way, when a 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 ship operator even when is away from the AIS transponder. In **Figure 2 (Right)** is illustrated interface of Icom MA-500TR Class B AIS Transponder, which can be installed on Non-SOLAS small vessels, such as pleasure craft **[1. 2, 3, 4].**

2.1. R-AIS Shipborne Equipment and Features

A technical solution that enables the identification of other vessels and navaids are fitted with the VHF based AIS technology. This can be either on a stand-alone display or on the ship's electronic chart and radar. The ability to view and identify all vessels and their courses and speed, is a major contribution towards safer navigation for the maritime community. The vessel's primary GPS receiver onboard ship needs to be interfaced with the AIS and used as the primary positioning source. As stated earlier, the AIS 200 transponder also incorporates an "all-in-view" GPS receiver, which will be used as backup for the primary GPS receiver and as timing source for the SOTDMA.

Onboard AIS equipment provides authorities at shore with valuable information about routes, cargo and the ship itself. The AIS network is providing a major task for police, customs, military, Search and Rescue (SAR) centres and coastal and harbours authorities to monitor traffic in their territorial waters. Fortunately, AIS solutions can increase the situational awareness, efficiency, alert, SAS including to decrease the workload for those authorities tasked with usual monitoring and controlling coastal and offshore waterways.

There are many types of AIS units produced by numerous manufacturers, so here will be introduced just two common models:

1. Nauticast Class A SOLAS AIS (UAIS) Transponder – The name of this AIS is Universal Automatic Identification System (UAIS), which is using the VHF maritime band and AIS facilitates to exchange of navigational data between passing vessels and base stations. In such a way, knowing on-coming vessel names, course, speed and navigational status this unit increases safety at sea and reduces collision avoidance in low visibility conditions and big traffic circumstances.

Figure 3. Two Prototypes of Ships R-AIS – Source: Ilcev **[5]**

Designed for SOLAS vessels engaged in international voyages, the Nauticast Class A SOLAS AIS Unified Automated Information System (UAIS) Transponder meets stringent new port security requirements, shown in **Figure 3 (Left). I**t brings simplicity to navigation with its 3-in-1 graphical display allowing to adjust ranges to visually see ship's positions in a quick and easy to understand format. It is possible to use AIS data to call oncoming vessels in same path (course) or use the fully integrated Alphanumeric QWERTY keyboard to type and send messages to prevent accidents. This AIS unit uses 3-in-1 Graphical display with 3 different views at a fingertip: Alphanumeric with text of 40x16 char Graphical, Radar View and Fairway view.

With different zoom-levels, this representation of the surrounding traffic scenario can be selected directly using cursor keys. Man Overboard button automatically saves the precise coordinates of the incident and generates an immediate distress message to all AIS equipped vessels in the same area of navigation. The Nauticast software enables automatically check, read out/trace and evaluates the data received from sensor interfaces. All AIS sensor inputs are configurable and have built in test programs for evaluating and troubleshooting the unit connections. All additional particulars about this unit can be seen at: http://www.shinemicro.com/nauticastsolas.asp.

2. Kongsberg Maritime AS AIS 200 – This AIS unit, similar to other AIS transponders, is providing service of a shipboard VHF broadcast system that transmits and receives all information important to the safe navigation of ships, shown in Figure 3 (Right). The AIS data may be shown on the display of the AIS equipment, or on the RADAR screen or Electronic Chart Display and Information System (ECDIS). This unit consists of one VHF transmitter, two VHF TDMA receivers, one VHF DSC receiver, and can ne interfaced to a shipboard display, Transmitting Heading Devices (THD), radar, electronic chart systems and various sensor systems. Static and dynamic navigational data is sent via VHF from ship to ship using SOTDMA. Position and timing information is normally received from an external GPS or Diferential GPS (DGPS) receivers and other shipboard equipment for precise position in coastal and inland waters. Inteface between AIS unit and gyrocompass may require a gyro converter if the heading output from the gyrocompass is a stepper or synchro signal and not a serial line signal, which uses the National Marine Electronics Association (NMEA) data protocol for data exchange. Thus, in order to avoid interference the AIS VHF antenna shall be installed in accordance with IMO requirements. The SOTDMA protocol utilize time-slots for transmission and reception of data and in such a way unlimited number of users may operate on the system at the same time without causing interference problems, see more about at Web site: https://www.psicompany.com/man-prod-info/acr/aisinstallman.pdf **[1, 3, 4, 5].**

2.2. R-AIS Shore System and Equipment

A Physical Shore Station (PSS) with installed Base Station (BS) or Gateway is the site where the AIS data transmitted from ships is received. The AIS BS is the primary component in an AIS PSS, and the most important in a coastal AIS network. Tasks of AIS BS sites are to receive and communicate with AIS data from all AIS sources (AIS Mobile Stations, other AIS BS, AIS aids to navigation units etc) within the VHF coverage area. The AIS BS unit can operate alone or cooperate in an AIS area network, enabling a cost effective coastal surveillance system. This terminal is designed, tested and approved in accordance with all relevant international standards regulating AIS ground infrastructure, equipment and all functionality defined by international regulations.

Figure 4. Two Pprototypes of Shore System R-AIS – Source: **Ilcev [1]**

The AIS BS500 is type approved by Bundesamt für Seeschiffahrt und Hydrographie (BSH) according to IEC62320-1. The AIS BS Controller (BSC) is a rack-mountable unit, which interfaces capabilities are an Ethernet port (LAN), 10 RS232/RS422 serial ports, digital/analogue I/O ports and a SCSI connector. The BSC is running a Windows operating system with facilities for remote control via Ethernet of dial-up connection.

The Auxiliary and Power Control units control the power distribution to an PSS via 4 relays and Ethertrack Transmission Control Protocol/Internet Protocol (TCP/IP power switch), which control the power on/off to the different components of the PSS unit. The GPS splitter can be incorporated for the signal distribution to different BS units and components within the PSS. The Antenna Control Unit (ACU) is designed to handle the VHF antenna signals for one or two BS units. The ACU ensures an easy, flexible and well-arranged antenna set-up. The AIS VHF transceiving antennas needed for a physical shore station are often located in existing antenna parks. In order to utilize the same VHF antenna for more than one BS, an antenna signal combiner is necessary. In case of split Rx and Tx VHF antennas, a signal circulator is used to direct the VHF signal to the different VHF antennas.

In this context will be introduced the following two PSS terminals:

1. CNS Systems AIS PSS VDL 6000/FAAS Advanced – The PSS shore unit fulfills all the requirements of international AIS standards and provides features required for surveillance and management of vessel traffic, configured to the specific needs of individual users at sea. This PSS unit illustrated in **Figure 4 (Left)** is easily configured with an embedded controller device that provides extensive processing and all logging functions. The included VDL 6000/FASS advanced software can be upgraded through local or remote access. However, this AIS ground unit provides a number of remote functionalities, including PSS configuration, software updates, Aids to Navigation targets, power on/off, etc.

Other features are: local logging of AIS messages, local target filtering, replay of AIS data, AIS data catch-up (ensures delivery of data at network congestion or disconnection) and Simple Network Management Protocol (SNMP). The two FASS units provide redundancy if one should fail, thus their presence two controllers provide redundancy in cases of FASS component failure. A faulty unit can be replaced without interfering with the other units, thus FASS Advanced can be replaced without any downtime for the users of the system. However, this unit is also delivered with the Monitor and Control Tool (MCT) and the Power Supply Management Tool (PSMT). The MCT is a graphical interface that provides monitoring and control capabilities such as: change of status of the BS unit and its subunits, change of operational mode, enabling and disabling of services, configuration of the BS 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 BS and its subsystems. More information about BC is at: http://www.cns.se/Products/AIS_Base_Stations.

2. Kongsberg AIS BS500 – This is the new and third generation AIS BS from Kongsberg, shown in **Figure 4 (Right).** The BS500 is designed, tested and approved in accordance with all relevant international standards such as: IEC 62320-1, IEC 62320-1 PAS100, ITU.M-1371-3. The AIS BS is the primary component in an AIS PSS, and therefore the most vital component in a coastal AIS network. It receives and communicates VHF AIS data from all AIS sources (AIS mobile stations class A/B, other AIS BS, AIS Aids to Navigation units, SAR units etc.) within the VHF coverage area. The BS can operate as standalone or cooperate in a network, enabling a cost efficient coastal surveillance system. The new standard (IEC 62320-1) introduces two variants of AIS Base Stations:

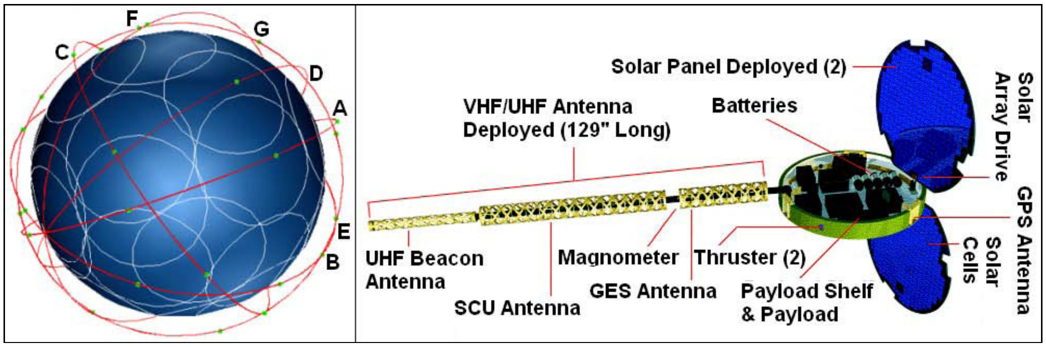

Figure 5. Orbcomm Satellite Constellation and Components of Deployed Satellite – Source: Ilcev **[4]**

a) Dependent – This is a centralized software and intelligence, which connection to a control centre is needed during normal operation.
b) Independent – Firmware and intelligence is located in the ground BS in order to make it independent of a control centre during normal operation.
As stated, in accordance with IMO requirements all SOLAS ships in international traffic above 300GT shall carry an AIS mobile station. The Kongsberg AIS BS500 can be delivered as dependent or independent according to IEC 62320-1, see at: http://www.km.kongsberg.com, **[1, 5, 6, 7].**

3. Satellite data Link (SDL) or AIS (S-AIS)

The GEO and Non-GEO (LEO) satellite systems can provide AIS for onboard broadcast system that transmits a ship's identification, position and other critical data that can be used to assist in ships navigation and tracking facilities for improvement maritime SAS. Most current terrestrial-based AIS provide only limited service nearby shorelines and are not able to provide global coverage. The satellite systems overcome many of these issues thanks to a fully satellite AIS data service, which is able to monitor maritime vessels including landed aircraft at sea well beyond coastal regions in a cost-effective and timely fashion.

3.1. Orbcomm S-AIS

Orbcomm was the first commercial satellite network who is developing and implementing AIS Data Service. In 2008, Orbcomm 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 maritime SAS initiatives. The Orbcomm Little LEO satellite constellation is illustrated in **Figure 5 (Left),** and in **Figure 5 (Right)** is shown Orbcomm spacecraft with long boom is a 2.6 m VHF/UHF antenna. The opportunities that Orbcomm presents are to improve maritime satellite communications, Mission Operations Centre (MOC) and provide global availability, high reliability, near real-time access, reduce service cost and to be flexible for many applications e.g. maritime Intranets and information systems. These properties allow extensive development of MOC and safety communications that encompasses many more ship's bridges applications.
Thus, also cabin crew access and passangers will have messaging service onboard merchant and cruise ships. The same technology could also be used to provide a number of passenger services from E-mail through to on-line duty, see more at: http://www.dailywireless.org/2011/02/08/orbcomms-space-based-ais-fails/.
The SDL network is a part of the folowing maritime communication solution:
1. SDL Tracking Messages Service – The concept of this service is similar to Radio VDL Mode 4 system, which is able to provide a satellite broadcast link supporting navigation and surveillance functions. The SDL system can provide transmission of Short Burs Messages (SBM) between mobile stations or mobile units with Gateways or Coast Stations (CES), Control Centres and Ships Operation Stations. In mobiles, such as ships and surface vehicles inside seaports, can be installed satellite transponders or satellite tracker devices. Mobile transponders can operate autonomously within the coverage of certain CES or can work with any compatible CES worldwide.

Figure 6. Two Generations of Orbcomm Satellite Terminals – Source: Orbcomm **[4]**

The SDL transponder can support the similar services that provide VDL4, but if is using Iridium transponder will be able to provide global coverage including both Poles. The transponder allows ship captains and maritime traffic controllers to ”display” vessels traffic in ocean or coastal navigation and on the seaport surface including vehicle movements with the highest possible precision, which can improve SAS at sea and Ship and Port Facility Security (ISPS).

The CES units can easily interface with other surveillance systems through the standardized Asterix protocol, enabling a complete surveillance picture at the seaport derived from several sources. The ground network and CES will provide increased functionality and capability for Wide Area Network (WAN) coverage of advanced Maritime Traffic Contorl (MTC) and Maritime Traffic Management (MTM). The functionality of the CES is tailored to system specific service applications by its software configuration. The convenient CES terminals can cover Inmarsat, Globalstar, Iridium, Orbcomm or same new Nano networks worldwide.

2. SDL of SBM and High Speed Data (HSD) Service **–** Every seagoing vessel caring AIS satellite transponders or trackers will be able to send and receive SBM or HSD for CNS purposes. This new technogy can deliver to the customers global SDL services and accurate Mairitme Operational Control (MOC) messages. Two-way text messaging, sailing movement data, text and graphical weather (WX), navigation alerts (NX), and route planning are just a few of the applications made possible by Inmarsat and Iridium satellite services around the world. Both operators also provide valuable redundancy for satellite services while requiring minimal equipage or upgrade costs, creating a cost-effective, safety and vital communications service for ships.This service also will provide real-time information on sailing, destinations, Estimated Time of Arrival (ETA), engine parameters, delays, positioning, maintenance, etc.

The Orbcomm global Little LEO MSS offers the following tracking devices for GST/AIS:

1. Magellan GSC 100 Terminal – This unit is the world’s first handheld satellite terminal that allows sending and receiving text and E-mail messages to and from anywhere in the coverage area, which first generation of SCU terminal is depicted in **Figure 6 (Left).** This unit offers communication and navigation using the Orbcomm network and GPS system. Integrated GPS receiver capabilities allow one to identify position, plot and track course, store waypoints and send this information to anyone, anywhere in the world. Unlike traditional landlines, cellular/paging systems, the GSC 100 and Orbcomm network operate from isolated parts of the world, where TTN systems do not reach.

2. Stellar DS300 Terminal – This device is a two-way satellite communicator for use with the Orbcomm network, which second generation of is shown in **Figure 6 (Middle).** The DS300 terminal is a complete hardware solution for companies using a wide variety of applications to track, monitor and communicate with fixed and mobile assets around the globe. Thus, it features a satellite modem, user-programmable application processor, integrated GPS receiver, adequate software configurable I/O options, and battery charger package.

3. Quake Q4000 Terminal – This unit is cost effective and fully programmable satellite and GSM data modem with 22 channel GPS global tracking capability, which is shown in **Figure 6** (**Right).** It has the same technical characteristics as serving as Iridium Q4000i and it can be used for SCADA (M2M) and business-to-business Internet links with land, marine or aviation based assets and equipment anywhere in the world, (04, 08, 09).

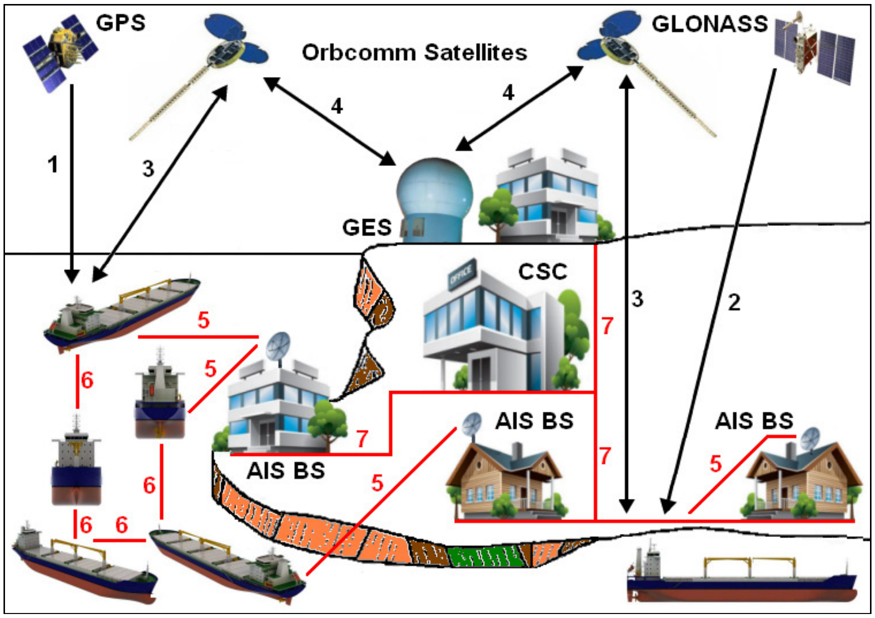

Figure 7. Orbcomm Satellite AIS (S-AIS) – Source: Ilcev **[4]**

3.2. Orbcomm Satellite AIS (S-AIS) Network

The Orbcomm LEO operator provides Satellite - Automatic Identification System (S-AIS) for oceangoing ships onboard broadcast system that transmitted ship identification, position and other critical data received from GES can be used to assist in navigation and improve maritime safety and security at sea. In the similar way, S-AIS system can be implemented for aeronautical applications that aircraft position and other critical data can be used to assist in flight and improve aeronautical safety.

Most current terrestrial-based Radio AIS (R-AIS) system is already implemented by IMO and provides only VHF limited coverage nearby shorelines and not able to provide global coverage. The Orbcomm system overcomes many of these issues thanks to a fully Satellite AIS (S-AIS) data service, which is able to monitor maritime vessels well beyond coastal regions and horizon in a cost-effective and timely fashion and send this data via GES to the Coastal Surveillance Centre (CSC) or Tracking Control Station (TCS). To spread R-AIS coverage globally some institutions and companies started with development S-AIS.

Namely, an AIS receiver using satellite will be able to extend the VHF range of R-AIS systems considerably and make it easier to monitor ship and fishing ocean navigation areas. In such a way, Orbcomm was the first commercial satellite network that started operations with S-AIS data service. In 2008, Orbcomm 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 next launches of OG2 (Orbcomm Generation 2) satellite started in 2011, namely one Orbcomm FM101 OG2 satellite was launched on 08 October 2012 by vehicle Falcon-9 v1.0, six OG2 satellites were launched on 14 July 2014 by vehicle Falcon-9 v1.1, and eleven OG2 satellites were launched on 22 December 2015 by vehicle Falcon-9 v1.2

In **Figure 7** is shown space and ground configuration of S-AIS integrated with R-AIS proposed by author of this book. In fact, all ships are receiving GNSS PVT signals from the US GPS (1) or Russian GLONASS (2), then ships out of R-AIS coverage are sending via service link (3) PVT data to AIS satellite, which this data transmits via feeder link to the GES (Gateway) terminal (4).

On the other hand, all ships sailing inside of R-AIS coverage are sending GNSS PVT data to R-AIS Base Station (BS) via radio link (5), while all these ships have AIS data communication via inter-ship links (6). Received AIS data GES and AIS BS are forwarding via terrestrial links (7) to the SCS terminal for processing. In such a way, AIS data with positions of all ships in certain sailing region can be displayed on radar like screen and used for collision avoidance.

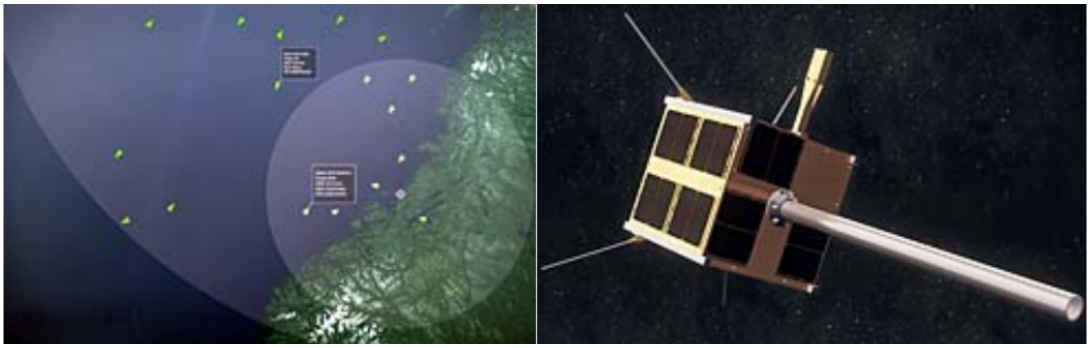

Figure 8. Coverage of AIS Networks and Nano-AIS – Source: Ilcev **[1]**

Automatic Identification System (AIS) is an automatic tracking system used on ships and by Vessel Traffic Services (VTS) for identifying and locating vessels. It is used mainly for collision detection but also for maritime domain awareness in national defense and security applications; search and rescue operations; and environmental monitoring.

Satellite-based AIS, where satellites are used to detect AIS signatures, provides a means to track the location of vessels anywhere around the world, especially over open oceans. It also provides unmatched coverage when compared to terrestrial-based AIS systems.

3.3. Nano Satellites S-AIS Networks

An AIS receiver using SPS will extend the range of R-AIS WHF systems considerably and make it easier to monitor ship traffic and fishing in the High North areas. In **Figure 8 (Left)** is illustrated larger coverage area using S-AIS or AIS via SPS versus using smaller coverage of conventional system of R-AIS or VHF AIS. The altitude of the satellite or SPS gives the AIS receiver a long range and both can therefore make observations over large sea areas. The signals are strong enough to be received by a LEO satellite or SPS. The new AISSat-1 is a Nano/LEO satellite measuring 20x20x20 cm, weight is 6 Kg and is shaped like a cube, shown in **Figure 8 (Right).**

The payload is designed by Kongsberg-Seatex AS and the purpose of the satellite is to improve 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. The AISSat-1 satellite is being launched in order to test these presumptions. The Norwegian AIS transponder is placed in a custom made Canadian satellite, built by the University of Toronto. The satellite's life span is estimated to three years. AISSat-1 will operate in a polar orbit at an altitude of 600 Km and will be launched by the Indian PSLV-rocket of Indian Space Research Organization (ISRO). The Norwegian Space Centre is project owner and the Norwegian Coastal Administration (FFI) will receive the data and the Norwegian Defense Research Establishment is responsible for the technical implementation, see more at: http://www.km.kongsberg.com.

The total cost of the satellite is approximately 30 million NOK (Norwegian Crown). After launch, FFI will start testing the polar orbiting satellite. The FFI will control it for about a year before Kongsberg Satellite Services (KSAT) takes over recently and so the FFI started to integrate the AIS data in the current land based AIS system locally and internationally. ESA has asked FFI and Norwegian companies to take part in a study on a satellite based AIS solution for the whole of Europe, while both USA and Canada have shown keen interest in the project **[4, 6, 9, 10, 11].**

4. Integration of R-AIS and S-AIS with Stratospheric Platform Systems (SPS)

The onshore AIS BS collects information and receives them through WAN to AIS database center where data analyze and processing is occurred. Every onshore AIS BS should be connected to power supply source and to WAN in order to provide remote control of AIS BS from control centre and data flowing to data centre and from one's. Thus, the current AIS system communicates in VHF-band with ships using LOS facilities only. This fact means that AIS Base Stations should be installed in such way to provide LOS to every possible point for ship from place where AIS BS is installed.

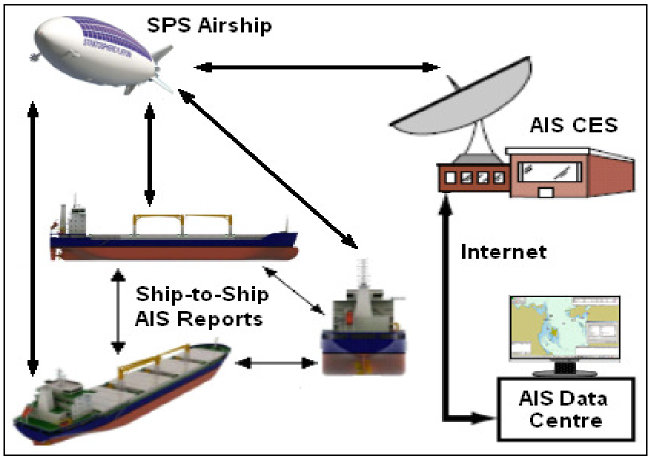

Figure 9. Configuration of P-AIS Network – Source: Ilcev **[4]**

Except Orbcomm S-AIS system, to establish SPS or Platform P-AIS system can be used existing SPS of High Altitude Platforms (HAP) on VHF-band, which P-AIS configuration is shown in **Figure 9.** In fact, it will be necessary to provide an adequate SPS, AIS Coast Earth Stations (CES) or Base Stations (BS) terminals, mission operation, data processing centre or P-AIS Data Centre, operation centers and customer delivery of P-AIS service. Onboard ships P-AIS equipment can send two types of messages, the first type is inter ship communication of ship-to-ship P-AIS reports, and second type is direct transmission of P-AIS messages via SES, Internet or terrestrial communication line to the P-AIS Data Centre. The shore-based P-AIS Data centre provides processing of all receiving P-AIS data and is forwarding P-AIS messages instantly to the customer facilities via Internet.

In case that one onshore AIS BS is not capable to provide reliable coverage due to geographical features of landscape, should be installed as many as necessary BS sites to cover particular sea areas. The new system under development phase is S-AIS and new proposed AIS via SPS have both to upgrade coverage and reliability of the AIS system. Due to geographical complications of Earth surface can be difficult to lay WAN between onshore AIS BS and ships in shadowing and not covered sea areas, so the SPS solutions can be successfully used instead of several onshore AIS BS and partly instead of satellites. As example group of islands can be covered by one or several SPS without installing of onshore AIS BS on every island along of costal line.

In **Figure 10** is shown how shore AIS BS can be replaced by one SPS in problematic landscape, namely where is not possible to get direct LOS between ships and BS at shore. However, if there is a LOS between BS terminalsl and ships it will be possible to establish a co,munication potential alternative for improving the range and reliability of Maritime AIS is system of SPS by special airships located at altitude of about 25 Km. Main idea in this proposal will be to use SPS as a very convenient tools to apply them in some areas where geographically complicated Earth surface or around groups of islands and fiords as well.

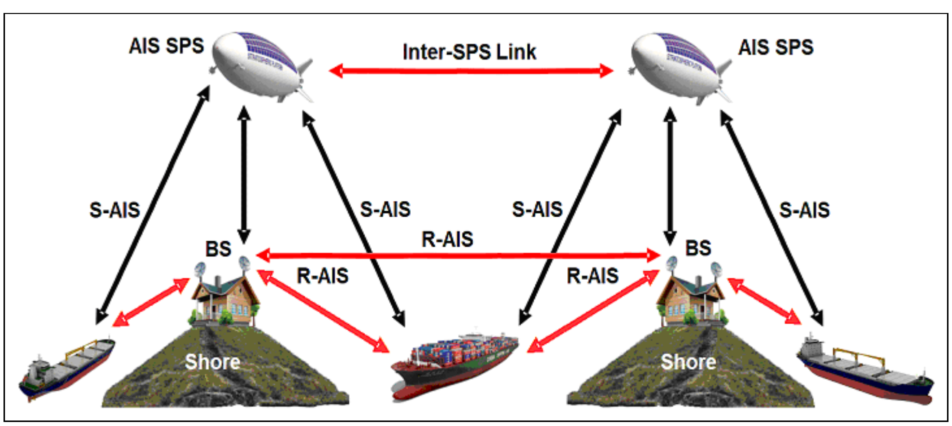

Figure 10. Communication of AIS Network via AIS-SPS – Source: Ilcev **[4]**

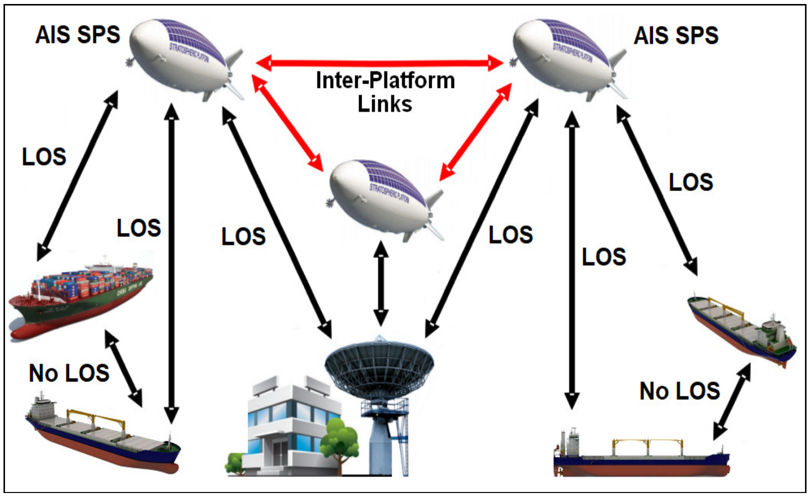

Figure 11. Space AIS Network via SPS Inter-platform Links – Source: Ilcev **[4]**

The big advantage of SPS that it can be installed and moved in any geographical point where necessary to increase redundancy. The SPS able to keep AIS ships in LOS due to high altitude and in such way can be engulfed large area of sea surface by one SPS with equipment equal to onshore AIS BS terminal. Also between SPS can be arranged radio or optical inter-platform links that in turn significantly increase flexibility of system application.

With using SPS Inter-Platform Links (IPL) oceangoing ships can exchange information and navigation data even in considerable distance between AIS ships without LOS between them, which space AIS network via SPS IPL is shown in **Figure 11.**

Diameter of covered area depends on two important parameters such as altitude *h* of SPS levitation (stratosphere layer begins from 20 Km and ends to 50 Km above of Earth surface) and angle α as a minimal angle between boundary line of antenna radiation pattern and horizon line (angle α should not be lower than 5°).

The angle α depends on mounted onboard of SPS VHF AIS antenna with radiation pattern per solid angle. Obviously, using bigger angle α and higher altitude *h* of SPS above sea level then larger diameter of covered area is obtained. Schematically SPS measurements are shown in **Figure 12.** Using Pythagorean Theorem for calculation of diameter covered area and formula of square circle can be simply calculated covered area with one SPS by the following quotation:

$$D = 2R = [h \text{ x } ctg\ (\alpha)] \quad (1)$$

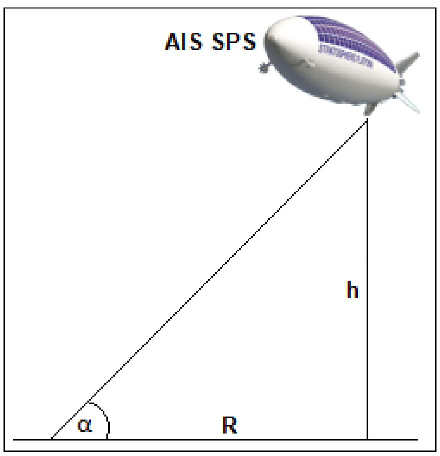

Figure 12. Coverage Area of one AIS-SPS – Source: Ilcev **[4]**

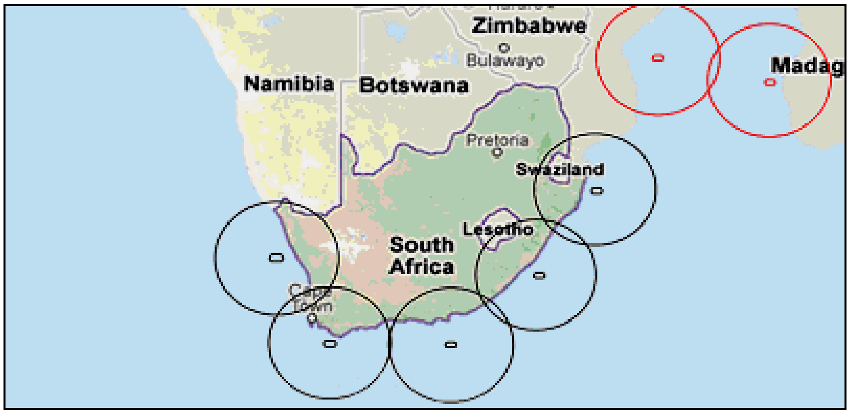

Figure 13. Example of Coastal Coverage of South Africa by P-AIS over the SPS Network – Source: Ilcev **[1]**

Where h = altitude of SPS levitation and α = angle of antenna radiation pattern. Inserting in previous formula numeric data such as altitude h = 20 Km and angle α = $5^{o,}$ is giving:

$$D = 2R = 2[20 \text{ x ctg } (5)] = 455 \text{ Km} \quad (2)$$

One SPS with altitude of 20 Km is able to cover area with diameter in 455 Km. If increase altitude up to 30 Km, diameter of covered area increase in 50 % or becomes 680 Km. In **Figure 13** is shown example that with 5 SPS stations is possible to cover all costal line of South Africa and to provide Maritime P-AIS via SPS airship. With 2- 4 SPS airships placed between Madagascar and Africa can be provided reliable P-AIS coverage in Mozambique Channel as well for safe ships navigation, shown by 2 red circles in the same **Figure 13 [1, 4, 6, 9, 11].**

5. AIS Information Management System (IMS) via SPS

The IMS network can be designed to enable continuous access to data both onboard and onshore through an interactive Web-based solution and to provide an efficient information flow via SPS, shown in **Figure 14.** The AIS IMS via SPS constellation solves the increasing challenge that each sub-supplier needs his own maritime data/communication infrastructure.

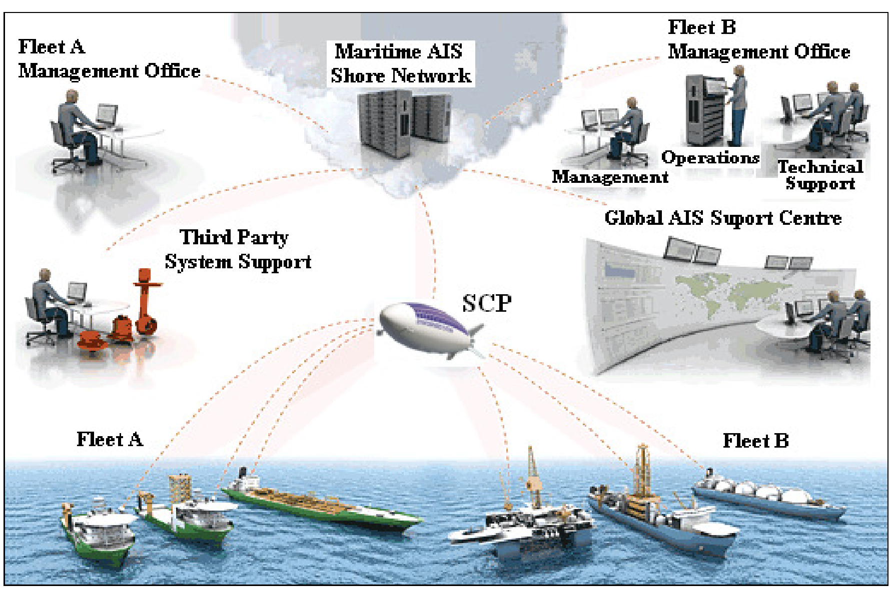

Figure 14. IMS Regional Covering of AIS via SPS Network – Source: Ilcev **[1]**

This system unites all data logging and communication into a single secure and maintainable solution. It gives the merchant fleet owner's possibility to control of the information flow and security of his fleet. Therefore, the AIS IMS network can use whether satellite or SPS constellation to provide more reliable coverage and communication of data. This system also enables secure and reliable information sharing between offshore and onshore locations.

Namely, the IMS via SPS provides a complete and up-to-date information portal for better traceability and quality of AIS communications between offshore and onshore organizations, so improves critical decision making and support, reduces need for service personnel onboard vessels, improves troubleshooting, enhances SAS through visualization and supervision and other features. This novel network will support overall systems interoperability through use of well-established open standards as well. The service-oriented architecture enables an information highway for applications across control and to business systems.

The IMS infrastructure includes different system components such as portal, data logging, secure network, malware protection, replication, security and integration by standard protocols such as OPC and Web services, unites all data logging and communication into a single and secure and maintainable solution. The System also provides proven and flexible offshore-to-onshore replication and supports low band with high latency SPS or satellite connections. Service Oriented Architecture (SOA) enables an information highway for applications across control systems, third party and business systems. In such a way, the portal is based on rich Internet application technology and it can be accessed using a standard web-browser and can provide an intuitive user interface. Thus, without space segment of SPS or satellites the IMS will be not able to transfer AIS data to Fleet A and B of vessel in certain sea areas not covered by VHF R-AIS.

The AIS IMS network provides authorities with valuable information on routes, approaching, cargo and the ships themselves. It is a major task for police, customs, military, SAR Centers and coastal and harbors authorities to monitor traffic in their territorial waters. This system increases the situational awareness, the efficiency and the safety and decreases the workload for those authorities tasked with monitoring and controlling coastal and offshore waterways. The main tasks of this Network is to improve transfer of AIS data, to enhance SAS, to enable better system for collision avoidance of ships and what is very important to provide better protection of propriety and lives at sea **[1, 6, 9, 11, 12].**

6. Conclusion

The AIS SPS is more cost-effective solution for AIS application in sea areas not covered by AIS VHF-bands. The SPS does not need many Base Stations for VHF-based AIS and huge expenses for launch and technical maintenance of satellite constellations. Similar to some satellite networks, between SPS airships can be arranged by inter-links, so in this case system becomes more efficient and the need of shore station will be reduced. Moreover, the SPS payload can be equipped by some extra equipment to provide more safety at sea, such as optical or infrared photo camera with high resolution or observation radar and can be used for other CNS systems. Also identification of pirated ships can be provided with installation of similar equipment on board of SPS airships or airplanes. The major goal of SPS is that, similar as satellite, provides Azimuth and Elevation angles and also can enable greater speed that Cellular and Fiber Optic Networks (FON).

Data Availability Statement (DAS)

The participants (only author) of this study did not give written consent for their data to be shared publicly, because no new data were created or analyzed during this study.

Therefore, due to the sensitive nature of the research supporting data is not available, namely data sharing is not applicable to this article.

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