An exactEarth Technical White Paper
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Satellite AIS

Executive Summary

exactEarth Ltd (www.exactearth.com) is a private data services company delivering global location-based maritime vessel tracking information for government authorities and a wide range of commercial organizations, through its exactAIS® tracking service. Automatic Identification System (AIS) is a mandatory navigation safety communications system under the provisions of the Safety of Life at Sea (SOLAS) Conventions which requires ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages, and all passenger ships irrespective of size to be fitted with AIS. Through such research and development activities at exactEarth, AIS signals can now be detected by a satellite in a low earth orbit and provide a global capability for monitoring all AIS-equipped vessels using a satellite constellation and extensive network of ground stations.

Satellite AIS is relatively new technology that has changed the landscape for monitoring the maritime domain. Improving upon existing technology already deployed aboard most large vessels across the globe, Satellite AIS is truly revolutionary in providing a complete and global picture of the world's shipping. The application areas for using Satellite AIS are abundant as maritime authorities begin to assess the critical information that is now readily available. This paper will explain Satellite AIS technology, the various devices and different types along with an overview of many of the various application areas for Satellite AIS data.

Introduction to Satellite AIS

AIS Background

Since 2004, the International Maritime Organization (IMO) has required Automatic Identification System (AIS) transponders to be aboard most vessels. The SOLAS Chapter V Convention states: All ships of 300 gross tonnage and upwards engaged on international voyages and cargo ships of 500 gross tonnage and upwards not engaged on international voyages and passenger ships irrespective of size shall be fitted with an automatic identification system (AIS). Over 165,000 ships worldwide have installed these transponders at a combined cost of several hundred million dollars, making AIS one of the most successful maritime technology deployments of all time. Additionally, equipment employing AIS technology is increasingly being deployed in smaller vessels as well as radio/AIS enabled Aids-To-Navigation (AtoN) and it is also being installed on Search and Rescue (SAR) vessels and aircraft.

The prevalence of AIS transponders has resulted in the increased value of AIS data that can be used not just by ships, but by naval forces, port authorities, coast guards and other competent maritime authorities to enhance the Safety Of Life At Sea (SOLAS) convention and improve maritime situational awareness. While AIS has been deployed successfully, it suffers from a major limitation in that, due to the curvature of the Earth, its range is limited to approximately 40-50 nautical miles under most atmospheric conditions. However, this can vary greatly depending on the site topology, density of ships in the area, and atmospheric conditions. Maritime agencies wish to gain greater visibility into vessel traffic over a much broader area in order to enhance their operational effectiveness. exactEarth believes the solution lies in collecting AIS transmissions from space.

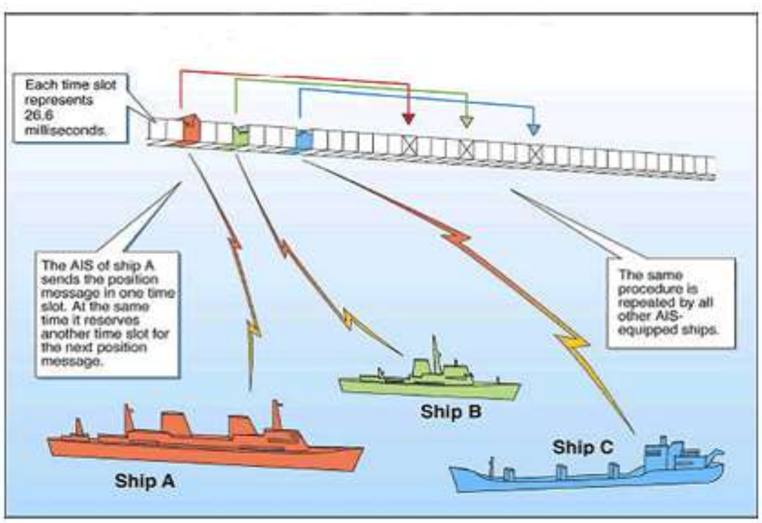
AIS & How it Works

AIS transponders automatically broadcast information, such as their position, course, speed, rate of turn and navigational status, at regular intervals via a VHF transponder. The information originates from the ship's navigational sensors, typically its global navigation satellite system (GNSS) receiver and gyrocompass. Other information, such as the Maritime Mobile Service Identifier (MMSI), vessel name and VHF call sign, are programmed when installing the equipment and are also transmitted regularly. The signals are received by AIS transponders fitted on other ships and on land based systems, such as Vessel Traffic Systems (VTS). The received information can be displayed on the radar or chart plotter, showing the other vessels' positions and call sign information, in order to augment these systems and improve safety of navigation world-wide. The additional data provided by AIS can be added to radar and chart plotting systems, making these critical systems much more effective.

AIS is an RF-based communications system based on TDMA (time division multiple access); similar to the first digital communications protocol used by cell phones, employing two VHF marine radio frequencies dedicated worldwide to the service. TDMA requires each device to communicate within a given slice of time, or slot. However unlike cell phones, the AIS does not have continuous communication with a controlling device for slot assignment i.e. cell tower. Therefore, the AIS architecture had to develop a strategy for defining how to keep ships within close proximity from using the same time slot to transmit a position report.

Self-Organizing TDMA (SOTDMA) fit this requirement as every AIS device will preannounce the time slots it intends to use for position reports and will not use the slots reserved by other AIS devices, effectively organizing around each other and creating a communication cell. These communication cells cover nine "one minute time frames", each frame consist of 2,250 26.6ms time slots per radio frequency channel.

Below is a representation of slot selection, by multiple ships within reception distance, over a single one minute frame:



Slot selection by an AIS unit is randomized within a communication cell and tagged with a random timeout across the nine frames of the communication cell. When an AIS unit changes its slot assignment, it announces both the new location and the timeout for that location. Each AIS unit chooses slots within the communication cell depending on its reporting rate, which varies between 2 seconds and 3 minutes as determined by the speed and heading of the vessel. As vessels pass in and out of communication cells there is a high probability of slot collision impacting receiver stations that may hear multiple communication cells simultaneously, such as terrestrial AIS base stations and satellites.

AIS Device Types

The AIS community consists of several types of devices which all interact using the AIS protocols and adhering to international performance standards. The performance standard for each device type provides a detailed technical specification which ensures the overall integrity of the global AIS system within which all the device types must operate. The major device types described in the AIS system standards are:

Class A: Shipborne AIS transceiver (transmit and receive) which operates using SOTDMA. Class A units must interface with the ship radar; it must also have an integrated display, transmit at either 1 W or 12.5 W, interface with multiple ship systems, and offer a sophisticated selection of features and functions. Class A units report every 2 seconds to 3 minutes depending on the speed and rate of turn of the vessel. Beginning in January 2013, all new installations of Class A devices will be required to transmit a position report for satellite detection on two new channels reserved exclusively for detection from space.

Class B SO: Shipborne AIS transceiver (transmits and receives) which operates using SOTDMA. Class B SO must have an integrated display, transmit at 5 W or 1W, and provide the capability to interface with multiple ship systems. Class B SO units report every 2 seconds to 3 minutes depending on the speed and rate of turn of the vessel Beginning in January 2013, all new installations of Class B SO devices will be required to transmit a position report for satellite detection on two new channels reserved exclusively for detection from space.

Class B CS: Shipborne AIS transceiver (transmit and receive) which operates using carrier-sense time-division multiple-access (CSTDMA), and is restricted to a single slot for transmissions. Class B CS units transmit at 2 W and are not required to have an integrated display however Class B CS units can be connected to most display systems. Default transmit rate is every 30 seconds, but this can be varied according to vessel speed or instructions from base stations. The Class B CS type standard requires integrated GPS and Class B CS equipment receives all types of AIS messages.

AIS SART: Search and Rescue transponder used for locating vessels in distress. These units do not have receivers and transmit in bursts using a position report and a safety text message. AIS SARTs transmit at 1W and must continue to operate for 96 hours after deployment.

AIS Aids to Navigation: AIS on Aids to Navigation are used to transmit the location of the buoy for display on the charting and radar systems. In addition, these stations may be used to transmit important meteorological and hydrological data important for safe navigation. There are two types of AIS AtoN devices, those that are receive only and transmit on reserved slots and full units that are capable of receiving and selecting free slots for transmission using SOTDMA. AtoNs can operate at various power levels from 1W to 12.5W, and usually transmit at intervals from 1 to 3 minutes.

AIS Base Stations: Fixed stations used by competent authorities to monitor and control ship traffic. These units are also capable of controlling AIS devices. This control can turn units on and off, reserve slots for special transmissions, control which slots mobile AIS units will use, control the power level of mobile units. In addition, base stations can command ships to stop transmitting the position report on the new satellite channels.

Coastal AIS

Coastal AIS systems are built and operated by competent authorities such as Coast Guards to improve safety and security for a country's shore line. These systems are expensive to build and maintain but offer the competent authority a way to monitor vast areas of shoreline that until AIS required far more expensive assets. Typically a coastal system will provide coverage to 50nm, however this coverage is highly dependent on the installation site, antenna height, etc., the coverage can also be affected by congestion in the area because slot collisions become much more likely.

Satellite AIS

The satellite will see many of these communication cells simultaneously and when the number of ships in the space-based AIS antenna's field of view exceeds approximately 1000, the problem of slot overlaps becomes critical and the number of 'uncollided' messages quickly drops. When the number of ships in the field of view exceeds approximately 2500, there are very few uncollided slots as seen from space. Ship traffic analysis indicates that there are very few areas in the world that have fewer than 1000 AIS transmitters within the satellite field of view.

Types of Satellite AIS

There are currently two methodologies in use for detection of AIS signals from space. The first method, commonly referred to as on-board processing (OBP), employs specialized receivers that, while much more sensitive, basically work the same as terrestrial AIS receivers. The second method, commonly referred to as spectrum decollision processing (SDP), employs receivers capable of detecting and digitizing the RF spectrum for the AIS channels and then processing the raw spectrum files to control the noise floor and reconstruct collided messages with highly specialized software algorithms.

OBP

OBP does not require special processing and is effective in very low density areas, such as the middle of the Pacific Ocean. However, the detection probability is significantly lower in areas where the satellite footprint contains a ship density approaching 1000 ships. Statistical analysis has shown that the first pass detection performance for OBP in high dense areas is quite low and a complete maritime domain picture is unlikely without multiple passes. If the ship traffic is very dense (over 2500 ships), it is unlikely that the complete maritime picture will ever be achieved using OBP because slot collisions will occur and OBP is not capable of resolving collided messages.

SDP

SDP requires the capture of the RF spectrum and processing of that spectrum using highly specialized algorithms to decollide message traffic. With SDP the first pass detection is high even within high ship density areas, thus quickly achieving maritime domain awareness. Statistical analysis has shown that the first pass detection performance for this detection methodology is very high and maritime domain awareness can be achieved in as little as two passes. If the area of interest contains higher ship densities, SDP methodology is vital to achieve detection at a level that will enable operational use of S-AIS.

Applications of Satellite AIS

Satellite AIS (S-AIS) provides unprecedented visibility into global maritime traffic. This information can be used for a wide range of vital applications including:

- Vessel Monitoring
- Security
- Environmental
- Search & Rescue

Within these areas, Satellite AIS has many uses for maritime traffic tracking and monitoring. Examples include:

Pollution Control: S-AIS provides tracks to assist governments in determining violations of existing regulations surrounding prohibited discharges. Authorities are able to validate positions recorded in the on-board logbooks to identify any discrepancies. Data can also be used to show ships that have deviated from a pre-defined route indicating they may be trying to avoid detection of prohibited discharge.

Ship Routing: S-AIS provides a global vessel monitoring capability that extends well beyond coastal based AIS and radar systems and this enables the possibility of extending ship routing measures to the open oceans where ships can be at increased risk from bad weather and adverse oceanographic conditions.

Natural Disaster Relief: Traditional coastal surveillance systems can be disrupted by inclement weather and natural disasters, whereas Satellite AIS provides consistent coverage for wide area surveillance. S-AIS also provides real benefits to Search and Rescue operations as authorities can compare the traffic image leading up to and following an event to locate probable survivors as well as refine the search area.

Piracy Monitoring: Satellite AIS data provides the ability to detect changes in a vessels velocity as well as disparities between course over ground and the ship's heading which may indicate that a vessel is drifting or pirated. Operators are then able to observe changes in velocity to alter their course when required. Satellite AIS data can be used to identify and analyze traffic patterns in highly pirated waters to help authorities determine safer shipping routes.

Environmental Preservation: S-AIS is uniquely suitable for the monitoring of maritime vessel traffic over large ocean areas and being geospatial in nature can be further leveraged to provide analysis in association with any user-defined region or zone. S-AIS can track and provide reports on vessels that have strayed into sensitive areas that are in remote areas away from coastal surveillance installations.

Arctic Monitoring: Satellite AIS provides the ability to monitor this remote region and identify ships traveling through Arctic waters, day or night, where previous surveillance systems had limited detection. Satellite AIS provides a better understanding of Arctic maritime traffic trends to allow for necessary analysis into proper shipping routes.

Validation of Ship Declarations: Competent maritime authorities have a very limited capability to monitor vessel's compliance to declaration protocol. Without S-AIS they must rely on aircraft routine patrols etc. for periodic checks. With S-AIS providing a track with time, position, heading and speed it becomes a very easy task to track whether a ship made the required deviation in course and provides a check against the Ship's log.

Fisheries Protection: Satellite AIS can assist in validating a vessel's reported position information into a Vessel Monitoring System (VMS) reducing the costs of individual "point to point communication" VMS reports. By determining legitimate fishing vessels using AIS, S-AIS can then determine proximity of non-cooperative IUU vessels.

Mitigating Infectious Disease: By tracking ships globally, Satellite AIS is able to locate ships traversing in infestation hot spots and can also validate a ship's declared voyage to ensure no deviations in route took place into diseased locations.

Increasing Vessel Safety in Hostile Waters: Satellite AIS provides information leading to better planning of escorts/convoy management as well as removes the need for voice communication which could lead to interception.

Search and Rescue: Satellite AIS provides global coverage and can best identify vessels in the vicinity of a distress call to ensure aid is received as quickly as possible. This allows authorities to be proactive, equipped with information on the status of vessels as well as a view into possible aid vessels in proximity. Traffic analysis provided by S-AIS reveals normal ship behavior and routing, this information can be used for effective planning of daily search and rescue patrols.

Arrival Management: Satellite AIS is able to monitor ships that are far out to sea enabling dynamic Notice of Arrival as it covers all notification areas. Authorities are then given the time for effective vessel management and route planning. Satellite AIS provides information to stakeholders of the port systems to allow for better planning to optimize the time for arrival. Competent authorities can then schedule administrative requirements well in advance improving the wait times for vessels.

Vessel Traffic Analysis: Satellite AIS extends analysis into remote coastal and offshore areas previously not covered. Traffic analysis can now be completed across the globe, even in high Polar latitudes.

Monitoring Aids to Navigation (AtoN) Operations: Satellite AIS extends the range of traditional VHF reception to cover all areas where remote AtoNs may be deployed. Most authorities use an AIS message to transmit the operational status of an AtoN and then use this information to effectively deploy their buoy tenders by only visiting those buoys with maintenance issues. Further, within the position report of the AtoN is an "off" position indicator for the buoy. Deep sea buoys can be quite large a presents a real danger to navigation when off position. These messages can be detected by S-AIS and competent authorities can quickly issue safety notices to mariners in the area of the off position buoy.

Conclusion

As 70% of the world's surface is ocean and 90% of global trade takes place on the ocean, the need for a complete global maritime picture is of critical importance. Satellite AIS is gaining notoriety as the maritime community begins to benefit from reliable vessel monitoring extending far beyond the horizon.

Further advances in satellite constellations and ground stations are increasing the amount and quality of data collected from space. This has created the ability to have a complete global view of all the world's shipping with more uses and analysis applications being discovered as the data becomes integrated into existing operational systems. S-AIS is the only means of providing comprehensive and persistent geospatial intelligence for the timely and accurate monitoring of vessels on a global basis.