OPTIMIZING A GLOBAL SATELLITE CONSTELLATION FOR AIS AND MARITIME DOMAIN AWARENESS

ABSTRACT

Although relatively new, Satellite Automatic Identification System (S-AIS) technology has fundamentally changed the landscape for monitoring the maritime domain. Improving upon existing AIS technology already deployed aboard all large vessels and many smaller vessels around the globe, S-AIS is truly revolutionary in providing a complete and global picture of the world's maritime shipping environment. To date, the exactView™ satellite constellation from exactEarth has shown that global coverage is possible with a variety of orbital regimes, but to provide a real-time view of the maritime domain, dramatic changes in a S-AIS constellation are necessary.

To address key changes in the AIS constellation architecture, exactEarth and Harris have partnered to provide real-time global maritime tracking and information solutions. This whitepaper examines the elements and architectures required to bring about these changes and provide a robust, real-time global view of the maritime domain in general, and AIS in particular. These include continuously improved onboard spectrum de-collision processing, a global and interconnected satellite constellation, and the ability to effectively adjust to and incorporate new and changing VHF maritime services including mandated frequency changes, new Application Specific Messages (ASM), and VHF digital exchange services and security protocols.

BACKGROUND

Since 2004, the International Maritime Organization (IMO) has required AIS transponders to be aboard certain vessels. Under the provisions of the Safety of Life at Sea (SOLAS) Conventions, 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 are to be fitted with AIS. Due to its worldwide mandate and adoption, AIS is one of the most successful maritime technology deployments of all time. Additionally, equipment employing AIS technology is increasingly being deployed on smaller vessels as well as radio/AIS enabled Aids to Navigation (AtoN) and Search and Rescue (SAR) vessels and aircraft.

AIS transponders automatically broadcast information such as ship position, course, speed, rate of turn, and navigational status, at regular intervals via a maritime VHF transponder. Much of the information originates from the ship's navigational sensors, typically its Global Navigation Satellite System (GNSS) (e.g. GPS, GLONASS) receiver and gyrocompass. Other information, such as the Maritime Mobile Service Identifier (MMSI), vessel name, and VHF radio call sign, are programmed when the equipment is installed and are transmitted regularly as part of AIS messages. Received AIS information can be displayed on a ship's situational awareness displays (e.g., radar, chart, plotter) to show other vessels' positions and call sign information, and the AIS information augments these systems to improve safety of navigation worldwide.

The worldwide prevalence of AIS transponders has increased the value of AIS data not just for shipping, but also for naval forces, port authorities, coast guards, and other maritime authorities by enhancing safety and improving maritime situational awareness. From a global perspective, however, AIS suffers from a major limitation in that due to the curvature of the Earth, its range is limited to approximately 20-30 nautical miles (nm) at sea, and 50 nm from coastlines under most atmospheric conditions.

Since AIS was primarily designed for collision avoidance between vessels within RF range of each other, the communication protocol scheme was architected to provide coordinated time slots, or opportunities to transmit, for a relatively large number of closely spaced (within 20 nm) vessels. These vessels form an AIS communication cell. Within this cell, the vessels' AIS transmissions are coordinated, resulting in no (or very few) message collisions.

The "view" from space however, is much different. While a ship at sea has an effective RF range of 20-30 nm, a low Earth orbiting (LEO) satellite field of view can be over 3000 nm. The basic AIS communication scheme was neither designed nor intended for this extreme range of coverage. As a result, S-AIS receivers see many AIS cells simultaneously, resulting in messages colliding with other messages. These message collisions make it difficult to properly receive and decode the messages, especially when a satellite coverage "footprint" covers areas of high-volume AIS message traffic.

To develop and deploy a satellite-based architecture that addresses these and other maritime VHF challenges, the following five key factors are presented as essential elements for an optimized global S-AIS constellation:

1. Continuous global coverage and superior detection rates
2. Real-time downlinks
3. Ability to detect all AIS broadcasters, not just those mandated by the IMO
4. Ability to handle the rapidly expanding use of ASM
5. Ability to adapt to evolving uses of the maritime VHF spectrum

KEY FACTORS

Continuous, global satellite coverage coupled with superior detection rates is paramount to maritime AIS products and services

When it comes to providing true, global, real-time maritime domain awareness, both the quality and size of a satellite constellation matters. For LEO coverage, the greater the number of satellites, the greater the coverage. In addition to having the right quantity of satellites, placing them into differing orbital planes with managed orbital regimes is essential for obtaining true global coverage.

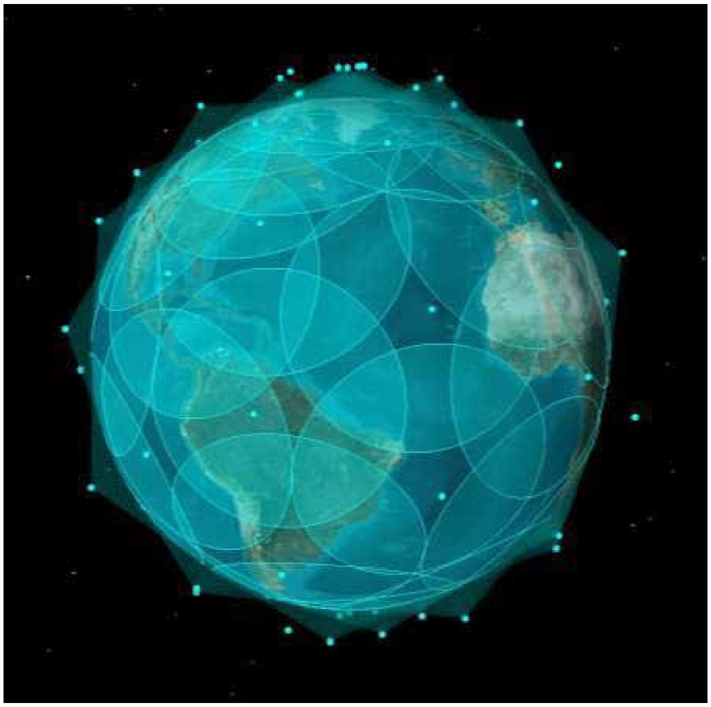
Continuous global coverage from LEO requires a substantial, orbitally diverse, and managed satellite constellation, such as the Iridium NEXT constellation. With 66 operational satellites in six polar orbiting planes and six in-orbit spares, Iridium NEXT will cover the earth with true, simultaneous global coverage.

Flying onboard Iridium NEXT satellites as hosted payloads, the Harris satellite VHF receiver system (the system) is a collection of space-based maritime VHF receivers and associated ground components. Coupled with exactEarth's ground processing and customer delivery infrastructure, the system will provide an unprecedented level of global, real-time performance for AIS and maritime data. Since the system provides true global, overlapping coverage, vessels will be "seen" not only by dozens of satellites a day, but also many times a day by multiple satellites simultaneously. This level of S-AIS coverage results in significant vessel detection improvement over the current state of the art and represents the largest and most advanced S-AIS constellation in the world.

Global, real-time satellite downlinks are required to provide instantaneous maritime domain awareness

Today, in addition to satellite transmission methods used when in range of a ground terminal (e.g., bent pipe technology), all S-AIS systems utilize store-and-forward designs. As the satellite travels through space, it collects and stores AIS messages until coming within transmission range of a dedicated ground terminal. The satellite then forwards (downlinks) the messages to the ground for delivery to customers. Because this mode of operation results in additional, system-wide latency for delivering AIS data to customers, a store-and- forward architecture cannot provide continuous global, real-time AIS performance. This is true for all four AIS channels, the new ASM channels, and equally important, the Digital Selective Calling (DSC) emergency hailing channel (channel 70).

Providing a global, real-time satellite-based maritime VHF and AIS system requires not only a large constellation of satellites as discussed in Key Factor #1, it also demands that the architecture provides real-time satellite downlinks. One way to achieve this is to deploy enough ground stations so that every satellite is in view of a tracking ground terminal at all times. Since simple tracking ground terminals can only communicate with one satellite at a time, this would result in a very high number of satellite terminals strategically placed across the globe and/or sophisticated antenna and frequency allocation systems on the satellite and ground sites. Another solution is to interconnect the satellites in space with crosslinks, essentially creating a satellite network in space so that all satellites at all times receive and downlink AIS messages in real-time to strategically located ground sites. The Iridium NEXT constellation uses this type of architecture and provides true real-time communication performance via globally interconnected satellites and real-time downlinks.



This maritime VHF receiver constellation provides continuous global coverage

Harris' satellite VHF receivers leverage the power of the Iridium NEXT constellation, enabling true global, real-time maritime domain awareness. Because the Iridium NEXT satellites are networked together with cross-links (fore/aft and orbital plane-to-plane), and are in constant communication with multiple ground stations, global AIS messages are received and delivered in real time with essentially no satellite-induced latency. The Harris system is the only one in the world that can provide the level of performance required for instantaneous global maritime domain awareness.

Detection and processing of class B AIS signals in addition to class A signals is needed for complete maritime domain awareness

The equipment that corresponds to the SOLAS carriage requirements with full maritime functionality is termed Class A AIS. Class B AIS was developed for smaller, non-SOLAS commercial craft and recreational vessels. It has reduced functionality and is often optional. Regardless, some government/territorial administrations may require the carriage of AIS on non-SOLAS vessels in their managed areas. Recent estimates predict that the quantity of class B AIS equipped vessels could reach 500,000 to 1 million vessels in the next decade. Therefore, reception and processing of class B AIS signals from space in addition to class A AIS signals is critical to establishing a complete maritime domain picture.

However, since class B AIS signals are subservient to class A transmissions and transmit less frequently and with lower power (2 Watts vs 12.5 Watts), detecting these signals from space is challenging. One way to address this situation is to partner with Class B AIS equipment providers to develop signals and/or waveforms that significantly increase the detectability of these signals from space.

Recognizing the need for effective Class B signal detections, the Harris satellite VHF receiver incorporates the ability to receive exactEarth's proprietary tracking waveform so that various products (e.g., Class B transmitters, identifiers, AToNs) can be tracked by the system once outside the range of coastal systems. Named ABSEA™, this revolutionary new technology jointly developed by SRT Marine Technology and exactEarth enables class B and Identifier type AIS transmitters to be tracked beyond the range of terrestrial AIS networks. This proprietary technology uniquely provides the capability for detecting the significant increase in Class B AIS messages.

Detection and processing of AIS ASM is critical for a comprehensive maritime view

The use of AIS has expanded dramatically due to the effectiveness of the technology and now includes other applications such as AtoN, ASMs, Search and Rescue Transmitter (SART), Man Over-Board (MOB) units, and Emergency Position-Indicating Radio Beacon (EPIRB)-AIS. This has caused significant increase in VHF Data Link (VDL) loading which is an active concern in the IMO and the International Telecommunications Union (ITU) because it interferes with fundamental Cass A AIS performance.

As captured in the USA Federal Communications Commission (FCC) document, Proposals for the Work of the Conference1, S-AIS effectiveness was determined to be unacceptably limited where VHF Data Link (VDL) loading is high. The resulting need for a separate, dedicated S-AIS service was confirmed at the WRC-12 in January-February 2012, and two additional (satellite or long-range) AIS channels were designated to increase the effectiveness of S-AIS systems. While these new designations address the problem for satellite detection, AIS VDL loading remains a serious issue to an increasing degree in many parts of the world due to the proliferation of AIS applications, message types, services and equipment types, plus the significant increase in user volume. To address the problem of overloaded AIS (channels AIS1 and AIS2), and to protect the integrity of the AIS VDL, experts have recommended a revision to the AIS system that would move ASMs to two additional channels. WRC-12 facilitated this concept in a revision to Appendix 18 of the ITU Final Acts WRC-122.

As ASMs are migrated off of AIS channels 1 and 2 onto their own, separate frequencies, it is critical that a comprehensive S-AIS system provides the means to receive and transmit to the ground this information in conjunction with the AIS and long-range AIS messages. The Harris satellite VHF receivers provide these capabilities as part of their standard operation. The associated RF and digital circuitry receives and processes all of these various signals and frequencies and transmits them via real-time downlinks to the ground for delivery to the customer.

1 http://transition.fcc.gov/bureaus/ib/wrc-15/citel/AI_1_16_USA_Proposal_2015-01-14.doc
2 http://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-WRC.9-2012-PDF-E.pdf, page 140

On-orbit reprogrammability is essential to ensure compliance and compatibility with future AIS and maritime services

Just as there have been recent changes regarding ASM traffic being moved off of the AIS channels, there are, and will continue to be, changes in the maritime VHF domain. One that is of near-term significance is the new VHF Digital Exchange Services (VDES) currently being discussed by the IMO. At the World Radio Conference in Geneva, Switzerland, in November 2015, changes to the maritime VHF domain were approved, including "regulatory provisions and spectrum allocations to enable possible new Automatic Identification System (AIS) technology applications and possible new applications to improve maritime radio- communication in accordance with Resolution 360 (WRC-12)"3.

The referenced Resolution 360 (WRC-12) (page 80 of the ITU publication), recognizes, among other items:

a) that the implementation of AIS globally offers the ability to improve search and rescue operations;

b) that the AIS Search and Rescue Transmitter (SART) is identified by the International Maritime Organization (IMO) as an alternative device to the Radar SART;

c) that AIS is used for channel management of AIS channels and future VHF digital data channels, and for ship-to-shore data exchange;

d) that additional AIS channels may be required for radio communications involving, but not limited to, area warnings and meteorological and hydrographic data, as well as channel management of AIS, future VHF digital data and ship-to- shore data exchange;

e) that additional channels for AIS may be required for search and rescue;

f) that due to the importance of AIS in ensuring the safe operation of international shipping and commercen, it should be properly protected from harmful interference;

g) that studies should be carried out to identify additional spectrum needed for emerging AIS terrestrial and satellite operational requirements;

h) that, in ensuring the safe operation of international shipping and commerce, additional spectrum for AIS applications should be given priority in the maritime mobile and mobile-satellite services; …

It is clear from ongoing discussions at the international level that changes in the maritime VHF domain, including AIS, ASM, and VDES, are on the near-term horizon. (VDES Initial Operational Capability is currently planned for end of 2017 with Final Operational Capability planned for early 2020.)

To keep up with and take advantage of these changes, spaceborne elements must either be replaced often with increasing levels of sophistication (and associated costs) or provide on- orbit flexibility and reconfigurability, including reprogrammability. The constellation of Harris satellite VHF receivers for AIS and maritime domain awareness provides the necessary flexibility by virtue of the Harris AppSTAR™ reconfigurable payload platform. This proven space payload platform provides the ability to simultaneously receive multiple maritime VHF channels, is reprogrammable due to its FPGA-based processing architecture, and provides a highly capable and adaptable VHF receiver to effectively deal with and take advantage of changes in the maritime VHF domain.

CONCLUSION

As evidenced in the industry today, satellite-based maritime domain awareness is both achievable and valuable to businesses and organizations that use and rely on global AIS information. However, current S-AIS systems have not yet achieved simultaneous global coverage, nor do they provide global, instantaneous delivery/downlinking of collected AIS information. These capabilities require a large constellation of LEO satellites distributed in orbits that ensure coverage of the entire globe, superior detection algorithms, and an architecture that provides real-time delivery of the collected AIS information without the latency associated with a store-and-forward satellite architecture. With maritime VHF domain changes on both the near-term horizon and in the future, a satellite-based maritime VHF system must also be capable of adapting to and taking advantage of these future changes.

The Harris satellite VHF receiver system specifically addresses and satisfies these needs. It represents a fundamental change in the way AIS and maritime data is received from space and provides unprecedented improvements in maritime domain awareness for business services and products. The Harris satellite VHF receiver provides significant flexibility and on- orbit reprogrammability that can adapt to the changing maritime domain and meet future customer needs. By combining the Harris satellite VHF receiver system with exactEarth's data delivery services, customers around the world can dramatically improve their maritime domain awareness through global, real-time information delivery of the world's shipping.

3 http://www.itu.int/dms_pub/itu-r/oth/12/01/R12010000014A01PDFE.pdf, paragraph 1.16

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