Real-Time AIS Tracking from Space Expands Opportunities for Global Ocean Observing and Maritime Domain Awareness

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Abstract* — Satellite Automatic Identification System (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, satellite 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 satellite 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 paper examines the elements and architectures required to bring about these changes to provide a robust, real-time global view of the maritime domain in general, and AIS specifically. 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. In addition, this paper discusses performance metrics and a few key capabilities that will be greatly enhanced with this new real-time capability, which can be applied to a number of security, safety, economic and environmental use cases.

***Index Terms* – Automated Information System (AIS), real-time ship tracking, Maritime Domain Awareness (MDA), hosted payload, global ocean observing**

I. Introduction

We live in an ever-changing environment where there is a vital need for persistent monitoring of human activities whether it be for security, safety, economic or environmental purposes. Our oceans are no exception and may even be the region of our globe that is most at risk. Unbeknownst to many, there is limited visibility and awareness of maritime activity beyond 40-50 nautical miles from our coastline. Shore-based technologies have limited range, space-based radar and other sensors have limited coverage, and marine patrol and synthetic aperture radar (SAR) assets are too costly to deploy over a wide area. Nevertheless, the ability to assess *who, what and when* of any transiting vessel near our coastline or in the open ocean is a critical piece of intelligence – be it to secure our borders, counter piracy, prevent illegal drug smuggling, reduce response time for search and rescue operations, combat illegal fishing, monitor marine protected areas (MPAs) and so on.

One recognized solution is to use Automated Information System (AIS) to track vessels. Since 2004, provisions of the International Maritime Organization's (IMO) Safety of Life at Sea (SOLAS) Convention require ships of 300 gross tons or more engaged on international voyages, cargo ships of 500 gross tons or more not engaged on international voyages, and all passenger ships irrespective of size to be fitted with AIS. In addition to the international requirements set by the IMO, many national administrations have mandated AIS across regional fleets. 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 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 very high frequency (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 display (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 radio frequency (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. A good introductory description can be found in [1].

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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 3,000 nm. The basic AIS communication scheme was neither designed nor intended for this extreme range of coverage. As a result, satellite 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.

II. Real-Time Satellite AIS Approach

Developing and deploying a real-time satellite-based architecture that addresses the VHF and other maritime challenges discussed in the previous section requires five essential elements: 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 Application Specific Messages (ASM); and 5) Ability to adapt to evolving uses of the maritime VHF spectrum.

1. Continuous, global satellite coverage and superior detection rates

True, global, real-time maritime domain awareness (MDA) is dependent on both the quality and size of the satellite constellation. For low Earth orbiting (LEO) satellites, the greater the number of satellites, the greater the coverage. In addition to 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 (see Figure 1). Other advantages of LEO satellites are small latencies and link losses, and, due to their close proximity to Earth, they can utilize very small antennas and require less amplification for transmission [2].

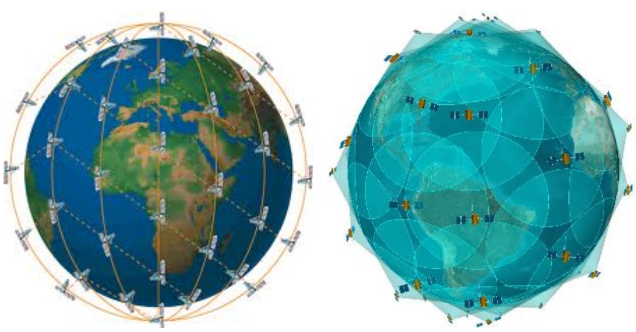

Figure 1. Satellite configuration (left) providing real-time global coverage (right)

Flying onboard Iridium NEXT satellites as hosted payloads (Figure 2), 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 (up to 4) simultaneously. This level of satellite AIS coverage results in significant vessel detection improvement over the current state of the art and represents the largest and most advanced satellite AIS constellation in the world.

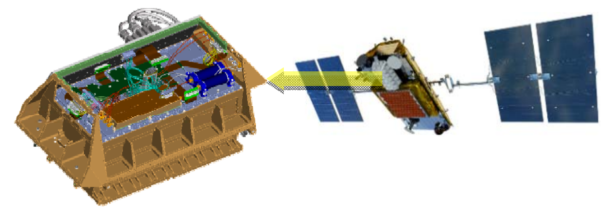

Figure 2. Hosted payload (left) on Iridium NEXT satellite (right)

2. Real-time downlinks

Today, in addition to satellite transmission methods used when in range of a ground terminal (e.g., bent pipe technology), all satellite 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 ultimate 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 element 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.

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 truly instantaneous global MDA.

3. Ability to detect all AIS broadcasters, not just those mandated by the IMO

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 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.

4. Ability to handle rapidly expanding use of ASM

Use of AIS has expanded dramatically due to the effectiveness of the technology, which 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 class A AIS performance.

As captured in the USA Federal Communications Commission (FCC) document, *Proposals for the Work of the Conference* [3], satellite AIS effectiveness was determined to be unacceptably limited where VHF Data Link (VDL) loading is high. The resulting need for a separate, dedicated satellite AIS service was confirmed at the World Radiocommunication Conference in Jan/Feb 2012 (WRC-12), and two additional (satellite or long-range) AIS channels were designated to increase the effectiveness of satellite AIS systems. While these new designations address the problem for satellite detection (for Class A devices only), 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 1 and 2), 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 [4] (page 140).

As ASMs are migrated off of AIS channels 1 and 2 onto their own, separate frequencies, it is critical that a comprehensive satellite AIS system provides the means to receive and transmit to the ground this information in conjunction with the AIS and long-range AIS messages. This affords the ability to collect and transmit various oceanographic and meteorological (MET) data (e.g. bathymetry, temperature, salinity, wind speed, wind direction, etc.) from vessels of opportunity as they transit across the globe. The HARRIS satellite VHF receivers provide these capabilities as part of their standard operation over the frequency range shown in Figure 3. 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.

5. Ability to adapt to evolving uses of the maritime VHF spectrum

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 upcoming World Radio Conference in Geneva, Switzerland, in Nov 2015, changes to the maritime VHF domain will be considered and discussed, 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)" [5] (see paragraph 1.16).

The referenced Resolution 360 (WRC-12) (page 280 of the ITU 2012 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 radiocommunications 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 commerce, 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, which is not economically feasible) or provide on-orbit flexibility and re-configurability, including re-programmability. The constellation of HARRIS satellite VHF receivers for AIS and MDA 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.

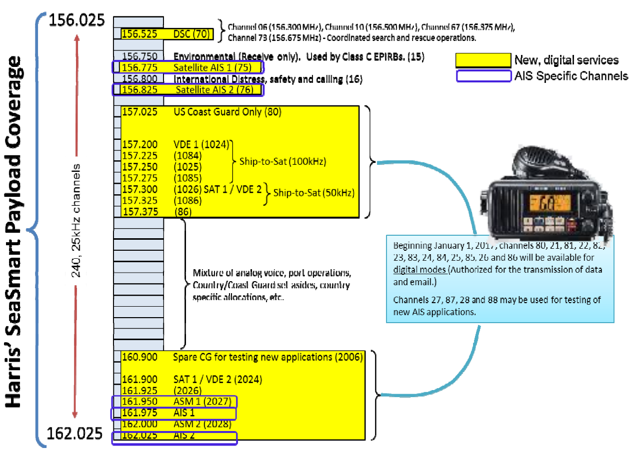

Figure 3. Maritime VHF band showing new digital services including ASM and AIS specific channels

III. Real-Time Performance Metrics

As described, this new generation of satellite AIS tracking provides unrivalled *global coverage* in *real-time (RT)*. This system leverages Iridium's real-time down-linking capability to minimize latency; exactEarth's patented, proven AIS message processing capability; and HARRIS' leading reprogrammable payload architecture. Once all of the satellites are deployed we expect to receive over 50 million satellite AIS position reports daily from over 140,000 unique vessels with less than 1 minute average global revisit time and less than 1 minute customer data latency. Over 98.5% of the globe will be under persistent coverage from 1 to 4 satellites at any given time.

The system is configured with both an omni and collinear antennas to provide broad area coverage that will dramatically improve detection in congested areas. Terrestrial AIS can also be added to improve coverage along coastal and port areas. Frequencies ranging from 156.025 to 162.025 kHz over the entire marine VHF band are collected that contain the AIS specific channels as well as new digital services including VHF radios that are typically used for short range communications (< 20nm) for ship-to-ship or ship-to-shore communications. This performance supports sophisticated algorithms to analyze the behaviors of vessels at sea to gain increased global ocean observing and MDA for a number of applications.

IV. Use Cases

There are many use cases for real-time AIS tracking that fall within security, safety, economic (commercial) and/or environmental categories. Table 1 lists a few. Specialized algorithms can be written to analyze the AIS data stream and alert users when certain anomaly conditions occur. Three key capabilities that benefit from real-time data are the ability to: detect dark targets coincident with other data, detect when AIS is turned off immediately, and estimate position of vessels broadcasting spoofed positions. A few sample use cases are described below that illustrate these and other capabilities.

Table 1. Sample Use Cases

Name	Security	Safety	Economic	Environmental
Federal ECA Monitoring				*x*
Search and Rescue		*x*		
Vessel Rendezvous	*x*			
Arctic Monitoring	*x*	*x*	*x*	*x*
Counter Piracy	*x*	*x*	*x*	
Vessel Traffic Monitoring	*x*	*x*	*x*	*x*
Positional Anomalies	*x*		*x*	*x*
ETA & Destination Changes	*x*		*x*	
Anti-Proliferation	*x*			
Counter Narcotics	*x*			
Coordinated Collection	*x*	*x*		*x*
Fisheries Protection			*x*	*x*

1. *Arctic Monitoring*

The Arctic Sea covers vast regions of the Earth's surface and are becoming ever more important as the ice cover reduces making these areas more accessible to fishing, tourism, mineral exploitation and a viable shipping route. The region is not only covered with ice, but also is prone to poor visibility for vessel traffic. As such it is one of the most hostile maritime environments on our planet, causing hazards such as ice accretion on vessels which can lead to instability, or colliding with icebergs and growlers which are not easily detected by radar. Sea ice, universally thick in winter, is subject to piling up in summer months, thus preventing ice free passage. To deal with these problems, an International Code of Safety for Ships in Polar Waters (Polar Code) is being developed, with support from the International Maritime Organization (IMO). The Polar Code requires all vessels traversing in these waters to be equipped with AIS.

Satellite AIS provides complete global coverage in the vast Arctic region and is able to identify ships where previous surveillance systems had limited detection. Coastal systems cannot provide complete coverage and are not economical to install in such remote areas.

Data in Figures 4 and 5 show increased traffic through Arctic shipping routes as environmental conditions permit. As ship traffic continues to increase, the HARRIS-exactEarth system will provide these advantages:

- Easily integrate with weather and ice prognosis data enabling the implementation of Vessel Traffic Monitoring and Information Services, especially for the Northern Sea Passages to allow vessels to navigate safely even in the area's heavy fog conditions.

- Allows critical tracking of passenger ships in Arctic waters to validate their compliance with the advice of coastal state authorities ensuring safety measures are being followed. Data also enables monitoring of other vessels in the vicinity of passenger ships in case they may be required to assist taking on passengers as a result of rescue operations.
- Provides more frequent AIS coverage over polar areas than any other system, delivering a better understanding of Arctic maritime traffic trends to allow for necessary analysis into proper shipping routes.

Figure 4. In 2012, LNG gas tanker *Ob River* (top) travelled through the north of Russia en route to Japan (blue track). It was the first of its kind to make this Arctic journey. *Icebreaker 50 Let Pobedy* escorted *Ob River* through part of the region (red track).

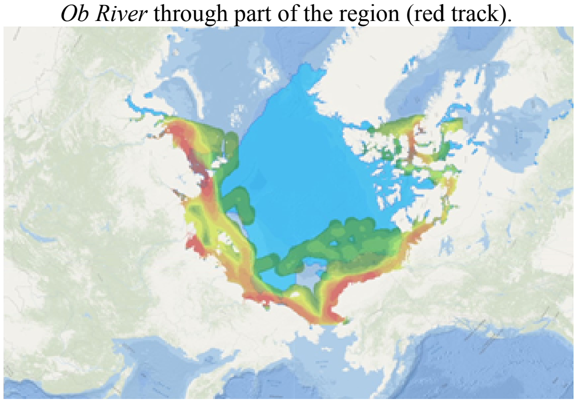

Figure 5. Density map displaying ship traffic through the remote Arctic region in August 2013

2. *Correlated/Coordinated Collection*

Satellite AIS data can be correlated (or coordinated) with other data, such as SAR and electro-optic (EO) imagery, to create a common operating picture of all vessels whether AIS is turned on or off. Figure 6 illustrates an example where AIS data from two satellites and SAR imagery from another satellite is used to validate the vessel identity.

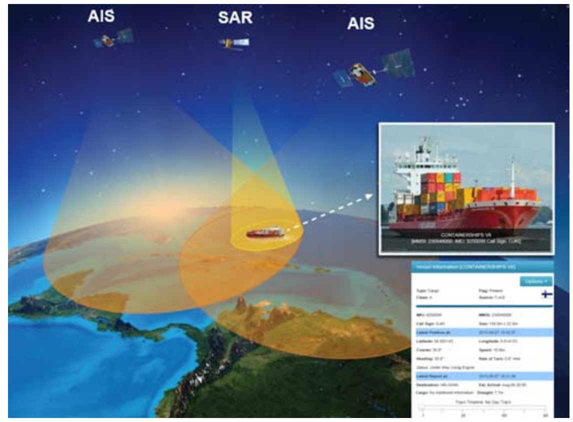

Figure 6. Coordinated data collection using AIS and SAR satellites

In this process, satellite AIS signals are cross-referenced with satellite SAR imagery to verify that the AIS is turned on. Vessels that are detected by SAR and not by AIS pose suspicion. Figure 7 shows two suspicious examples that are highlighted in red.

Other useful data can include images of the vessel or the vessel's wake, and numerical measurements such as length and width of the vessel that allows for validation on size matching in the image or to the vessel type description in the database.

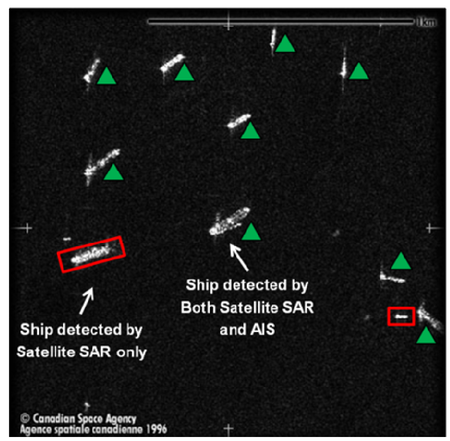

Figure 7. Detection of ships with AIS turned on (green triangles) and AIS off (red rectangles)

3. *Search and Rescue*

Vessels often do not declare they are in trouble until it is too late, resulting in distress signals being sent at the very last moment or in some situations net being sent at all. There are three stages to alerting authorities of any problems at sea, the highest being the Mayday which is the final signal used. However, in many cases a vessel might flounder without any previous communication announcing trouble or without any distress message at all.

A Rescue Coordination Center (RCC) needs to have an up to date image of all vessels and their status within the vicinity of a distress position. The RCC can then select the most appropriate vessels to proceed to the distress call, and which vessels to keep on station for backup. The RCC will take into account not just range and speed, but also the freeboard of a vessel, its cargo, and availability of assets such as helicopters and medical facilitates.

The International Cospas-Sarsat Program is a satellite-based search and rescue distress alert detection and information distribution system that is an intrinsic part of the Global Maritime Distress and Safety System (GMDSS).

However, there is ambiguity within the system that could provide two possible locations of a distress. If one is on land then the signal is discounted, but if both positions are at sea, then it is possible that a search and rescue operation could be performed in the wrong area.

Satellite AIS provides global coverage and can help to resolve ambiguity surrounding rescue incidents. Authorities are equipped with information on the status of vessels as well as their proximity to a vessel that may be in distress. This allows them to be proactive when a rescue incident occurs.

An example search and rescue operation was tracked by the exactEarth system in February 2011 when the United States Coast Guard assisted a disabled 432-foot ocean freighter just outside of Cape Cod, MA (Figure 8). The MV Dintelborg lost propulsion when a small fire broke out on the bridge and the ship went adrift without power in 16-foot seas with no ship-to-shore communications.

Figure 8. Track of Tug McAllister that assisted in the rescue and towed the Dintelborg to safety.

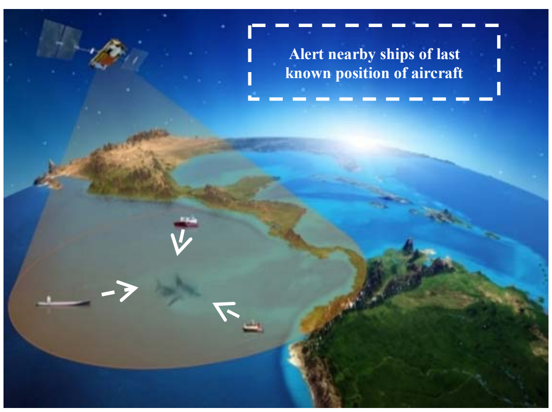

Figure 9. Satellite AIS and ADS-B data can be coordinated to quickly and efficiently direct a search and rescue team

The HARRIS-exactEarth system will provide these advantages:

- Historic tracks of the last known position of a vessel in distress will help ensure that resources are mobilized quickly and effectively.
- Data can be used by authorities to assess probable risk to ships, allowing for proper escalation procedures and ensuring an appropriate state of readiness to reduce response time.
- Data provides the current status of a ship, and can be used to help the selection of the most appropriate rescue vessel in the vicinity. This ensures that authorities can best utilize resources in the area for a quicker rescue operation.
- Historic track of the stricken vessel as well as other traffic, may indicate the proximity of other vessels failing in their duty to report an incident, or even to identify a vessel that may have caused the incident.

Another scenario might involve searching for aircrafts, such as Malaysia Airlines Flight 370. In these cases, another Iridium NEXT payload, Aerion's air traffic surveillance system's ADS-B receivers [6], can be used in combination with satellite AIS to immediately determine the last known position and most probable current position. This scenario is illustrated graphically in Figure 9.

4. Fisheries Protection

Several decades of overfishing in most of the world's major fisheries has created large declines in many commercially important fish populations around the world. The United Nation's Fisheries and Agricultural Organization (UN FAO) report that 53% of the world's marine fishery resources are fully fished, or fished to the maximum sustainable level [7].

Today, illegal, unreported and unregulated (IUU) fishing is recognized as a major threat to achieving sustainable fisheries. IUU vessels may or may not be using AIS, but they will usually be found in areas populated with legitimate fishing vessels, and often around a mother ship for transshipment. Traditionally, vessel monitoring systems (VMS) are used for monitoring fishing activities by National and regional Fishery Management agencies to prevent IUU fishing. UN FAO guidelines suggest VMS should transmit every 1 or 2 hours, but since its inception crews have tried to defeat VMS by spoofing the information.

Satellite AIS offers many advantages:

- Validate vessel positions received by the VMS to eliminate false reporting.
- Reduce the individual 'point-to-point' communication costs of VMS reports.
- Determine the proximity of non-cooperative IUU vessels in the area, having locations of other legitimate fishing vessels that are equipped with AIS.
- Extend surveillance range beyond VMS to include areas where vessels are not intended to be fishing. Often ships used for transshipment wait in Polar waters, where satellite AIS can now monitor.

In addition, the HARRIS-exactEarth system will provide these advantages:

- Detect non-cooperative vessels over an extended surveillance area which allows authorities to shift their attention to these ships and prosecute more violators.
- Compare dynamic data to the vessel's reported latitude and longitude, allowing authorities to identify spoofed position reports where illegal fishing may be taking place. Detecting spoofed positions and computing accurate positions will be greatly enhanced by having multiple satellite coverage in the real-time system.
- Assist in efficiently tasking patrol assets to the vicinity of fishing vessels, saving time and money.
- Assist authorities in identifying fishing activities as well as determine between licensed and IUU activities using collected data.
- Track vessels used for fish transshipment of suspected IUU catches as well as show historic tracks of suspected undeclared transshipment allowing for prosecution of all vessels involved.
- Correlate AIS database information with the vessel's registration to the Fishery Management Agencies to quickly identify unregistered vessels in fishing waters.

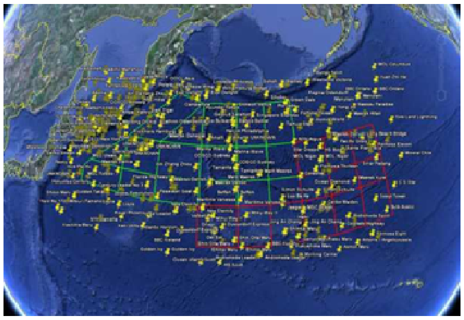

Figure 10. Operation Driftnet observations

One example where exactEarth has participated in fisheries protection is Operation DRIFTNET [8], implemented to combat global overfishing and improve the way the world's fish stocks are managed. During operation from 1-18 Sept 2009, exactEarth provided daily satellite AIS observations over the monitoring area shown in Figure 10. An average of 600 vessels were detected during each daily 90 second observation period. Coordinated collection was used during this operation with a radar satellite, as described in use case 2. The data helped confirm the process was feasible for identifying and intercepting illegal fishing vessels.

Figure 11 illustrates an example of how the real-time AIS system might be used to detect potential illegal fishing in a Marine Protected Area (MPA), represented by the white dashed boundary line. Green check marks on the vessel's picture indicate the AIS has been updated within the expected timeframe; whereas a red "x" indicates the AIS message has not been received. Note that the fishing vessel in the scene has not transmitted a recent AIS message.

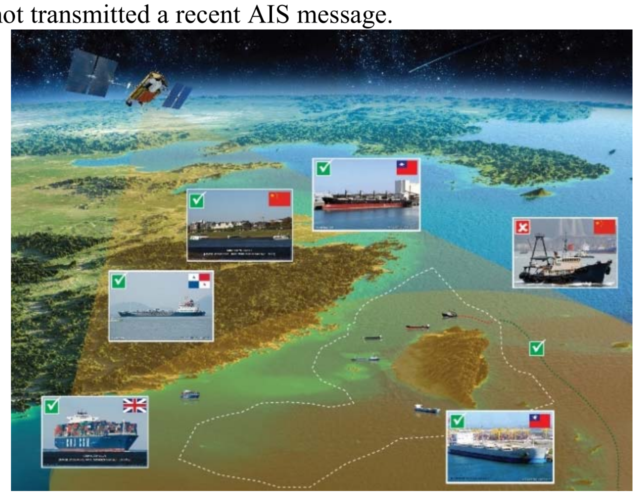

Figure 11. AIS is turned off on the fishing vessel as it enters the MPA

With real-time AIS updates a change in state, from AIS on to AIS off, will be obvious after a certain period of time. This behavior may be indicative of a hardware failure or hardware accidentally being turned off, or it might represent suspicious behavior. The green dashed line represents the fishing vessel's track based on historical AIS messages. As the ship entered into the MPA the AIS signal was no longer detected (indicated by red dashed line); thus the current position is unknown unless coordinated collection described in capability 1 is applied.

V. 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 satellite 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 re-programmability 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 ocean observing and MDA capabilities through global, real-time information delivery of AIS messages from space.

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