IALA

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SATELLITE AIS CONSIDERATIONS

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Association Internationale de Signalisation Maritime

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1.2 PURPOSE OF THE APPENDIX

Terrestrial AIS systems have the benefit of continuous coverage and detection rates that approach 100% close-in to shore. They have the disadvantage of very limited range and high cost per square mile covered. Satellite AIS (S-AIS) has the advantage of providing complete global coverage with comparable average detection performance as well as low cost per square mile covered. It has the disadvantages of lower detection rates close to shore stations and only periodic vessel refresh. Therefore, S-AIS and terrestrial systems each provide capabilities offering unique and complementary benefits to national administrations, which mean that both are needed for complete maritime domain awareness

This appendix will describe satellite communications methodology, special considerations for receiving and displaying AIS messages and several use-cases for satellite AIS data.

2 SATELLITE AIS

2.1 FUNDAMENTAL CONCEPTS

2.1.1 Satellite Orbits

The AIS satellites are all placed in Low Earth Orbit (LEO) where they travel at about 27,400 km/h at a distance of 650km to 800km from the surface of the earth. A single revolution around the earth takes approximately 90 minutes as these LEO satellites are not geostationary, therefore a constellation of satellites is required to provide coverage in a timely method.

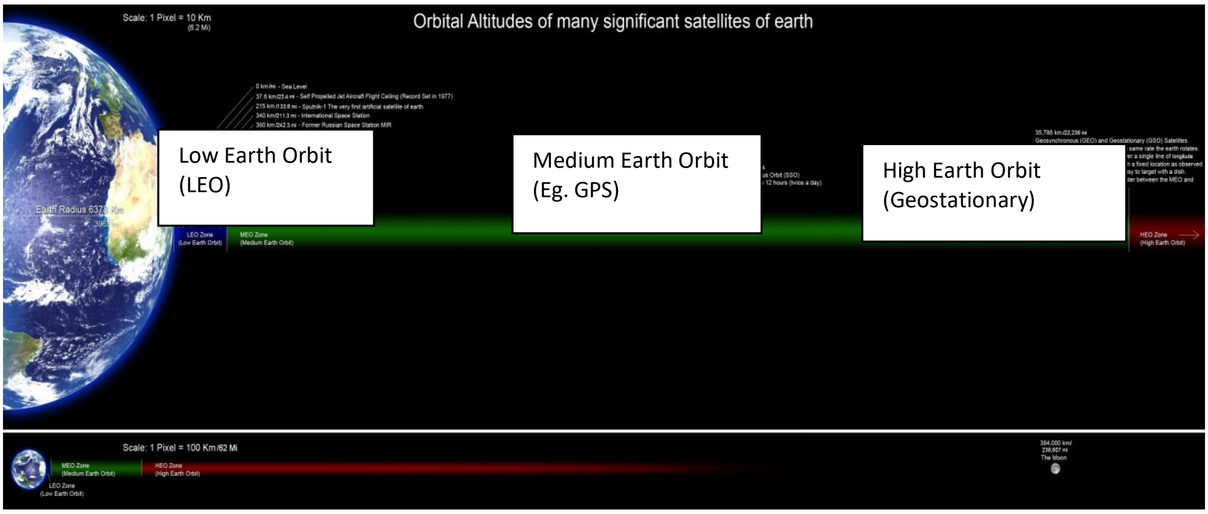

Figure 1 Orbital altitudes

There is a standard type of orbital elements called the Keplerian elements that are most used and most useful. The Keplerian orbital elements define an orbital ellipse around the Earth; in Keplerian mechanics, all orbits are ellipses. The orbit ellipse lies in a plane, and this plane forms an angle with the plane of the equator. This angle is called the inclination; the tilt between the orbit and the equator. The inclination ranges from 0 to 180 degrees. Inclinations of near 0 degrees are called equatorial orbits, and those near 90 degrees are called polar orbits.

The orbital plane of a LEO satellite can vary from a polar to an equatorial orbit, however only the polar orbit provides coverage of the entire earth. A full constellation of satellites, providing maximum coverage and minimal revisit intervals will include satellites in both the polar an equatorial orbit and with at least four satellites covering the angles between.

2.1.2 Ground station communication

The type of ground station infrastructure required to download and backhaul the data for processing and delivery to the customer is varied depending upon the communications capabilities on the satellite. Therefore, the possible locations for download are dependent upon the antenna and modem capabilities at the ground station. The location and number of ground stations has an impact on the overall latency from capture to presentation to the user. However, it would be far too simplistic to assume that more ground stations and more satellites directly correlate to a timely and complete maritime domain picture. The overall capabilities of each satellite, the method of detection and the location of the ground station versus the satellite footprint must all be considered when developing the ground station infrastructure necessary to support the satellite constellation.

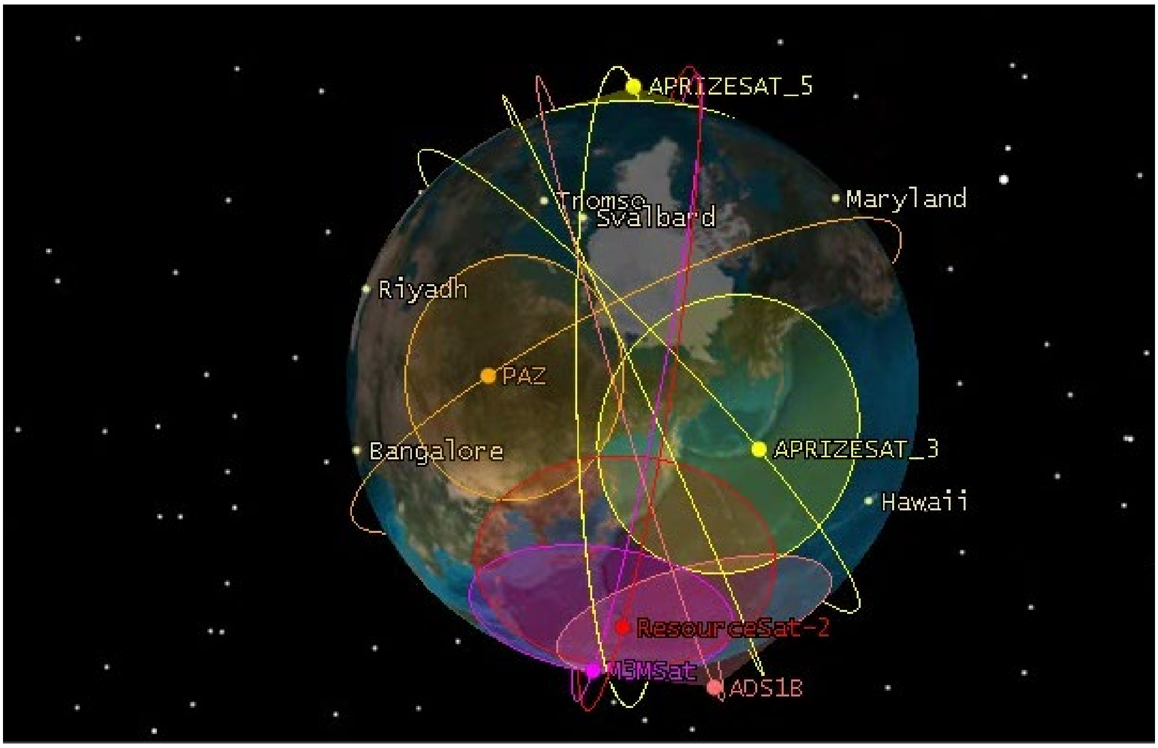

Figure 2 Typical Satellite Constellation

2.1.3 Data Detection and Refresh considerations

2.1.3.1 Detection methodologies

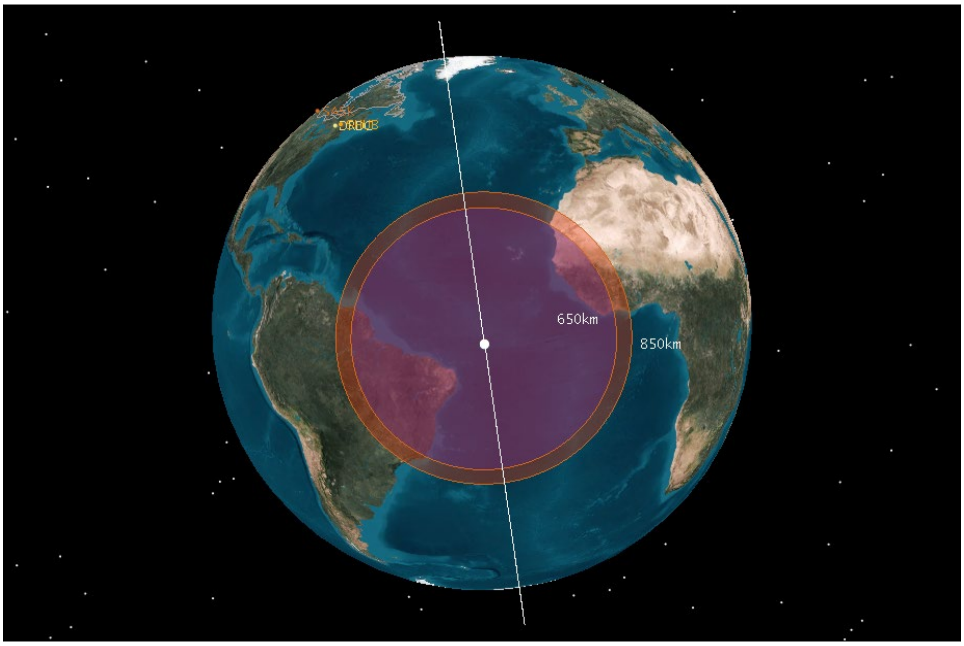

Figure 3 Field of view from an AIS satellite at 650 km altitude (purple) and 850 km altitude (red) approximately 5000 km in diameter

When the number of ships in the space based AIS antenna's field of view exceeds about 1000, the problem of signal overlaps becomes critical and the number of 'uncollided' messages quickly drops. When the number of ships in the field of view exceeds about 2500 there are very few uncollided signals as seen from space. With 1000 ships are in the field of view, observing a region for 15 minutes statistically results in at least one clean, uncollided message received from each ship due to the nature of the signal scheduling and the capacity of the AIS channel frame of 4500 messages per minute. Increasing the observation time results in a slight increase in the maximum number of ships statistically detectable in the field of view, but the hard-limited frame capacity of 4500 messages per minute prevents significant improvement. Considering the reception of AIS signals from Low-Earth Orbit (LEO), and assuming the maximum possible spacecraft footprint for a LEO spacecraft, at best, a single spacecraft will remain over a particular ship for no more than 10-15 minutes per orbit. Ship traffic analyses indicate that there are very few areas in the world that have fewer than 1000 AIS transmitters in the above field of view.

In order to overcome slot collisions 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.

The advantage of OBP is that it will reduce latency time to the time from the satellite pass to download at a ground station and the backhaul time over the internet from ground station to the end-user. This method does not require any special processing. The disadvantage of OBP is that the detection probability is very low in areas where the satellite footprint (~5000 km in diameter) contains a ship density approaching 1000 ships. Statistical analysis has shown that the first pass detection performance for OBP in high dense areas is, on average, about 15%. Therefore, maritime domain awareness is never achieved unless multiple satellite passes occur over a several hour period and if within the area of interest the ship traffic is very dense, over 2500 ships, it is unlikely that the complete maritime picture will ever be achieved using OBP.

The advantage of SDP is that the first pass detection is very high even within high ship density areas, thus achieving faster maritime domain awareness through the post processing of the raw RF spectrum and the decollison of individual SOTDMA cells. Statistical analysis has shown that the first pass detection performance for this detection methodology in high dense areas is, on average, 65%, and newer advances in processing can yield up to 75%. As a result, the complete maritime picture can be realized in as little as 2 satellite passes. The disadvantage of SDP is that is does require ground based processing and therefore latency time is increased by the processing time. If the area of interest contains higher ship densities then SDP is required to achieve detection at a level that will enable operational use of S-AIS.

2.1.3.2 Refresh considerations

Data refresh in any given area of interest is a function of the revisit times of the satellite and the latency time between the collection of the data and delivery to the end-user. Data refresh and the first pass detection capability of the satellite constellation, (OBP, SDP or both) are the major contributing factors to the accuracy of the maritime domain picture.

Latency is defined as the time required from the moment the data is collected over an area of interest by a satellite to the time that data is delivered to the user. Latency can vary depending upon the location and capabilities of the ground infrastructure relative to the area of interest, the speed of the internet connection, and any post processing requirements.

Revisit time is defined as the time between each satellite pass over a given area of interest on the earth. The revisit time is a function of the orbit and inclination of the satellite constellation. This metric will differ widely by provider and even for a given provider the exact time of day of the revisit may vary as the footprint of the satellite changes. However, the pattern for each satellite pass will remain roughly constant over time. It is the relationships between multiple satellites that can shift and makes the net gap seen from the whole constellation vary over time. Further the length of the visit needed to achieve high detection varies depending on the density of the ship traffic; a dense area will need a satellite pass lasting at least 10 to 15 minutes.

2.2 DATA INTEGRATION

2.2.1 Data Formats

Given that S-AIS data must be processed, at some level, before delivery to the customer it is possible to introduce variant formatting options to support not only the display of S-AIS data but also historical archiving such that the data is ready for historical analysis.

2.2.1.1 IEC 61162-1/NMEA 0183 v4.0

The data feed for S-AIS is similar (no VDO messages) to the data feed provided by a standard base station (PSS) compliant to IEC 62320-1. The standard VDM sentences defined in IEC 61162-1 are augmented with the Tag Block defined in NMEA v4.0 to provide time and source information. A sample output is listed below:

```
\s:rEV03,c:1294912484*55\!AIVDM,1,1,,B,13gJ1kg00?NA77@ULmG8mqiB0<0f,0*21,1294912
```

2.2.1.2 CSV Format

Depending upon the provider of the S-AIS message feed, the AIS messages can be transmitted using the Comma Separated Values (CSV) format. Information contained in the CSV row includes a combination of position, static and voyage related information. Data elements include ship's identification, GPS position, course, speed, rate of turn, ship name, navigational status, ship type, IMO number, ship length and time-stamp. A sample CSV formatted message is included below.

Stamp,UTC,UTCdisplay,MMSI,LAT,LONG,COG,Heading,ROT,SOG
20/03/2011,013149,01:31:49,734862330,-23.5373883333,-69.3473816667,306,365,-0.845129938728,10
20/03/2011,135606,13:56:06,717769104,37.88706,32.046745,65,361,2892.24593281,31
20/03/2011,153635,15:36:35,423376840,109.479383333,-27.732415,84,119,-1065.07500528,35
20/03/2011,074838,07:48:38,879109387,79.5940066667,-51.8314566667,389,403,409.042890344,81
20/03/2011,105912,10:59:12,872626816,94.1250933333,87.2365666667,366,212,2603.21149377,38
20/03/2011,190435,19:04:35,149759689,34.5435166667,132.951578333,368,108,2892.24593281,63
20/03/2011,190432,19:04:32,769075542,-69.3978666667,-191.932253333,362,146,-686.456792732,61
20/03/2011,203756,20:37:56,25041002,-90.2714883333,23.0509733333,102,426,1005.91590957,59
20/03/2011,204251,20:42:51,49967206,-24.8448233333,-49.402765,56,220,-2794.21085992,20
20/03/2011,033201,03:32:01,251191110,64.1342316667,-21.8272416667,305,163,0.0,0
20/03/2011,033201,03:32:01,316007862,48.12799,-69.7309666667,163,336,0.0,3
20/03/2011,033201,03:32:01,240847000,49.6107666667,-16.2384166667,38,40,0.0,13
20/03/2011,033201,03:32:01,309951000,38.8022116667,-74.0505533333,187,189,0.0,22
20/03/2011,033201,03:32:01,305178000,42.9731166667,-27.0931833333,227,230,0.0,14

2.2.2 Display and analysis considerations

Satellite AIS is a data rich source of information increasing maritime domain awareness in new and inventive ways, however there are some important fundamental differences between AIS data sources based on receptions at the terrestrial PSS and AIS data sources based on reception from space. As most VTS applications are real-time centric, it must be understood that S-AIS is historical by nature, and should never be used for collision avoidance or other real time applications. Satellite AIS provides, for the first time, a wide area maritime awareness whether it is covering a countries EEZ, SAR area, or complete world-wide port to port traffic monitoring.

The capability to track a ship, or population of ship types, many days or hours away from a port enables the creation of a complete picture of that ship's behaviour on approach to a VTS. Given that S-AIS is an analysis and strategic tool, the display software must be capable of indicating the latency of the track, whether providing the associated time tag, or colour coding data, it is important that the user be given visual cues to quickly analyse the reported track in relation to the current time. Further tools that will allow the user to bring up the historical tracks for this ship, or for all ships passing in the region, can provide additional tools to quickly analyse whether the ship is behaving as expected or is somehow deviating from expected behaviour.

It is also worth note that S-AIS can offer such a volume of data that the capability to filter the data by all the various fields within the AIS messages, e.g. MMSI, SOG, COG, Ship type, etc., is a very important tool. Further, the capability to define areas of interest (AOI) where traffic patterns or violations of protected zones can quickly be determined is necessary to make full use of S-AIS data.

Finally, the capability to integrate S-AIS data with coastal AIS data is vital. Given that S-AIS data provides vessel tracks for behavioural analysis and Coast AIS provides the last position for collision avoidance it is important the display software provides strong visual cues on the source of the data and provide a tool to quickly display the complete track of a ship when necessary.

2.2.3 Data Quality and Quantity

The quality and quantity of satellite AIS data is dependent upon the field of view for the satellite, the mechanics of the constellation, and the type of detection technology employed by the satellite. It bears repeating that the field of view for a satellite is typically 5000 km and will most likely encompass populations of ships outside the area of interest for a VTS.

2.2.3.1 Ship Density

As explained in previous sections, the likelihood of detection and therefore a complete maritime picture is dependent on the population of ships within the satellite footprint. When the number of ships in the space based

AIS antenna's field of view exceeds about 1000, the problem of signal overlaps becomes critical and the number of 'uncollided' messages quickly decreases. When the number of ships in the field of view exceeds about 2500 there are very few uncollided signals as seen from space. As a general rule of thumb, when a satellite footprint includes a coastal area, the population of ships quickly increases over the 2500 level. At this point, timely and complete maritime domain awareness can only be achieved using SDP.

2.2.3.2 Message Frequency and Length

The expected broadcast interval and length (number of slots required) of the message type will also impact the likelihood of reception by a satellite. Given that a satellite pass is typically ten minutes those messages that are transmitted infrequently and require more than one slot, such as Message 5 and 21, are much less likely to be detected in a dense population of ships. This is because during any given satellite pass these message types will only have a single transmission and because they are multi-slot messages are much more subject to slot collision. Where these type messages are coupled with high ship density, as is the case for ships that rarely leave coastal waters, it may be necessary to augment the S-AIS data with coastal AIS data. If an administration wishes a transmission to be detected by satellite, such as AtoN status binaries or position reports, the frequency of transmission must be such that a satellite is likely to receive the transmission during a pass.

2.2.3.3 In-Band Interference

In-band interference can have a large impact on the likelihood of detection from space. While most countries take careful and effective measure to police the maritime band within coastal areas it must be remembered that the field of view for a satellite can, include inland areas. These inland areas may allow for the use of the maritime band for other applications. This does not cause a problem for the coastal areas but for a satellite it can increase the noise floor such that discriminating individual SOTMDA cells becomes a very difficult exercise requiring SDP and in some cases making detection unlikely.

2.2.3.4 Refresh and First pass detection

Given the nature of satellite mechanics, the collection of AIS data via satellite must consider both the refresh interval and the first pass detection capability of the satellites within the constellation when determining the completeness of the maritime picture within the AOI. The latency of any given data point is impacted not only by the mechanics of satellite constellation, i.e. the refresh time, but also the likelihood that any given pass will update, or detect the traffic in the AOI, i.e. the first pass detection.

While the mechanics of the refresh rate is fairly stable over time, the likelihood of first pass detection can be impacted by all of the items listed above: ship density, message frequency, and in-band interference. Since these variables are completely dependent upon the AOI, understanding the first pass detection percentage must be based upon an established ground truth for the AOI. Understanding ground truth for the entire area can be achieved through historical analysis or by an aggregate of all satellite passes over a given period, e.g. 24 hours.

2.3 SATELLITE AIS USE-CASES

Satellite AIS offers the capability to provide a new definition of maritime domain awareness, but it also offers some very specific applications providing benefit both to the mariner and to administrations. While Coastal AIS can support some of these same use-cases it does have a significant range limitation that can limit an administrations ability to plan for off-shore structures based on waterway usage, coordinate responses, take enforcement action, and prepare logistics.

2.3.1 Ship reporting

Many countries operate Voluntary Ship Reporting (VSR) systems with coverage extending over very large areas of ocean. Voluntary Ship Reporting enables Search and Rescue (SAR) Authorities to have a better understanding of where ships are within their SAR area. Though SAR is the motivation behind voluntary ship reporting, the information may be used by various authorities for a number of other applications.

Voluntary ship reporting requires a number of information sets that include both dynamic and static information on the hull and cargo. Currently, this information can be sent by Telex or email and follows IMO guidelines. The reporting interval is anything from a few hours to daily. Once the authority receives the cargo and passage plan information, it then requires position reports (ID, Position, Course and Speed) on a regular basis. Relying on these being entered and sent manually can be problematic. These can now be provided automatically by using S-AIS.

The use of S-AIS in voluntary ship reporting provides many benefits to both ship owners and operators, as well as to the maritime authorities, from both a cost saving and a safety and environmental perspective. It enables:

- More efficient planning and allocation of SAR and pollution prevention resources;
- More regular and automated reporting systems, providing earlier detection of potential vessel problems;
- A lower cost of reporting for ship operators.

2.3.2 Monitoring

2.3.2.1 Fishery Monitoring

Most fishing activity is monitored via a vessel monitoring system (VMS) in which equipment that is installed on fishing vessels provides information about the vessels' position and activity; VMS position reports are required every 2 hours. However, Satellite AIS is a passive system that requires nothing more than a Class A device installed on the fishing vessel. The data provided in the standard position report provides velocity and heading information for use in dead reckoning calculations. Further, the higher quality of the first pass detection the more likely the Satellite AIS data will provide multiple position reports for any given target. The existing VMS data augmented with Satellite AIS data can provide an accurate picture of fishing fleet behaviour world-wide.

2.3.2.2 Monitoring Areas of specific interest for incursions

To protect offshore installations and reduce the risk of a maritime casualty and resulting marine pollution, some exclusion zones and precautionary areas have been established. Precautionary areas might envelop wind farms or oil and gas fields and apply to vessels of a certain size. Vessels may be prohibited from entering certain sea areas due to environmental concerns. Any vessel wishing to enter such areas may only do so after clearance by the mandatory reporting system for the area concerned. An example of such an area is that set aside seasonally for Right Whale breeding off the US coastline.

Other areas may be prohibited or tightly controlled due to ecological disasters, or to allow endangered marine species and organisms to thrive or recover.

With satellite AIS, these areas can be monitored both for singular violations and for trending of ship populations. Satellite AIS can provide:

1 A report of all vessels whose route appears to be heading for sensitive areas, rather than the extremities of them. A ship that has the intention of passing around, or avoiding such an area, will not head directly for it, but the optimum safe route to avoid it!

2 A report on vessels such as tankers that have deviated from their "route" which might indicate they are trying to avoid detection of dumping tank slops.

3 A report on vessels that have strayed into remote, sensitive areas away from coastal surveillance installations.

4 The ability for authorities to extend their sensitive areas outside where they can monitor using coastal installations.

5 SAR and AIS collated images to show non cooperative vessels, outside areas covered by coastal surveillance installations.

2.3.2.3 Watched vessel approach

Port state control applications require listing of ships that are in violation of SOLAS requirements or in need of repair but have been allowed to exit port. Through the use of satellite AIS, the approach of these vessels can be monitored and if necessary additional assets deployed to escort or intercept these ships before they pose a danger to coastal waters.

2.3.3 Traffic Waterways Usage and Analysis

Data that is derived from S-AIS sources provides AIS shore stations with accurate information for far greater ranges than that of shored based AIS sources. With S-AIS, authorities can build a complete picture for maritime traffic approach to areas of interest. Uses for this information includes that of identifying traffic patterns and density, which is particularly useful when analyzing effective deployment of Aids to Navigation, developing exclusion zones around sensitive maritime locations (e.g. protected ecological areas and wind farms). The figure below shows traffic patterns captured via S-AIS in the Gulf of Mexico, clearly identifying the concentration of marine traffic routes.

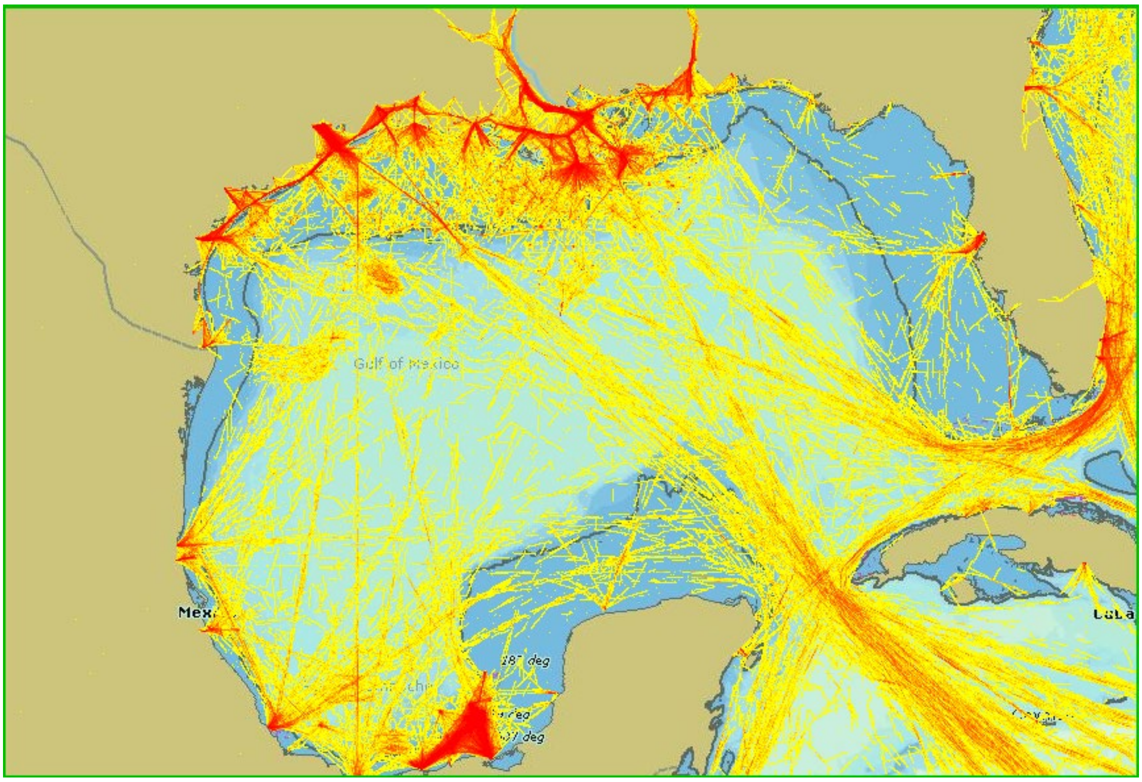

Figure 4 Example Traffic Patterns

Analysis of the S-AIS data can enable any competent authority and maritime based resource developers to study the impact of new proposals (e.g., wind farms and traffic management schemes) and to produce impact and/or risk assessments for the effective deployment of AtoN assets and perhaps adjustments to ship routes in general.

This information source can also enable Search and Rescue (SAR) authorities to improve their effective co-ordination of a response to an incident by understanding the traffic pattern in the area of a detected GMDSS alert.

2.3.4 Forensics

Satellite AIS provides accurate information on ship behaviour and position such that determining, or definitively concluding, pollution violations, route violations, or irresponsible navigation for the purposes of prosecution or establishing innocence. While SAIS can only report the position information during a given pass, the quantity of those position reports can establish a pattern of ship behaviour where activity during the time when the ship is not being monitored can be conclusive, i.e., if a ship is at position A at time t; and at position B at time t_1; it must have taken route C. If an oil spill is on the route, administrations can now determine which ships would have been in the area at the time and take necessary action. If a S-AIS position report is within environmentally sensitive areas, or outside allowed fishing zones administrations will now have conclusive evidence for the leveraging or fines or prosecution.

3 FUTURE CONSIDERATIONS FOR SATELLITE AIS

The continued growth of the AIS population and impact on the overall AIS Service will further challenge the ability to receive AIS signals as a significantly high number of slots will be garbled resulting in very poor reception for satellite and AIS shore stations.

Several changes to the AIS specifications and new frequency allocations have been proposed to enhance wide area situational awareness and support potential future uses of AIS. The following section describes the changes:

- New Long Range AIS position report designed to facilitate reception of AIS signals from satellite;
- Managing the behavior for when to control the transmission of the Long Range AIS position report;
- New proposed frequencies (AIS channels 75 and 76) to initially exclusively broadcast Long Range AIS position reports.

In order to facilitate reception of AIS position reports from satellite, a new message is defined within the ITU-R 1371 specification[1]; Message 27, which is a shortened AIS position report designed to transmit an updated position every 3 minutes. A longer reporting interval and shortened message content greatly enhances a satellite's ability to receive the transmissions due to the reduction of slot collision.

There are circumstances when it is not desired to transmit message 27 (such as approach to coastal range) and this is achieved through the Group Assignment (Message 23) and Base Station Report (Message 4) commands. The process to instruct AIS mobile stations to turn off the broadcasting of Message 27 is as follows:

- The AIS shore station issues the Group Assignment (message 23) command with Station Type set to 10 (use geographic coordinates only for this command) and the latitude and longitude area for which the group assignment will occur;
- The AIS shore station issues the Base Station Report (message 4) command with the "Transmission control for long range broadcast" field set to 0 to turn off transmission of Message 27 for all AIS mobile stations within the geographic area as specified in the previous Group Assignment command;
- Once the AIS mobile stations are beyond the range of the Group Assignment's geographic area, the stations will resume broadcasting of Message 27 within 4 seconds.

It should be noted that Message 27 is designed to broadcast using the MSSA Access Scheme on the proposed new satellite AIS frequencies (CH 75 and 76).

[1] *ITU-R 1371 Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band*

4 SUMMARY

Satellite AIS is a tool that can enhance overall wide area maritime domain awareness in conjunction with other sensors and systems currently in use. While the original AIS system was conceived and implemented to enhance safety at sea and to enhance VTS capabilities near shore, it has a significant range limitation and requires large investments in monitoring infrastructure support. Satellite AIS, however, can provide fill-in coverage for remote coastal areas with comparable detection performance and also provides complete global coverage with comparable average detection performance but with the disadvantage of periodic vessel refresh (i.e. several times per day). Therefore, both AIS systems are required for complete wide area maritime domain awareness.