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A preliminary concept for deployment of a European Space-Based AIS System

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Abstract

An important system in the field of global maritime surveillance is the Automatic Identification System (AIS), which is responsible for transmitting logistical and navigational data of surface vessels. Performance of a space-based AIS system is measured in terms of probability of detection of a ship's AIS message in case the satellite receives a multitude of AIS messages. As these messages can overlap and interfere with each other, which will not happen at land-based receivers, the challenge is to separate and decode single AIS messages. In Europe, several activities have been initiated by ESA and EC to validate AIS receivers, set up first operational missions and to develop a full European AIS constellation. In this paper, a concept of deploying a European space-based AIS system is presented. The user requirements collection process and the maritime traffic model are shown. Challenges of the space-based AIS system are identified, which leads to the description of design options.

1 Introduction

An important system in the field of global maritime surveillance is the Automatic Identification System (AIS), which is responsible for transmitting logistical and navigational data of surface vessels [1]. Many entities also use shore based AIS to monitor maritime traffic. The shore based AIS stations can also be used to provide guidance to the maritime traffic in their coverage area. This requires ships to be equipped with an AIS transmitter, which sends logistical and navigational data about the corresponding vessel in the VHF frequency range.

In order to be able to perceive the maritime traffic situation beyond the land-based AIS range, introduction of a space-based AIS system is proposed. Performance of a space-based AIS system is measured in terms of probability of detection of a ship's AIS message in case the satellite receives a multitude of AIS messages. As these messages can overlap and interfere with each other, which will not happen at land-based receivers, the challenge is to separate and decode single AIS messages. Besides these measures taken to manage and mitigate AIS message collisions, other issues have to be addressed during the development of a European space-based AIS system:

- Implementation of an operational and affordable system, consisting of satellite constellation, ground station network, data dissemination and distribution.
- Creation of an operational data policy regulating the responsibility and access to AIS data by users and service providers.

In Europe, several activities have been initiated by ESA and EC to validate AIS receivers, set up first operational missions and to develop a full European AIS constellation. In this paper, a concept of deploying a European space-based AIS system is presented. Relevant users of the AIS system include coast guards, port authorities, immigration authorities, and national customs, but also Pan-European projects and EU initiatives (e.g. GMES).

2 User Requirements

As a starting point in the European space-based AIS system study, user requirements were collected and formatted. This process involved making use of the findings in recent studies concerning space based AIS and maritime surveillance in ESA and EU, as well as contacting entities connected to the field of maritime surveillance. The entities can be divided into the following groups:

- Coast guards
- Military bodies
- Commercial operators
- National governmental institutions
- European agencies
- Port authorities

In total, 110 user entities from 16 European nations have provided input to the user requirements.

These user requirements has subsequently been refined into a comprehensible set of mission requirements, which will serve as the main driver for the design of the European space-based AIS system. Key mission requirements include:

- System shall be able to track surface vessels carrying Class-A AIS transmitters
- System shall be able to geographically cover all global areas
- System shall allow for updates of the AIS data within intervals of at maximum 3 hours (1hour goal)
- AIS data shall be available on ground maximum 1 hour after being received by a spacecraft (0.5 hours goal)
- System shall have a minimum ship detection probability of 80% (95% goal)

3 Maritime Traffic Model

The ship traffic model used in the European space-based AIS system study is based on several different sources, which include data on the east coasts of US and Canada, Gulf of Mexico, Greenland, Iceland, European waters, North Africa, Red Sea and the Gulf of Persia.

In the traffic model representing present-day shipping traffic, the vessel distribution has 57,500 active vessels. This only includes surface vessels carrying Class-A AIS transmitters. In Figure 1, a plot of this traffic distribution is presented.

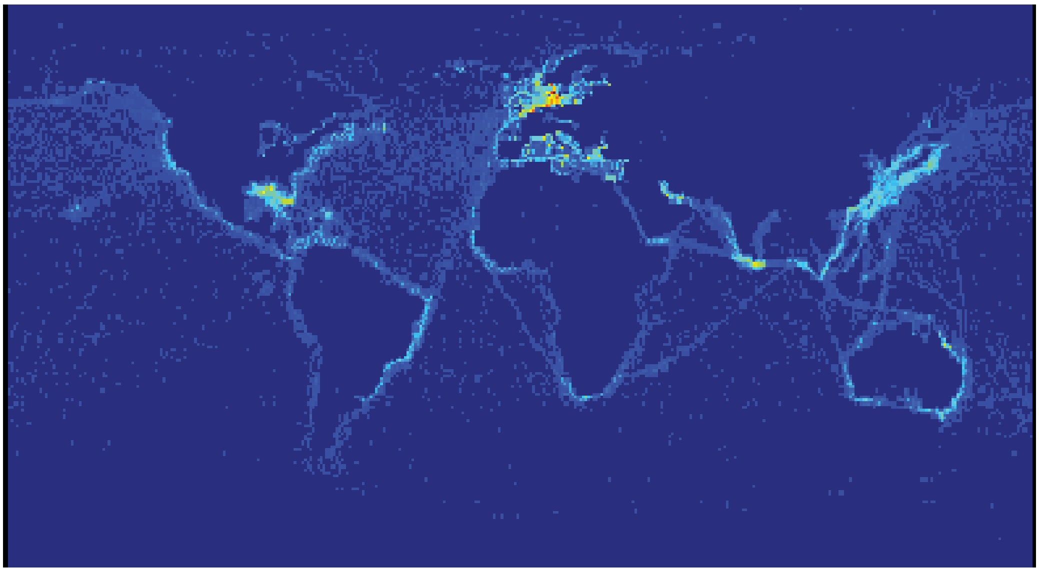

Figure 1: Plot of vessel density distribution [source: FFI]

It has been identified that the shipping traffic carrying Class-A AIS will grow in the next 15 years due to economic conditions. Predictions show a high amount of uncertainty, but in a worst-case situation, global shipping traffic will grow to 93,500 vessels. Furthermore, up to 20,000 vessels have to be added due to a regulations change. Class-B AIS traffic will also grow subsequently in the coming 15 years, which has to be included as an extra 50,000 vessels that act as weak interference sources. As ITU regulations have not prohibited land-based emitters from transmitting in the AIS frequency bands, these have to be modelled as interference sources, too.

4 System Scenarios

Based on the mission requirements and a first analysis of the visibility of ship traffic from space, the main geographical areas and key performances were used to define a first set of different system scenarios. In Table 1, the candidate scenarios are listed.

Scenario Number	Geographical Area	Update Interval
#1	Global minus HTZ HTZ (North Sea, Caribbean)	3 hr N/A
#2	Global (incl. HTZ)	3 hr
#3	Global (incl. HTZ)	1 hr
#OPT	Global minus coastal zones (using 3rd AIS frequency)	1 hr

Table 1: System Scenarios Overview

Scenario #1 demands an update interval of 3 hours, which is considered as a minimum performance requirement. Global coverage is needed, but so-called high traffic zones (HTZ), which are locations where the ship traffic is exceedingly high, e.g. North Sea, Caribbean Sea or Chinese / Yellow Sea, do not have to be taken into account. This means that the requirement regarding update interval does not apply to these high traffic zones.

Scenario #2 has a requirement for a 3 hours update interval for all global waters including high traffic zones. This scenario represents a medium performance solution.

In scenario #3, the requirement with respect to update interval is equal to 1 hour for the global ship traffic. No distinction will be made between high traffic zones and non-high traffic zones. This scenario represents a high performance solution of the space-based AIS system.

The last scenario is a potentially interesting add-on for the other scenarios. It considers the introduction of a third frequency for transmission of AIS messages. By using this third frequency, the mutual interference of the AIS messages is drastically decreased in areas where also the coastal zones are within the field of view of the satellite AIS reception antenna(s).

Every scenario will require a probability of vessel detection of at least 80%, while aiming at a value of 95%. Furthermore, the timeliness (i.e. interval between AIS message reception by the system and delivery to the user) has to be at most 1 hour, while aiming at a value of 30 minutes.

5 Challenges & Design Options

5.1 Message Collision Problem

Because the AIS system has been developed for the terrestrial application of ship collision prevention, attempts to receive signals with a space-based platform are accompanied by several fundamental difficulties. The main principle behind AIS functionality is the SOTDMA (Self Organizing TDMA) protocol, which ensures that AIS transmitters are organized into cells, in which every transmitter is assigned a time slot for message transmission. By operating a space-based platform for AIS message reception, so-called message collision will take place, which is illustrated in Figure 2. This phenomenon is caused by:

- AIS transmitters in different SOTDMA cells transmitting in the same time slot
- AIS transmitters emitting in different time slots, which overlap due to distance caused time delays

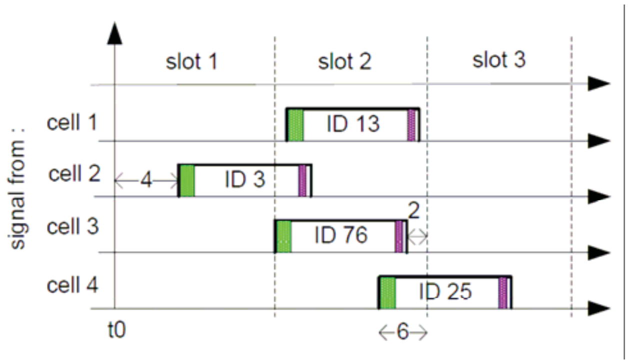

Figure 2: Illustration of the message collision problem [2]

In the so-called high traffic zones, these problems will have severe consequences for the AIS reception performance, because the antenna can have up to 20,000 different vessels in its field-of-view. However, the problem of message collision can be mitigated by applying innovative technologies.

5.2 Receiver Architecture

As the main building block of the AIS payload, the AIS receiver is responsible for receiving and demodulating the AIS messages. Therefore, application of an SDR (Software Defined Radio) is proposed, which allows for the implementation of powerful signal detection algorithms.

Two types of receiver architecture can be used for the overall demodulation of AIS messages:

- On-board processing

In an on-board processing architecture, the separation and demodulation of the AIS messages out of the corrupted input signal is performed on-board the satellite. This requires significant processing power in order to implement the required decoding algorithms, but reduces the needed downlink bandwidth as the transmitted data is equal to the original AIS information.

- Digital bent-pipe

In a digital bent-pipe architecture, the downlinked data package consists of a sample package of all AIS channels mentioned in the protocol. By reconstructing the AIS signal on-ground, high performance decoding algorithms can be used for separation and demodulation of the AIS messages. This saves much processing power on-board the satellite, but requires a wideband downlink channel for transmission of the sampled AIS signals.

No particular receiver architecture is preferred in terms of performance. Therefore, the required implementation resources will dictate, which architecture will be most suited.

5.3 Digital Signal Processing

Digital signal processing algorithms have the task to separate the multiple AIS messages in a particular time slot, so that they can be successfully decoded. These include:

- Core GMSK demodulation algorithm
- Multi-user detection algorithms
- Multi-receiver combination algorithms

A core GMSK demodulation algorithm is used for demodulation of the AIS GMSK modulated message. Coherent demodulation provides the best performance, but is most complex. Slightly less performance is gained with a noncoherent demodulation algorithm, which is simpler though.

A multi-user detection algorithm is used to separate multiple AIS messages occupying a single slot. This will be done in an iterative way by subtracting previously demodulated messages from the original noisy signal containing multiple AIS messages. Although these algorithms are capable of decoding a low amount of messages (between 2 and 5), their performance quickly diminishes when large amount of messages are present in a single slot. Performance will significantly increase by introducing a large amount of discrimination between the signals.

A multi-receiver algorithm can be used when multiple receivers are flown on a single satellite. This algorithm combines the received AIS signals from all receivers in an attempt to increase the probability to demodulate individual AIS messages.

5.4 Antenna

Every spacecraft in the AIS constellation has to be equipped with one or more antennas to enable reception of AIS messages. The choice of antenna technology can positively influence the probability of detecting an AIS message in a signal band with interference. This is accomplished by exploiting the following phenomena, which are related to the choice of antenna technology:

- Polarization diversity
- Frequency diversity (i.e. Doppler shift)
- Power diversity

For the choice of antenna, various technology options are available. These include:

- Monopole
- Helix
- Patch

The monopole antenna and optionally the patch antenna offer linear polarization, and are therefore able to introduce polarization diversity. The other types of antenna suffer from a 3 dB gain loss due to polarization mismatch in addition to losing the benefit of polarization discrimination. Nevertheless, they offer a steeper gain slope in their antenna pattern, which improves the power diversity in the received signals.

Additionally, the antenna configuration has the possibility to improve the AIS detection performance by use of the following options:

- Off-nadir pointing
- Phased array

5.5 Constellation Design

The design of the spacecraft constellation has a significant impact on the performance of the space-based AIS system. After all, the probability to detect a particular ship (i.e. to demodulate at least one message sent by this ship) is directly related to the cumulative contact time. Orbital altitude plays an important role in this respect as well, because a higher orbit increases the contact time of a single pass. It is found, however, that the increased noise of a higher amount of ships in field-of-view is larger than the gain due to a longer contact time.

Furthermore, the constellation has to be designed such that the complete Earth surface is covered, leading to selection of (near-)polar orbits. Fine-tuning of the constellation parameters has to be done in order to meet the requirements. A constellation meeting the minimum performance requirements (i.e. scenario #1) is represented by 6 satellites in a near-polar orbit at 600 km that are evenly divided over 3 planes. In Figure 3, a possible constellation answering to the 1 hour update interval requirement is shown.

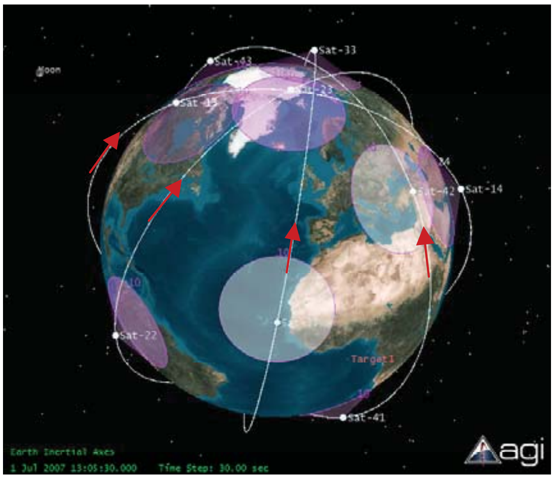

Figure 3: Preliminary constellation lay-out for European space-based AIS

In addition, the constellation has to be designed in conjunction with the ground segment to meet the requirement on data timeliness. This poses a challenge, because the requirement sets a very low value for timeliness (< 1 hour). Design options, which are available for the ground segment to fulfill this requirement are:

- Few (2-3) polar ground stations for 1 hr timeliness
- Many (> 10) polar & equatorial ground stations for 0.5 hr timeliness
- GEO data relay (EDRS / Artemis) for NRT timeliness

6 Performance Simulations

In order to assess the performance of the European space based AIS system, FFIs dedicated simulation environment is used. This simulator, AISDET, uses the maritime vessel distribution model to simulate reception of AIS messages using the LEO constellation [3]. Each vessel transmits according to the SOTDMA scheme on two channels. The signal strength at the receiver of each message is computed to check whether it can be decoded according to receiver performance parameters. In case of message collision, the received power ratio between the desired and undesired signal (D/U) at the receiver input determines whether a particular message can be decoded or not.

The software model has the following features:

- Each vessel transmits according to the SOTDMA scheme
- Received signal strength and Doppler shift are calculated for each message
- Travel time is computed for each message to check for message collisions
- Output from antenna simulation software is used for computing antenna gain patterns
- A detailed ionosphere model is used to take Faraday rotation into account

In addition, the simulator makes use of mathematical models of the digital signal processing algorithms in order to define the detection threshold of the receiver. An example performance figure based on output of the AISDET simulator is shown in Figure 4.

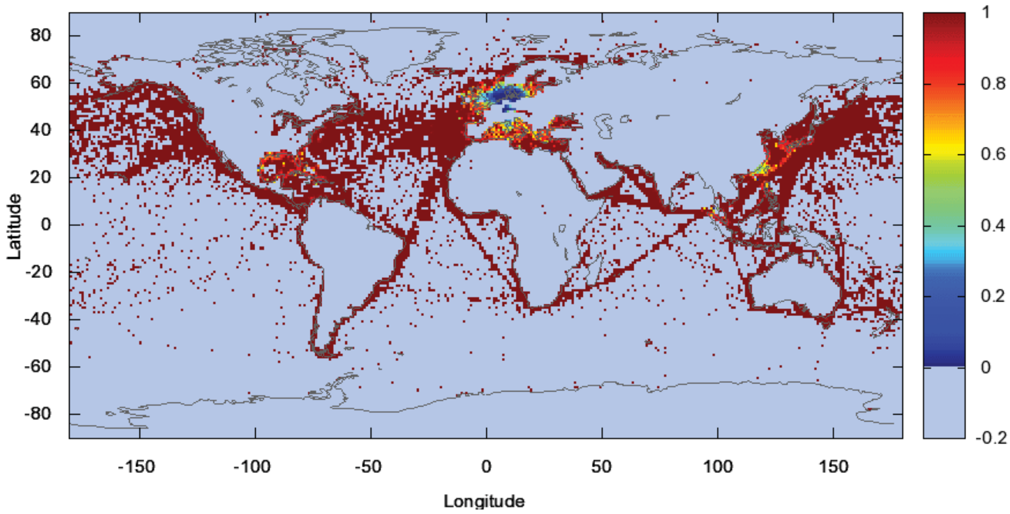

Figure 4: Example performance figure based on output of the AISDET simulator

7 Study Team AIS Experience

The study team responsible for performing the European space-based AIS study has ample experience in the field of maritime surveillance and AIS. Recent examples are the Rubin–7 and –8 satellites, which were fully constructed by team prime OHB-System [4]. Rubin–7 was the first spacecraft used for successful validation of space-based AIS. Rubin–8 was a highly successful spacecraft flying 2 AIS receivers, which were responsible for the reception of over 600,000 messages during its first week of operation. Figure 5 shows the characteristics of AIS signal sources received by Rubin–8.

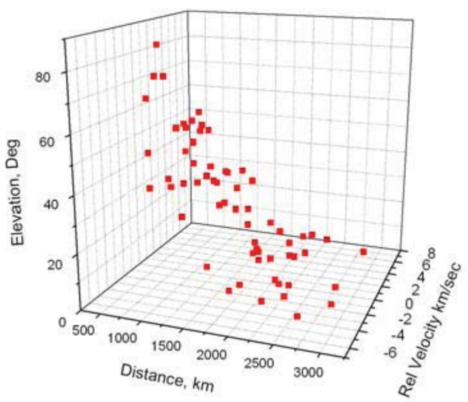

Figure 5: Distance, elevation and relative velocity between the AIS signal sources

Rubin–9 will be equipped with two newly developed types of spaceborne AIS receivers. It is planned for launch with a PSLV launcher in 2009.

Other OHB projects involving AIS are the 6 Orbcomm-QL spacecraft, AISat (together with DLR and Hochschule Bremen) and Max Valier (together with University of Süd-Tirol). Team member FFI has worked on studies related to space based AIS for more than 5 years and has been the prime for previous studies on space-based AIS for ESA. Nationally, FFI is responsible for the Norwegian AIS satellite AISSat-1, which will be launched with a PSLV launcher in 2009. Team member Kongsberg Seatex is responsible for designing the AIS receiver payloads aboard AISSat-1 and the International Space Station. Development of a similar maritime space-based data collection system, ARGOS, is led by team partner Thales Alenia Space. At the application side, CEON in Bremen, in which OHB is participating, takes interest in AIS data for data fusion and service products.

8 Conclusions & Next Steps

In order to improve the performance of the existing land-based AIS system, a European space-based AIS system is proposed. User requirements dictate that this system must provide global coverage with at least an 80% detection probability of the shipping traffic within a 3 hour time interval. For this purpose, a maritime traffic model has been generated, which takes into account growth in the global shipping traffic within the next 15 years. Several scenarios have been defined, which describe various levels of attainable performance of the system.

The main challenge in space-based AIS is the collision of multiple AIS messages in a single slot. In order to mitigate this problem, several innovative design options are available. A main design choice is the applied receiver architecture, being either on-board processing or digital bent-pipe. Smart solutions in digital signal processing and spacecraft antennas enable discrimination of the received AIS messages, leading to an improvement in detection performance. The constellation shall be optimized for high performance, sufficient coverage and low timeliness. Assessment of the AIS constellation performance is done by using a dedicated AIS simulator.

In the coming phase, every defined system scenario will be mapped onto a design solution, while considering the system requirements. This will require extensive optimization and simulation loops in order to find the most suitable options. Keeping the user requirements in mind, the scenario with the best cost/performance ratio will be selected as a baseline for the further design of the European space-based AIS system.

Acknowledgement

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References

[1] International Telecommunication Union, *Technical Characteristics for a Universal Shipborne Automatic Identification System Using Time Division Multiple Access in the VHF Maritime Mobile Band, ITU-R.M.1371-2*. September 2007.

[2] M.A. Cervera and A. Ginesi, *Satellite Based AIS Feasibility Analysis*. ESA-ESTEC, Noordwijk, the Netherlands, May 2008.

[3] Ø. Helleren, Ø. Olsen, P.C. Berntsen, K., Strauch, N. Alagha, *Technology Reference and Proof-of-Concept for a Space-Based Automatic Identification System for Maritime Security.* Proceedings of the Small Satellite Systems and Services Symposium, Rhodes, Greece, June 2008.

[4] B. Ziegler et al., *Rubin – an Evolutionary Approach from Testbed to MNT-Enabled Satellite*. Proceedings of the 6th IAA Symposium on Small Satellites for Earth Observation, Berlin, Germany, April 2008.