



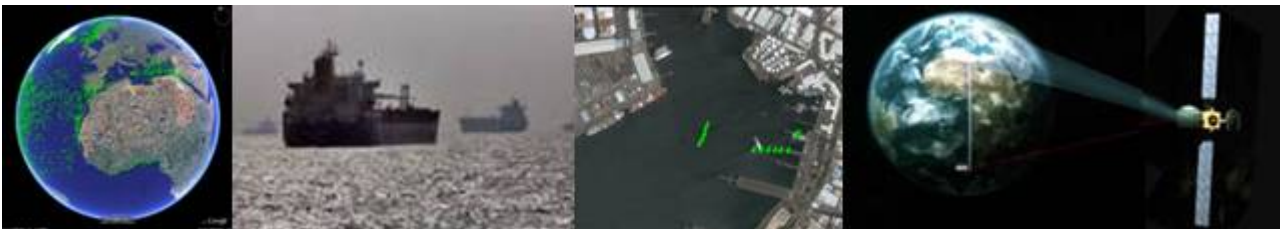
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**Technical Note TN-16 and 17:
PASTA MARE Project summary and conclusions
Issue 3**

Preparatory Action for Assessment of the Capacity of Spaceborne Automatic
Identification System Receivers to Support EU Maritime Policy

DG MARE Service Contract MARE/2008/06 – SI2.517298

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1. Background

The PASTA MARE project aims at assessing the capacity of space borne AIS (Automatic Identification System) for supporting the European Commission's maritime policy.

PASTA MARE is a study contract issued by the European Commission and awarded to a consortium led by LuxSpace Sarl.

Space borne AIS is a new emerging technology with the potential to provide a cost effective solution for monitoring vessel traffic, the individual positions of ships, activities and cargoes around the world. Such vessel monitoring information is of particular interest of ship owners and port authorities but is also expected to be extremely useful for supporting maritime policy.

There are several activities ongoing, both from space research institutes and from space industry to further develop and operate space borne AIS satellites. Several AIS satellites are already in orbit, primarily to prove the feasibility and the potential of Satellite AIS systems. Due to their demonstration character, they have specific constraints related to their performance. However, the few results published so far clearly show the potential and usefulness of space based AIS systems, which needs to be exploited further.

2. Introduction

The deployment of space borne AIS satellite constellation has its own challenges due to the fact that AIS is primarily intended for sea-level reception.

One major concern is related to the self-organization principle of the terrestrial AIS communication system. All exchanged messages transmitted from ships within the VFH range of 30-40 nm are synchronized, meaning that there are no AIS reports sent at the same time at the same frequency. This guarantees the functioning of the system without any message loss. An AIS receiver mounted on a satellite however sees within his footprint (>3000 km diameter) several of these self organizing cells. Due to the fact that there is no synchronization between the cells, it's likely that the satellite receives AIS messages from various vessels send at the same time with the same frequency. This causes a message collision and leads to message loss.

Another issue is the saturation of the satellite sensor due to the high amount of messages, particularly in high density traffic areas such as the Mediterranean or the Baltic Sea.

Message collision and receiver saturation are know to be the main factors impacting the performance, measured as the Probability of Detection (PoD) of picking up an AIS position report transmitted by an AIS carrying vessel.

An in depth assessment of the real performance of the space based AIS systems in operation is not yet available, but required by the users to identify its potential benefit and the systems initiations.

2.1 PASTA MARE Objectives

The PASTA MARE project tries to fill the knowledge gap, aiming at assessing the performance of space based AIS through an in depth analysis of the system's particularities, capacities and limitations.

The results of the assessment will be the basis for DG MARE and other European Stakeholders to take an informed decision about the promotion of the utilization of space borne AIS data and the integration for supporting EU's maritime policies. Moreover, the increased understanding of space based AIS gained through the PASTA MARE project shall contribute to the development of a future European space based AIS system currently planned by the European Space Agency (ESA) and the European Maritime Safety Agency (EMSA):

2.2 Tasks defined

The PASTA MARE project was conducted in three phases throughout the 2 year study period. The main tasks of the study were to:

1. Develop a digital global map of maritime traffic density in order to identify regions where the performance of a space borne AIS system may reach its limits.
2. Identification of potential radiofrequency interference which may have an impact on the AIS signal reception and the overall performance of space based AIS.
3. Assessment of the performance of space borne sensors already in orbit or to be launched during the time span of this project to detect vessels. The main parameter to be determined is the confidence that a vessel can be detected in a given geographical position.
4. Sampling of AIS raw frequency data which can be used to calibrate and validate sensors for future space missions.
5. Draw conclusions, draft lessons learned and recommendations for possible next steps towards a space-borne AIS service, supporting EU Maritime Policy.

3. Summary of the results of the PASTA MARE study

In the following chapters, the results of the PASTA MARE activities are presented, including the conclusions, lessons learned (chapter 4) as well as recommendations for a future European space based AIS system (chapter 5).

3.1 Ship Density maps

Vessel density maps provide an overview on the global maritime traffic, allowing the identification of areas with a low ship density (e.g. the Antarctic, Coast of Somalia), regions with high density areas like the English Channel and international shipping lanes as part of the worldwide maritime network. Global ship density maps serve two main purposes:

- improved understanding of global vessel traffic
- indispensable input dataset for satellite AIS mission planning and simulation

Recalling that around 90% of the world trade is transported by ships (equivalent to 7.4 billion tons of goods) and that the trade volume currently exceeds 30 trillion ton-miles, it becomes obvious that monitoring the ship transport network is essential for economic reasons but also for security and safety issues.

Ship density maps are one way of to analyze ship movements and contribute to a better understanding of the global maritime traffic. They may help to answer questions like

- where are the main shipping lanes,
- how frequently there are used,
- which ship types are following which route,
- who transports what where etc?

Space based AIS data represent a unique data source for producing such a detailed insight in the global maritime traffic pattern, exemplifying the added value of global vessel tracking data for many other applications.

For any satellite based AIS mission design vessel density maps are an indispensable precondition. Only the detailed knowledge about the distribution of class A vessel carrying an AIS transponder allows for the estimation of the number of vessels in the Field of View (FoV) of the satellite. Based on this key figure the corresponding number of messages arriving at the satellite can be derived, necessary for estimating potential receiver saturation, number of message collisions and other important parameters needed for a sound payload and satellite mission design.

The approach developed in PASTA MARE is based on a combination of satellite and terrestrial AIS data:

- satellite AIS data from Orbcomm and Pathfinder 2 covering high sea areas, outside the reach of terrestrial AIS (t-AIS) station network or regions where t-AIS stations do not exist or data are not accessible.

- t-AIS data are used in high density areas, such as the North Sea or the Baltic Sea, where current capacities of space based satellite reach their limits.

Apart from ability of S-AIS to obtain vessel position data far beyond the reach of terrestrial AIS stations, AIS data provide a lot of details about each detected vessel, allowing the computation of specific density maps, e.g. differentiated according to ship type or navigation status. Moreover, for a huge share of the global vessel fleet precise track records are available, avoiding the need for any interpolation.

In order to gain a deeper insight into the global vessel traffic pattern, ship density maps for specified vessel types have been generated based on the baseline density map covering all class-A ships:

- Tankers
- Cargo vessels
- Passenger Ships
- Fishing Vessels

Moreover, particular density maps are produced in order to distinguish between the navigation status of the vessels (moored, under way), which is of utmost importance for satellite AIS mission planning due to the distinctive message update interval:

- All class A – vessels under way: AIS message update every 2-10 seconds
- All class A vessels moored, at anchor: AIS message update every 3 minutes

The global ship density map of all class A vessels clearly depicts the high vessel density areas Baltic Sea, North Sea, the Mediterranean Sea, Red Sea, Persian Gulf, Strait of Malacca, Japanese East Coast, China as well as Gulf of Mexico. Moreover, the global maritime traffic network becomes visible i.e. the main traffic lanes connecting the economic centres in Asia, Africa, Europe and the Americas crossing the Atlantic, Pacific and Indian Oceans. On the other hand also the low density areas are highlighted, for example the South Pacific and notable the area off the Somali Coast, a region where vessels are rarely encountered due to the recent piracy attacks.

The production of the various density maps exemplifies the value of historical space based AIS data, which goes far beyond the value of real time monitoring data. The historical AIS data archive represents a unique data source of global ship movements, providing not only precise track records but also detailed information about the ship itself (type, length, flag state etc). Within PASTA MARE the statistical analysis focused on the compilation of a small set of ship density maps. The results illustrate the usefulness and the potential of the S-AIS data for many stakeholders. More detailed

maps could be produced focusing for example on particular ship types, ship fleets, regions, or considering seasonal effects, changes over time. In collaboration with experts from the various maritime domains (business intelligence, fishery control, environment) additional data exploitation studies should be conducted, identifying the added value of globally available S-AIS data for other purposes, applications and users.

3.2 AIS frequency Interference Maps

There are both legal and illegal terrestrial sources that can create interference with a space borne AIS. Due to the potential harmful impact of frequency interferences which limit the overall performance of the system, a systematic analysis of the existence of interferences sources is essential. The identification of interference sources, their location and signal strength provides the foundation for:

- Delimitation of areas where space borne AIS services might be impacted, i.e. in the worst case might not be available, and/or
- Need to improved receiver/antenna design as well as for a mission planning aiming at coping/mitigating the effect of the interference.

Within PASTA MARE, the International Telecommunication Union (ITU) reports were consulted to investigate the spectrum allocation.

Article 5 of the Radio Regulation (RR), its corresponding footnotes and Annex 18 defines the regulatory status of AIS VHF frequencies. In essence the Radio Regulation specifies that:

- the use of the VHF frequencies 161.975 MHz and 162.025 MHz for AIS satellite reception is on a secondary basis with regard to Mobile and Fixed services, i.e. satellite shall not claim protection from emissions of Mobile and Fixed stations.
- In the mobile service, apart from ships, the only specific applications mentioned in the RR that could use the same frequencies are aircraft stations involved in search and rescue operations/safety related communications in the Americas and Asia-Pacific
- Concerning the Fixed service, no specific application is mentioned in the RR. However, those applications have to protect VHF transmissions from ships.

The analysis of the International Frequency Information Circular (BR IFIC) revealed that there is not any relevant information for the frequencies of interest. This is not surprising, since there is no obligation for national authorities to register all of their terrestrial stations and frequency assignments. Only if neighboring countries are impacted, coordination and notification to ITU is requested. ITU in that case is to ensure frequency coordination at the borders so no information on the stations inside a country is available.

An example for such a national assignment of the AIS frequency was identified during the flight campaign over Spain and Italy as well as from other airborne campaigns over Denmark and Germany. Local taxi companies use the AIS frequencies for communication between the taxi driver and the central unit.

Illegal interference sources are created by countries or entities interested in hiding specific areas. In addition, there might be voluntary “jammers” of the signal, who are interested to blank out the view of the space based AIS receivers over certain areas.

Those interference sources can be detected through a space based AIS sampling device, allowing the creation of snapshots of the whole AIS frequency and to localize the sources of interference and jamming with a precision of several kilometers.

Due to the non availability of sampling data from the COLAIS during the project lifetime, a thorough analysis could not be performed, although essential for future AIS missions.

However, from the sampling of PATHFINDER2 and the sampling of the PASTAMARE flight campaign, it could be exemplified that an AIS satellite over Europe can have each AIS channel jammed several minutes. This obviously lowers considerably the detection rate of the messages, thus the PoD of ships.

3.3 Assessment of current space based AIS satellites

The main activity within PASTA MARE was the assessment of the performance of current satellite AIS systems, bearing in mind that these are demonstrators.

The results obtained from Orbcomm, Pathfinder2 and NTS1 clearly demonstrate the feasibility to capture AIS signals from space. Considering that the currently in orbit AIS missions are experimental satellites or demonstration missions with certain performance constraints, the results clearly indicate that space based AIS is able to deliver a quality of service in terms of high probability of detection of class A ships.

Assessment approach/methodology:

Regarding the methodology applied for assessing the capabilities of space based AIS, three basic approaches were developed.

The first approach is the most straight forward performance measurements respectively performance indicators of space based AIS, counting:

- the number of messages received in a defined time interval,
- the average number of messages per vessel during one orbital path and
- the total number of ships detected during a defined time interval

These indicators specify in particular the receiver's capabilities to decode AIS messages and allow the comparison of the performance of different receiver designs. This approach was applied in the evaluation of the raw AIS frequency data sampled during the flight campaign.

The second approach tries to cross correlate the S-AIS data with reference data (ground truth data such as terrestrial AIS data) to assess the Probability of Detection (PoD). For those coastal areas where terrestrial AIS is available, this approach delivers robust performance indicators.

The third approach tackles the assessment of S-AIS outside the reach of terrestrial AIS stations. Long Range Identification and Tracking (LRIT) data could serve as a reference dataset, but due to confidentiality reasons could not be made available to the project. The lack of independent validation data was compensated applying a statistical approach, estimating the "real" number of ships using the observation of several AIS satellites at the same time in the same region (multiple sensor approach). This method allows the compilation of a reference number of ships which was used to deduct the share of vessels by each individual S-AIS system. Thus the comparison of two or more space based AIS systems is possible in relative terms.

The performance of the different space based AIS is often attributed just to the receivers capability to decode AIS messages. However, it should be born in mind, that

advanced decoding and demodulation algorithms are important, but just one component of a more complex system.

The overall performance is in addition determined by the capability of the entire system – composed e.g. of the antenna, on board processing capabilities, storage and download capacity as well as the ground station network. Only the proper functionality of all components together determines the performance of a space based AIS systems (end to end system performance) which is of relevance for the users.

Concept of PoD – dependencies and limitations

Apart from the above mentioned impacts of receiver saturation, message collisions and interferences, the investigations revealed that additional factors having a strong impact on the system performance:

- Orbit geometry
- Navigation status
- Ship AIS antenna gain
- Topography

The capability of the satellite to identify a vessel strongly depends on the satellites orbit geometry. Depending on the satellites orbit, an AIS satellite “sees” a certain region during its successive orbits from different viewing geometries. The Field of View (FoV) changes accordingly, hence the number of vessels varies in successive orbits. It may happen that a high density shipping area completely “fills” the FoV of the satellite, causing receiver saturation and returning only a small share of or even not at any AIS message. During the successive orbit the high density area is only partially within the satellites FoV, still allowing the receiver to decode more AIS messages. This explains the high variability of the PoD in many regions in successive orbits.

The PoD also shows a strong dependency regarding the navigation status of a vessel. Under way, a vessel transmits every 2 – 10 seconds an AIS message report, while moored or anchored only every 3 minutes. The probability of receiving a message from a moored vessel is thus significantly lower than that of receiving a message from a ship “under way”, considering a maximum visibility of a vessel of about 13 – 15 minutes.

Another important issue is the AIS equipment on board the vessel and particularly the vessel's AIS antenna. The radiation pattern of the AIS antenna looks like a toroid with omni-directionality in the horizontal plane, usually with 3 to 5 dB gain. An AIS message can be best received by the receiver at a low satellite elevation angle,

meaning that the satellite can best capture AIS signals when it is close to the horizon. However, since installation of the AIS transmitter and the location of the antenna are not tightly regulated, it might be possible that parts of the superstructure of the ships (chimney, masts, etc.) distort antenna radiation pattern. The angular relationship between the ship and the satellite makes the signal path highly unpredictable. For some ships, messages are received during almost all of the passes, whereas, for others, messages are received only at low elevation or only within a restricted azimuth angle.

Examples from the Norwegian Coast show, that also the topography also impacts the reception of an AIS message. Particularly in rugged mountainous coastal areas, signal blockage due to obstacles is quite frequent. Combined with the horizontal directivity of the vessel AIS antenna and a transmission interval of 3 minutes it is likely that AIS messages cannot be received by a satellite.

Orbcomm – Pathfinder – NTS1 – AprizeSat performance

Regarding the difference in the performance of the existing demonstration S- AIS systems, it can be shown that:

- Orbcomm FM 39 seems to identify slightly more vessels than Orbcomm FM 37
- Compared to Orbcomm FM 39 and FM 37, Pathfinder 2 is able to decode significantly more messages and thus showing a better performance.
- NTS1 performs best, within 90 seconds the receiver is able to gather a considerable number of messages and thus to identify more ships

The reason for the observed difference in the performance is closely linked to the different system concepts used for these AIS satellites. The Orbcomm AIS data collection system is a subset of the Orbcomm satellite messaging system, i.e. most of the infrastructure used by the AIS data collection is shared with the Orbcomm messaging system (e.g. antenna, data downlink). Pathfinder2 is an attached payload and with certain power restrictions. The NTS1 system concept differs considerably since it just records raw AIS frequency data. The data processing is done on ground, using the full computer power available in the ground segment, enabling also the use of latest decoding and demodulation schemes.

The comparative analysis between on-board satellite processing using AprizeSat3 (AS3) and ground base processing of the raw AIS spectrum data down-linked via AprizeSat 4 (AS4) confirms the advantage of ground processing, since the algorithms in general enhances the AIS signal detection, thus the number of messages detected.

The performance test conducted in the framework of PASTA MARE returned promising results over low and medium dense shipping areas (South African Coast, Atlantic, Pacific Ocean).

Over high density areas, such as the North Sea and the Baltic Sea the performance of current demonstration satellites is limited. The main reasons for this are high number of vessels causing message collisions and receiver saturation but also the existence of interference sources such as the Russian radar.

Unfortunately the data of ADS1, the first operational AIS satellite with advanced receiver and antenna technology, were not available during the project lifetime due to the shift of the launch date to Q1 in 2011. It would have been of particular interest and benefit to the project to investigate the impact of the advanced satellite design on the performance, especially over high density vessel areas.

Cross correlation with terrestrial AIS

The comparison of space based AIS data with terrestrial AIS data showed that t-AIS data do not necessarily provide a 100% reference to which S-AIS can be compared. The examples from Iceland as well as those obtained during the flight campaign showed that the terrestrial AIS coverage in certain areas can be patchy and not necessarily covering the entire coastal areas. Thus satellite AIS data is perfectly complementary to terrestrial AIS, extending the geographical reach and filling the gaps of the terrestrial AIS station network.

Increase of PoD through multiple passes

Examples from Pathfinder2 over the Pacific Ocean show that the number of vessels can substantially increased if the target area is observed in successive passes. The number of vessels and hence the PoD can be increased by round 20% through the multiple observation of sea area in successive passes.

3.4 AIS frequency sampling during the flight campaign

The flight trials along the European Coast Areas generated huge amounts of raw data (approximately 2-3GB per flight) and it is certain that this data will be invaluable in the future to be used during mission, payload and satellite definition. In particular several key conclusions can be drawn:

- When comparing the same geographical area and time, the airborne receiver consistently identified more ships than the terrestrial data. This has

implications for the 'ground truthing' exercise as it is clear that terrestrial AIS data is not a complete 'truth'.

- Due to the availability of AIS data from a third party satellite (AprizeSat operated by SpaceQuest) an additional element of correlation between the airborne trial, S-AIS and ground AIS data was possible. This shows some of the problems with S-AIS data for these first generation systems in getting reliable data. Some element of work was also done to compare on-board processed data and ground processed data showing the benefits of the additional computing power available for ground based processing systems.
- Comparison of COM DEV and Luxspace processing of the same raw data showed similar performances (COM DEV being marginally better). The raw data acquired by the air campaign has been provided to ESA and the consortium remains open to assist ESA in their evaluation of the data using their in-house developed algorithm.
- The excellent sensitivity of the receiver (the same design that will be used in the ADS1 satellite) was proven and it is unfortunate that the launch delays in the ADS1 mission prevented further comparison.

3.5 Complementarities between S-AIS terrestrial AIS and LRIT

Another important finding of PASTA MARE relates to the complementarities between different the different ship position reporting systems. The comparison of space based AIS with terrestrial AIS exemplifies the mutual benefit which can be gained in combining the current vessel position reporting systems:

- S-AIS provide valuable data for regions outside the reach of the terrestrial AIS stations network and at a global scale.
- S-AIS fill the gaps of the terrestrial station network.
- T-AIS provide position reports over high density vessel areas, i.e. in regions where the S-AIS performance is limited.
- LRIT adds value to S-AIS as it provides position updates every 6 hours, not for the entire global vessel fleet, but at least for EU flag states through the LRIT data centre operated by EMSA.
- The combination and integration of terrestrial AIS, space based AIS as well as LRIT can form part of the International Maritime Organisation (IMO) e-navigation strategy currently under development.

Table 1 presents the results of a SWOT analysis of all terrestrial AIS, satellite based AIS and LRIT.

Project summary and conclusions

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| | Strength | Weaknesses | Opportunities | Threats |
|--------------|---|--|--|---|
| S-AIS | <ul style="list-style-type: none"> o availability beyond the reach of t-AIS o means for global vessel tracking and monitoring o high information content o high market value of the data leading to competing commercial systems in various stages of 'roll-out' (e.g. Orbcomm, exactEarth, SpaceQuest, LuxSpace etc) | <ul style="list-style-type: none"> o timeliness (latency) of current S-AIS systems in delivering data to users o limited performance in high density traffic areas | <ul style="list-style-type: none"> o technological developments (antennas, receiver) can overcome performance limitation in high density areas o 3rd AIS frequency will increase performance even in high density vessel traffic zones o Extension of the AIS satellite ground segment enhances timeliness of AIS data o Real time supply through other satellite developments (SB-SAT) | <ul style="list-style-type: none"> o AIS transmitter on vessel can be switched off o If AIS data are considered as security relevant/sensitive, commercialization of AIS data to non institutional users might be blocked o Lack of an international regulatory framework related to S-AIS data policy |
| T-AIS | <ul style="list-style-type: none"> o high information content o high message update frequency o real-time data provision o low implementation costs for terrestrial stations | <ul style="list-style-type: none"> o available only along coastal regions (40nm) o connected station network needed to provide reasonable coverage | <ul style="list-style-type: none"> o enlargement of AIS stations network straight forward due to low investments needed for a terrestrial station | <ul style="list-style-type: none"> o access to t-AIS is restricted due to confidentiality of the data |
| LRIT | <ul style="list-style-type: none"> o global availability o near real time data provision o possibility to poll LRIT position reports every 15 minutes o LRIT is based on an international regulatory framework o confidentiality of data important criteria for institutional users | <ul style="list-style-type: none"> o limited information content o communication costs o data accessibility limited, data belong to Flag States and treated as confidential | <ul style="list-style-type: none"> o | <ul style="list-style-type: none"> o Access to LRIT data can be denied by flag state (due to the confidentiality of data) |

Table 1: SWOT analysis of terrestrial, space based AIS and LRIT

4. Final conclusions

The overall conclusions of the PASTA MARE study are the following:

Tracking and tracing of vessels using satellite AIS is feasible. The current demonstration AIS satellite systems of Orbcomm, ComDev/ExactEarth and LuxSpace already deliver quite some good results depending on the area to be covered. The next generation satellites from these companies as well as others will definitely further improve the data quality and if those satellites can be pooled together, the update frequency can be largely improved in a rather short time scale.

The comparison of the available experimental space based AIS systems revealed, that these space systems do not fulfil the 80-90% PoD requirements specified by European users. There are many areas, specifically on high sea, where the demonstration systems already come close, but for other areas – and coastal zones are among them, the PoD is limited for several reasons:

- Moored vessels only send AIS signals every few minutes and thus the probability of capturing their signal during the satellite passing over is limited
- AIS is sent in a VHF frequency, which is also used by other fixed or mobile terrestrial services (e.g. taxi) causing at least temporary interferences with the satellite receiver and thus decreasing PoD.
- In other cases, the coastal geography (mountains) prohibits the reception as the vessel is simply out of view of the satellite
- There are several parameters that largely influence the probability of detection but cannot be influenced by the satellite manufacturer or operator. These parameters are mainly the mounting of the antenna on the ship as well as the output power of the receiver. Needless to say that no signal can be obtained if the vessel master decides to switch off the AIS equipment.
- There is a close link between vessel direction (in combination with the vessel antenna) and satellite tracking capability. During the comparison analysis, we have seen examples where two different sensors captured over a given area at the same time each 300 vessels but only 150 of them were identical. The only explanation we have today is that different satellite orbits and orbital planes (individual view angle of the vessel) have a strong influence on the capture of the signal due to the placement of the antenna on the vessel.

The implementation of a dedicated S-AIS frequency will definitely improve the PoD from satellites as it will reduce the number of collisions and thus reduce the saturation of the

receiver on board of the satellite. However, even this will not solve the above described problem related to the antenna installation onboard a ship.

Despite the limitation of existing experimental space based AIS systems, the potential has been clearly demonstrated.

Currently space based AIS data is provided to various institutional users, such as EMSA, EC national coast guards as complementary data for compiling maritime awareness pictures.

It is also interesting to observe that NATO has recently issued an ITT to obtain S-AIS and T-AIS data for the operation "OCEAN SHIELD" in the Indian Ocean. Even though, existing S-AIS satellites can't meet the hourly refreshment rate asked within the ITT, a combination of T and S-AIS might be capable to satisfy the requirement.

The commercial market is in development with port operators, ship owners and trading companies realising the added value of space based AIS. In fact it is likely that commercial systems will be firmly established well in advance of institutional systems thus questioning the need for institutional investment in infrastructure rather than service.

It becomes obvious that satellite AIS can be considered as one further tool to improve the overall maritime awareness picture but it is certainly not the solution for all maritime reconnaissance requirements. Terrestrial and satellite AIS are complementary. A coastal AIS station today can be manufactured for less than 500€ and more and more of these stations are established by institutional and commercial operators. One example is the recently mounting of antennas on oil platforms in the North Sea to cover the northern approach to European waters.

Earth Observation data coming from optical, SAR or even navigation radar (NAVRAD) detection sensors will be also required in the future to detect vessels that are too small to carry a transceiver, have switched off their AIS or are not visible for some other reasons. Needless to say that oil spills can only be detected by SAR. Even though LRIT could not be utilised within the study for comparison reasons, the pooling of the data (to obtain higher update frequency) is a powerful tool to observe vessels closely and a very large and rather unrealistic number of satellites would be required to obtain the same result.

5. Recommendations and Next Steps

5.1 Implementation of Demonstration Projects

Within the study, examples provided to different customers showed the overall utility of S-AIS for maritime monitoring. This application driven approach should be further evolved by setting up more demonstration projects in the field of S-AIS. In addition to raise the awareness of S-AIS capabilities and limitations, the implementation of application projects would also support the fine-tuning of the requirements for a future European space based AIS constellation.

Furthermore, developments should be implemented related to the:

- automatic extraction of information from the growing S-AIS database by comparing actual with historical data sets in order to identifying thus vessel behaviour anomalies
- problem of different timeliness of terrestrial and space based AIS data when merging both sources. t-AIS data are usually almost real time, while S-AIS, even when a constellation is in place will only be at the user 30 min to 1 hour after acquisition. As such, while the display of the T-AIS shows the real position of the vessel, the S-AIS data provide a deferred position.

Today, EO data are provided to GMES and other applications through a specific mechanism and funding on EU level and it might be worthwhile to consider a similar approach for S-AIS data.

5.2 Improved Technical Understanding

Several projects will be implemented within ESA under ARTES 5, 20 and 21. These are linked to:

- The establishment of an end-to-end system test bed to validate an optimal technical solution
- The comparison of different AIS sensors through performance tests. It should be underlined here that first tools have been developed within the study and should be further evolved in the ESA frame
- The development of an improved VHF patch antenna, which provides a new approach for detecting AIS messages
- A Phase B1 on a possible future constellation
- The development of an AIS processing centre, which will be connected to the BOP of EMSA

These studies will provide valuable inputs to a technically sound basis for a future AIS constellation improving the knowledge in Europe in this field.

In addition, we would propose, based on the outputs of PASTA MARE, to further investigate the AIS signal behavior and specifically the parameters not linked to the satellite but to the vessel itself.

5.3 Dedicated Satellite AIS Frequency

The assessments of the performance of S-AIS revealed their current limitations. The ITU Radiocommunication Study Group 5b is discussing a new proposal for modifying the AIS system, aiming at overcoming the current limitation and to improve the capabilities of space based AIS¹. In the proposal detailed specification are given on how the enhancements can be achieved:

- A special short AIS message (proposed Message 27) of only 96 bits shall be introduced, that is tailored for satellite reception. This would solve the problem of blurred reception.
- A special reporting interval of 3 minutes of the message 27 is envisaged, lowering the message collision rate and increasing the PoD.
- Ships within range of an AIS base station should suppress transmission of message 27, since they are monitored by terrestrial AIS stations. Hence, S-AIS is considered as complementary to existing terrestrial AIS networks.
- Separate operating frequencies in addition to AIS channels 1 and 2 are proposed which are not subject to terrestrial use. Candidate frequencies are channels 75 and 76, which are exclusively dedicated to maritime services and thus not impacted by interferences from other land services (e.g. taxi radio).
- Satellite detection of the ship-borne AIS should be limited to the AIS Class A (SOLAS Class). The inclusion of AIS Class B population is definitely too large to be included in a space based AIS system.

According to simulation results, it is expected that the 3rd AIS frequency increases substantially the performance of space based AIS, reaching a PoD on high sea areas of almost 100%.

¹ Radiocommunication Study Groups (2008): "Improved satellite detection of AIS", Document 5B/175-E, Annex 5 to Working Party 5B Chairman's Report, Preliminary Draft New Report ITU-R M [SAT-AIS]

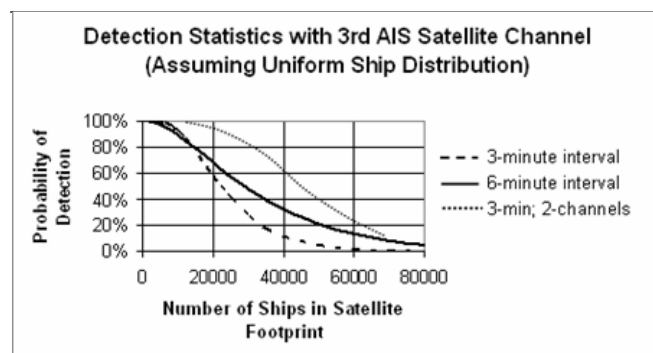


Figure 1: Optimising the PoD for AIS Class A ships by means of 3rd AIS frequency (Source: Radiocommunication Study Groups 2008: “Improved satellite detection of AIS”)

The ITU working group is currently reviewing the proposal and discussing to add the proposed Message 27 to ITU-R M.1371-3, along with its transmissions on the designated channels 75 and 76, and the AIS Class A equipment should be updated to add this message to facilitate improved satellite AIS detection.

The adoption of the recommendation elaborated by the ITU working group would allow the deployment of less complex satellite AIS system at reduced costs, with a high performance on high seas and thus complementing the terrestrial AIS station network.

5.4 Commercial Distribution of Satellite AIS data versus Institutional Access only

The commercial market for S-AIS is also developing. Port operators, ship owners, trading companies and others realise the added value of space based AIS. Several companies are already using the S-AIS data for internal or external activities either as trials or on an operational basis.

Even though, the recording of T-AIS data is not forbidden and the number of stations is rapidly growing, there are still some major questions about the commercial distribution of S-AIS data on global scale. IMO and ITU are still discussing a possible approach. However, some countries have a strong interest in keeping S-AIS for institutional use only. The definition of a legal framework related to the data policy definitely requires a global approach. In case Europe would not allow European S-AIS operators to commercialise AIS data to non institutional customers, but other countries like the US could, this would be certainly disadvantageous for European economy.

Allowing operators to serve the commercial and institutional market would certainly improve the business case for a private company. Investigations on a possible Public Private Partnership (PPP), hybrid model (combining institutional and privately owned assets) or even

the alternative scenario (provision of S-AIS data through a commercial entity) will be soon carried out under ESA ARTES 21 programme and results will show, which approach is most suited for Europe.

5.5 Future S-AIS services

The set up or design of future European space based AIS system is currently envisaged by EMSA and ESA. The system set up is mainly driven by the requirements of EU and national institutional users. Out of the various requirements specified by ESA, three of them determine largely the overall system setup:

- **Probability of Detection:** determines the capability of the AIS receiver to detect the vessels. A high PoD requires a sophisticated and complex satellite design (receiver, power supply, antenna etc) associated with a manufacturing and operation high cost.
- **Update frequency of the AIS messages** (update interval of the AIS position report from a single vessel) determines the number of operational satellites. The higher the wished update frequency, the higher the number of satellites. Initial simulations show that for an update interval of 135 minutes 6 satellites on 6 different orbital planes are needed. An increase of the update frequency to 40 minutes requires 12 satellites, on 6 orbital planes.
- **Latency/timeliness** (delay from acquisition of an AIS message by the satellite till final delivery to user) sets the number of ground stations, since data captured by the satellites need to be downloaded to earth as quickly as possible.

Based on the findings of the PASTA MARE study, there are several open points which shall be considered for future space base satellite constellations:

- Are S-AIS data in coastal zones really required? S-AIS have to cope with a very high vessel density, particularly moored vessels with an AIS message interval of just 3 minutes and strong impact of interference. Whether even with an advanced satellite design a 100% PoD can be reached has to be investigated. In any case, S-AIS system complexity and thus the cost of a satellite system coping with this challenges increase considerably.
- Installation of the AIS equipment (antenna, cabling) on vessels is not tightly regulated. Thus it can be expected that S-AIS will not be able to pick up messages from such vessels just because of unfavorable installations. This has a considerable impact on the maximum achievable PoD.
- New dedicated S-AIS frequencies, the proposed restriction to Class A vessels and the operation outside coastal AIS station will improve S-AIS capacity on high seas, allowing the deployment of less complex AIS satellite systems.

- Passive localization allows the identification of vessels spoofing their AIS signal. If this will be part of the user requirements, more satellites need to be deployed. At least three have to be in view of the vessel for triangulation.

Several options for dedicated S-AIS systems have been investigated by various parties including ESA in the past: homogeneous and non-homogeneous constellations:

- Homogeneous constellations refer to a number of identically constructed satellites, evenly distributed in dedicated and synchronized orbital planes. Such a constellation requires dedicated (thus expensive) launches for batches (e.g. 12 satellites in 4 planes require 3 launches). Since station keeping is required, a propulsion system needs to be integrated, causing also considerable costs for satellite control and operation. If one satellite in one plane fails, replacement is required, either hot spare, demanding for pre-invest or cold spare requiring relatively high launch costs (dedicated launch of one satellite). In order to cope with these weaknesses, satellites with a long lifetime need to be envisaged. Drawback here is the fact that limited possibilities exist to adapt the system capabilities if changes in the requirements or overall system parameters are needed.
- Non-homogeneous constellation satellites refer to “mix” of differently sized satellites, launched in an ad hoc manner, benefiting from available launch opportunities. Within the resulting constellation, each AIS satellite follows its own orbital plane in a kind of “uncoordinated” way. Launch of satellites (< 100 kg) can be realized on available piggy-back launches, with the advantage of much lower costs, easy replacement after failure within a few months and quick uptake of technology changes and new requirements. However, a non-homogeneous constellation needs a larger number of satellites (possibly 1/3 more) to compensate for changing revisit cycles. This approach becomes a valid option only if micro satellites with a low capital expenditure (CAPEX) are employed

With regards to the satellites systems, several options are possible:

- Larger satellites (300-400 kg weight) with highly complex AIS payload/antenna and additional Earth Observation (EO) payload and long life time (7.5 years)
- Smaller satellites (100-300 kg weight) with less complex AIS payload/antenna and very limited EO payload and life time of 5 years
- Very small satellites (< 100 kg weight) with less complex AIS payload/antenna and no EO payload and life time of 3-5 years

The major differences between large and very small satellites can be considered as follows:

- Large satellites are aimed at a life time of about 15 years, requiring less, but expensive replenishment/replacements.
- The simulated PoD for the complex system appears to be higher also in very dense vessel traffic (thus coastal) zones.
- The costs for the larger satellites are by a factor of 10-20 higher compared to the very small satellites.

The various approaches outlined above will be investigated in the ESA ARTES 21 Phase B1 project. The ITT will be issued in Q4 2010.

With regards to financing a European S-AIS system, two basic options can be considered:

- EU procures own S-AIS space and ground infrastructure (similar to Galileo, GMES Sentinel approach)
- EU procures services (i.e. data) from one or several commercial operators (similar to GMES Sentinel 3rd party mission approach) through long term commitments. These services might be based on:
 - A dedicated European satellite constellation (with private ownership)
 - A combination of European dedicated and existing European and non-European satellites (available or under construction)
 - Existing European and non-European satellites

The scenarios will be investigated within ESA ARTES 21 under the Private-Public Partnership (PPP) and the Hybrid/Alternative Scenario Studies. In this context, major questions to be tackled are:

- Does the European Union need and want an own infrastructure or is (at least partial) the utilisation of non-European satellite services suitable?
- Can Europe accept that S-AIS data are not exclusively used for institutional users but also for commercial utilization?

Costs for a dedicated constellation will be largely dictated by the requirements:

- The higher the PoD requirements and specifically for coastal zones the more expensive the system
- Update frequency: Compared to LRIT, where the user can “poll” the vessel transmitter and will pay per “message”, S-AIS is much less flexible and requires the manufacturing and launch of additional satellites to increase Nb of messages (Note: A constellation of 36 satellites would allow an almost comprehensive surveillance of open seas)

- EO payloads on board of the satellite(s) will largely drive the satellite sizing and thus is a major cost driver

First estimates of service costs for the provision of S-AIS data available to all EU and national institutional users in Europe from European Industry are in the range of 2 – 6 M€ per annum.

The cost estimate is based on:

- the observation of open seas, with a PoD between 90-95%
- an update frequency of real messages of 3-4 hours,
- a latency/timeliness of 1 hour (higher update frequency and latency achievable but at higher costs) and
- assuming non exclusivity, i.e. data distribution also to commercial customers (ship owners, port operators etc.)

The above mentioned point are just a general items emerged during the execution of the PASTA MARE study. They shall indicate the complexity of defining a future European space based system. An in-depth trade off analysis considering user requirements, system concept and associated cost is required in order to find the most suitable solution for a future space based AIS system for the benefit of all stakeholders.