FFI-rapport 2009/00316

ESA mulighetsstudie for et europeisk satellittbasert AIS system

Sammendrag

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Godkjent av

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Sammendrag

Denne rapporten gjengir rapporten ”Executive Summary” som FFI laget for den europeiske romorganisasjonen ESA under kontrakten: ”Contract No. 20492/06/NL/JA – Technology reference and proof of concept for a space based automated identification system for maritime security”. Studien ser på teknisk utvikling som kreves for å kunne tilby Europa en nyttig tjeneste for observasjon av skip via AIS signaler mottatt fra satellitter.

Rapporten som er gjengitt gir et kort sammendrag av resultatene fra studien. Kongsberg Seatex har sammen med Norspace bidratt med studier av en AIS mottaker for rommet, mens Surrey Satellite Technology Limited har bidratt med studier av satellittplattform og konstellasjonsløsninger. FFI har stått for signalanalyse, analyse av brukerkrav, lover og regler et slikt system vil måtte forholde seg til samt utforming av overordnet konsept og forslag til en demonstrasjonsløsning.

Studien konkluderer med at ikke alle utfordringer rundt et globalt satellittsystem for mottak av AIS signal er løst og at det trengs mer kunnskap før man bør gjøre et endelig design av et operativt system. Første skritt på veien mot et operativt system bør være en demonstrasjonssatellitt med tre monopolantenner som kan både dekode AIS signaler ombord og lagre basebåndsignalet for prosessering på bakken.

ESA har tatt resultatene videre, både mot nye studier rundt mottakerutvikling og demonstrasjonssatellitt, og også med utvidede studier som ser på en endelig konstellasjon.

English summary

This report reproduces the report “Executive Summary”, that FFI produced for the European Space Agency under the contract: ”Contract No. 20492/06/NL/JA – Technology reference and proof of concept for a space based automated identification system for maritime security”. The purpose of the study was to evaluate the feasibility of a European operational system for monitoring ships by the reception of AIS signals from satellites.

The report presents the summary of the results found in the study. Kongsberg Seatex together with Norspace has contributed with studies of an AIS receiver for space, while Surrey Satellite Technology Limited contributed with studies of possible satellite platforms and possible constellations. As well as being prime, FFI has had the main activity in the areas of signal analysis, user requirements, data policy and regulations, as well as mission concept both for a full operational system and a demonstrator.

The study found that a global system for receiving AIS signals in space is achievable for most areas of the world, but that a few areas exist where challenges still remains. It strongly recommends building a demonstration satellite before concluding on the design of an operational system. The suggested demonstrator should be a satellite in low Earth orbit with three orthogonal monopole antennas, which can handle both signal processing on-board and on ground.

ESA has used the results of the study to continue the work on space based AIS, with new studies on both receiver development and a possible demonstration satellite, as well as further studies on an operational concept.

Innhold

1 Innledning

Denne rapporten inneholder et sammendrag av resultatene fra en konseptstudie på en konstellasjon av satellitter for mottak av navigasjonssignaler fra skip. Arbeidet som er gjengitt i denne rapporten representerer resultatet fra studien FFI gjorde for ESA[1] fra 2006-2008. Under arbeidspakken ”Recommendations and Conclusions” leverte FFI en rapport på ”Executive Summary”, som er gjengitt i sin helhet i Appendix A. Denne rapporten sammen med den mer omfattende oppsummeringsrapporten ”Final Report” er åpne rapporter som gjengir resultatene fra studien.

Det vil videre bli gitt en kort bakgrunn angående studien og en liste over leveransene før den originale rapporten som ble levert ESA kommer i Appendix A.

1.1 Bakgrunn

FFI fikk i desember 2006 en 12-måneders kontrakt med ESA for å se på en fase 0-studie av et europeisk satellittsystem for mottak av AIS meldinger. Studien varte noe lenger enn først planlagt og en såkalt ”Final Presentation” ble først avholdt ved ved ESTEC[2] sitt hovedkvarter i Nederland den 6. mai 2008. Etter dette fikk ESA muligheten til å komme med kommentarer på rapportene, før en endelig leveranse ble sendt høsten 2008. Den endelige leveransen markerte at kontrakten med ESA, ”Contract No. 20492/06/NL/JA – Technology reference and proof of concept for a space based automated identification system for maritime security” var avsluttet.

I studien hadde FFI med seg industripartnerne Kongsberg Seatex AS (KSX), Norspace AS og Surrey Satellite Technology Ltd (SSTL) som underleverandører. KSXs hovedoppgave var å designe en nyttelast som muliggjør mottak av AIS fra rommet, og Norspace var med for å dele sin erfaring med elektronikk i satellitter med KSX. SSTL er en britisk leverandør av satellittplattformer som bidro med sin kunnskap om valg av egnede satellitter og bakkestasjonskonsept. FFI hadde det overordnede ansvaret og hadde spesielt ansvar for analyser og kunnskap om mottak av AIS fra rommet. Figur 1.1 viser hvordan studien var organisert i arbeidspakker der ansvaret var fordelt mellom FFI og industripartnerne.

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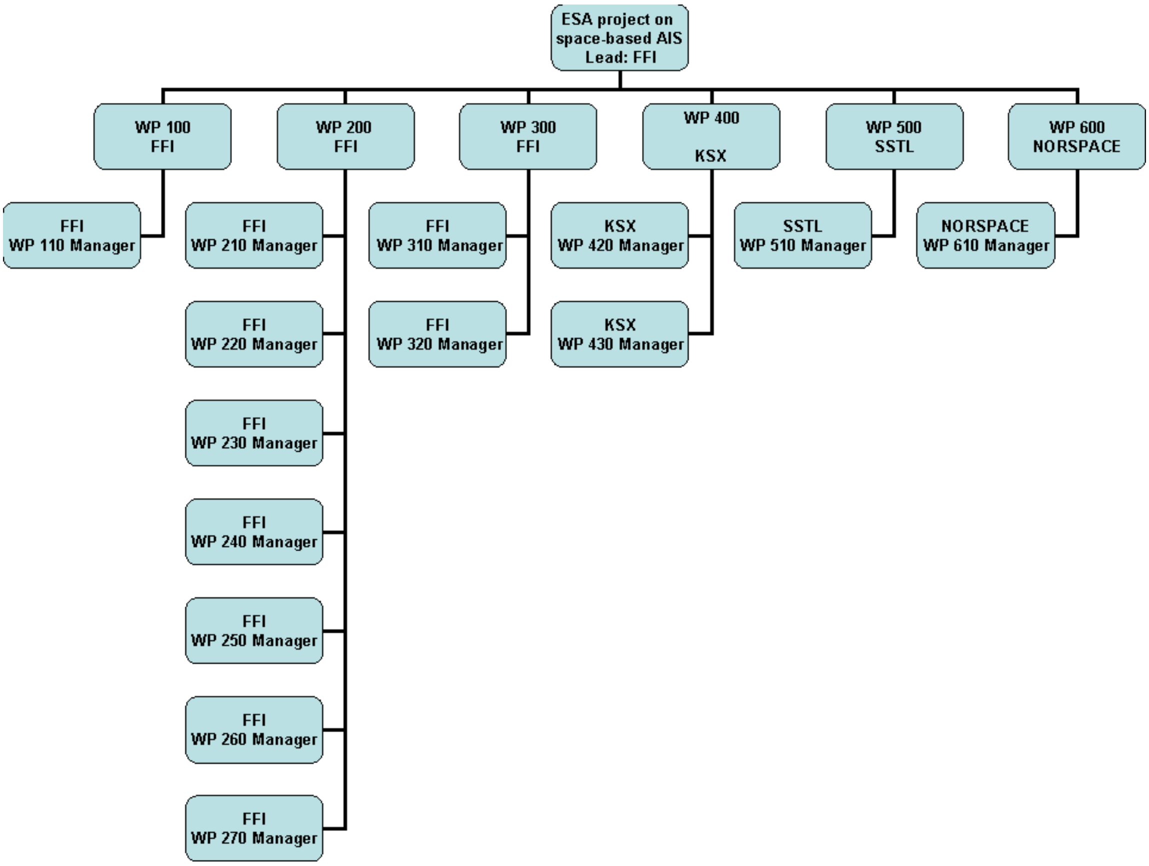
[1] European Space Agency

[2] Euroepean Space Research and Technology Centre



Figur 1.1 Organisasjonskart for studien, fordelt på arbeidspakker og partnere. Leveranser tilhørende de forskjellige arbeidspakkene kan finnes i Tabell 1.1.

Personell involvert i kontrakten hos FFI var Torkild Eriksen, Øystein Helleren, Richard Olsen, Øystein Olsen og Peter Selvik. Torkild Eriksen var prosjektleder for ESA kontrakten fram til 1.april 2007 da han gikk over i et oppdrag ved EU Satellite Center. Øystein Helleren overtok prosjektlederoppgaven. Prosjektet lå inn under 1002 INNOSAT[3] og 1104 INNOSAT-2 der Richard Olsen er prosjektleder. Størrelsen på hele kontrakten var på 500K Euro og første del av kontrakten var registrert som prosjekt 100209 hos FFI.

Første halvdelen av kontrakten så på brukerkrav, juridiske betenkninger og eventuelle konkurrerende system (LRIT[4]) for å gi en bakgrunn til å kunne komme opp med et konsept for et europeisk system for satellittbasert AIS. KSX kom fram til et konsept for en nyttelast (mottaker), og begynte på et detaljert design.

En stor utfordring for et system for mottak av AIS meldinger fra satellitt er at samtidig mottak av meldinger fra flere skip kan skje, og dette kan føre til tap av meldinger. FFI foretok derfor en rekke analyser og simulering for å finne fram til satellittbaner og antennesystemer som kan gi god dekning i alle europeiske farvann. Med denne bakgrunnen begynte FFI utarbeidelsen av en plan for hvordan et slikt satellittsystem kunne se ut. Dette ble gjort i samarbeid med SSTL som blant

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[3] Innovativ bruk av satellittovervåking for det nye forsvaret

[4] Long Range Identification and Tracking

annet fokuserte på mulige satellittkonstellasjoner for å oppnå regelmessig og hyppig dekning av alle europeiske farvann.

Det viste seg at det var store utfordringer forbundet med fartøystettheten i europeiske farvann. Det ble derfor besluttet at andre halvdel av studien i større grad skulle fokusere på et forslag til et demonstrasjonskonsept som et første naturlig steg på vei mot en operativ tjeneste. Det ble allikevel gjort en del arbeid også på mulige operative konsepter. Den siste delen av studien inneholdt også et mer detaljert design av nyttelasten.

Studien konkluderte med at det i flere europeiske interesseområder ville være vanskelig å motta og dekode AIS meldinger fra alle skip på grunn av det store antallet AIS meldinger en satellitt vil motta samtidig. Det ble derfor sterkt anbefalt å satse på å først lage en demonstrasjonssatellitt før man gjorde endelige bestemmelser på et eventuelt operativt system. Det er trolig at det kunne gjøres en del forbedringer når det gjaldt dekodingsalgoritmer, og det ble anbefalt en satellitt med tre antenner og tre mottakere. En ”software defined radio” ble foreslått som nyttelastkonsept.

Dette demonstrasjonskonseptet ville muliggjøre både dekoding ombord i satellitten og lagring av data for testing av nye dekodingsalgoritmer på bakken. Nye algoritmer ville også kunne lastes opp og testes ombord i satellitten. Bruken av tre ortogonale monopoler ville også kunne gi et tredimensjonalt bilde av signalmiljøet i rommet, noe som igjen ville kunne brukes til å forbedre simulerings- og modelleringsmodeller av systemet.

1.2 Leveranser i studien

Alle leveransene i studien er listet opp i Tabell 1.1. I parentes etter rapportnavnet er det markert (R) for rapport og (A) for animasjon. I tillegg er det markert hvilken bedrift som har vært ansvarlig for rapporten.

RES-210-10 User Needs and Requirements	(R) (FFI)
RES-220-20 Space-based AIS: Regulations and Data Policy	(R) (FFI)
RES-230-30 LRIT concept and impact on space based AIS	(R) (FFI)
RES-240-10 Space based AIS: Mission Concept	(R) (FFI)
RES-240-20 Preliminary Mission Requirements Document	(R) (FFI)
RES-240-30 Constellation Design and CONOPS	(R) (SSTL)
RES-250-10 Concept Definition of In-Orbit Demonstration	(R) (FFI)
RES-260-10 Development Plan and Cost Estimates	(R) (FFI)
RES-270-10 Final Report	(R) (FFI)
RES-270-20 Executive Summary Report	(R) (FFI)
RES-270-30 Abstract	(R) (FFI)
RES-310-10 Space-based AIS Signal Analysis	(R) (FFI)
RES-320-10 End-to-end Verification Simulator Model	(R) (FFI)
RES-320-20 Visualisation of System Performance Verification	(R) (FFI)
RES-320-20 Yagi simulation	(A) (FFI)
RES-320-20 Three monopoles simulation	(A) (FFI)
RES-420-10 Payload Analysis and Concepts of satellite receiving system	(R) (KSX)
RES-420-20 Preliminary Function and Performance Requirements Document	(R) (KSX)
RES-430-10 Payload System Requirements Document	(R) (KSX)
RES-430-20 Detailed Design for space-based satellite receiver system	(R) (KSX)
RES-430-30 Payload Interface Requirements Document	(R) (KSX)
RES-510-10 Platform Concepts and Definition	(R) (SSTL)
RES-610-10 Consolidation and evaluation of preliminary AIS receiver design	(R) (Norspace)

Tabell 1.1 Leveranser i ESA-studien: ”Technology reference and proof of concept for a space based automated identification system for maritime security”. R = rapport. A = animasjon.

2 Forkortelser

A	Animasjon
AIS	Automatic Identification System
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
FFI	Forsvarets forskningsinstitutt
KSX	Kongsberg Seatex
LRIT	Long-Range Identification and Tracking
R	Rapport
SSTL	Surrey Satellite Technology Ltd

Appendix A Executive Summary

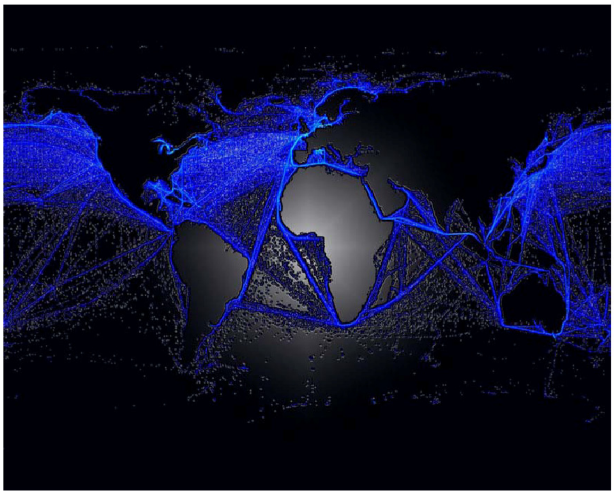
ESA ESTEC contract 20492/06/NL/JA

Technology Reference and Proof-of-Concept for a Space-Based Automatic Identification System for Maritime Security

RES-270-20

Executive Summary

Øystein Helleren



Forsvarets forskningsinstitutt/Norwegian Defence Research Establishment (FFI)

14.04.2008

Cover illustration: Global ship traffic routes.
Made with Adobe Photoshop as clean plastic wrap.
Artist: Øystein Olsen, FFI.

RES-270-20

ESA ESTEC contract 20492/06/NL/JA

Version 1.0

Keywords

Space based AIS

AIS payload

Software defined radio

AIS demonstration mission

AIS operational concept

Approved by

Richard Olsen	Company QA manager
Øystein Helleren	Project manager
Karsten Strauch	ESA manager

Change records

Issue	Date	Changes
1.0	14.04.2008	First draft of executive summary

A.1 Contents

WP 270 Recommendations and Conclusions
RES-270-20 Executive Summary v1.0
Date 14.04.2008

Contents

A.2 Introduction

WP 270 Recommendations and Conclusions
RES-270-20 Executive Summary v1.0
Date 14.04.2008

1 Introduction

There is a growing need to develop a global maritime surveillance capability to safeguard the security of people and infrastructure, the safety of life at sea, as well as the maritime environment. One candidate system to provide information to such services is the automatic identification system ,AIS, a system transmitting information about vessel identity, position, heading, nature of cargo, destination etc. on dedicated frequencies in the maritime VHF band.

In addition to improving safety between vessels, many countries today use AIS extensively for maritime safety and security, monitoring and guiding traffic near the coast. As the AIS system transmits information on VHF, the coverage from land is limited to a few tens of nautical miles, and there is a high interest in looking at space based AIS receivers as a solution to also enable monitoring of activity in the high seas.

In this study the Norwegian Defence Research Establishment together with Kongsberg Seatex AS, Norspace AS and Surrey Satellite Technology Limited has looked at the feasibility of a European space-based AIS system for maritime security. The study has focused on receiver technologies and antenna concepts, running advanced detection probability simulations to evaluate the best concepts and establish a technological reference for space-based AIS systems.

Establishing some basic user requirements and a preliminary data policy, the study first looked at concepts and constellations for a full operational system. Understanding that there are still challenges to be overcome in areas of high vessel density the second half of the study turned the focus on establishing a demonstration concept. A demonstration mission should be the next step in order to test how good advanced decoding algorithms can mitigate the challenge of simultaneously received messages in some European waters.

This document is an executive summary of the study, and more details can be found in the full final report.

A.3 AIS and LRIT

2 AIS and LRIT

AIS utilizes VHF communication to transmit and receive data. It operates primarily on two dedicated VHF channels, and the transmission alternates between the channels in order to balance the traffic between the available VHF channels. The frequencies AIS 1 and AIS 2 have been coordinated internationally and are used in most parts of the world. The radio coverage range is dependent on the height of the antennas. The propagation differs from that of a radar, due to the longer wavelength, so it is possible to "see" around bends and behind islands if the landmasses are not too elevated. A typical range value to be expected between vessels is 20 - 30 nautical miles. From highly elevated base stations the coverage area may be up til 60-80 nautical miles.

AIS broadcasts the vessel's position, speed and course over ground as well as static and voyage related information. Short safety related text messages can be sent between vessels or broadcast from shore based AIS stations or Aids to Navigation like buoys and lighthouses. The on-board installed system is designed to operate automatically and as a stand-alone unit. In addition to transmission of AIS data, the system can continuously receive position information from other vessels or shore based stations.

Figure 2.1 Overview of the AIS scenario (courtesy Kongsberg Seatex)

AIS was introduced as a anti-collision system between vessels, but is today widely used for vessel traffic services, enabling authorities instant overview of the vessel traffic along the coast.

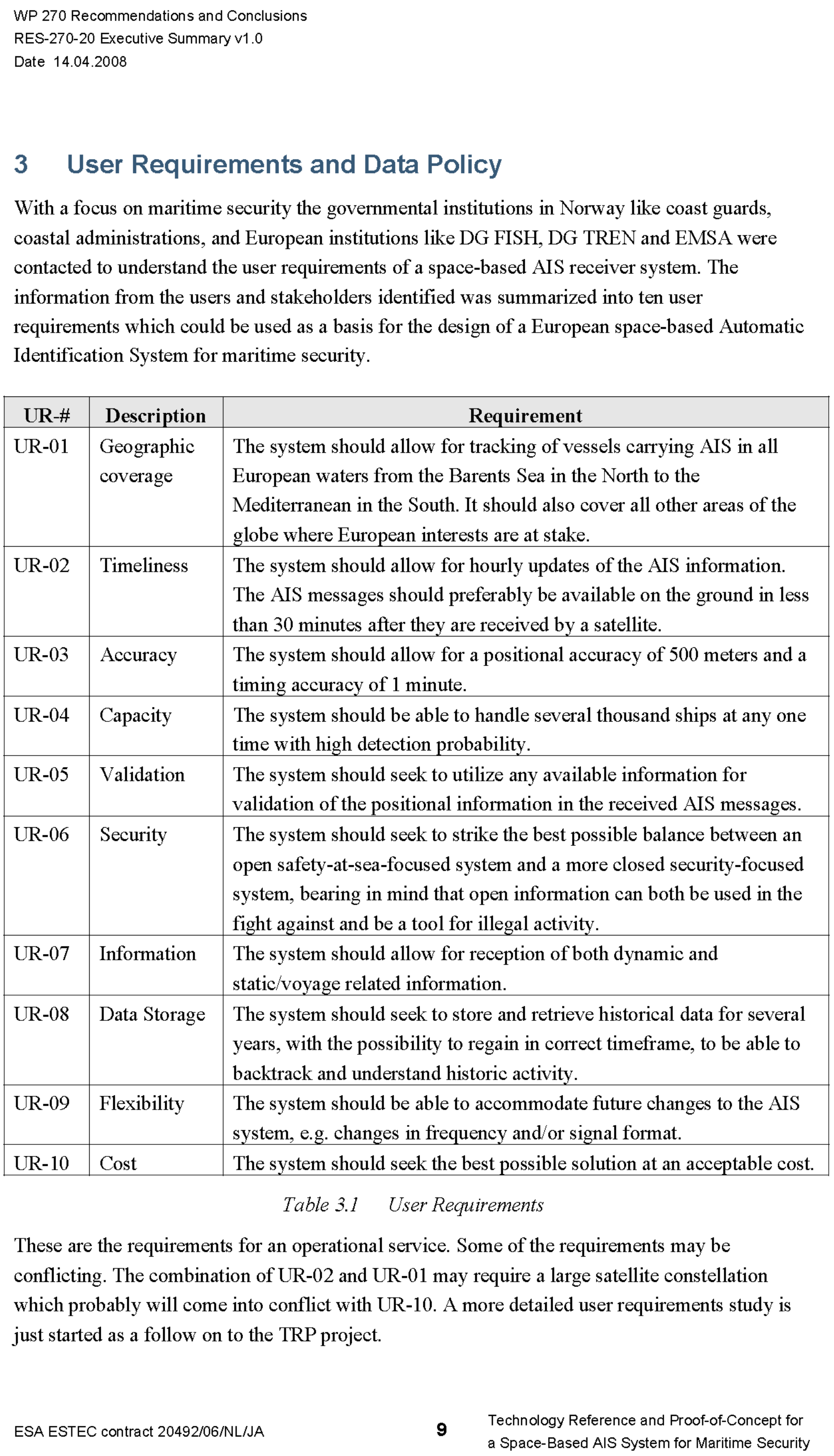
To enable monitoring of vessel traffic also further off the coast, space-based AIS has been introduced as an alternative. It is important to know that the International Maritime Organization also has introduced another system to cover some of these needs: The Long Range Identification and Tracking system (LRIT). This is a system where the vessels are obliged to report to a databank: vessel ID, position and time of position at given intervals through space based communication satellites (e.g. Inmarsat). Strict regulations then govern which authorities have access to the data, depending on distance to coastal nation, nationality of destination harbour etc. A comparison table of LRIT and space based AIS is set up in Table 2.1

	LRIT	Space-based AIS
Reporting Interval	6 hours (nominal) Down to every 15 minutes if requested	Dependent on constellation of satellite system. The user requirement is hourly updates.
Reporting Delay	Low	Up to 30+ minutes
Information Carrier	LRIT information is transmitted from the vessels through communication satellite networks to dedicated data centres which will redistribute to the end users which order the messages.	The AIS satellites receives the regular AIS messages the vessels report and downlink the information to a European mission control centre which will redistribute to registered users.
Cost	Not yet decided	Not yet decided
Message Information	Vessel ID Position Time	• Vessel ID • Position • Time • Course over ground • Heading • Speed over ground • Navigational status • Destination* • Hull ID* • Estimated time of arrival* • Ship name*
Includes Fishing Vessels	Not today	Includes fishing vessels over 24 meters long**
Coverage Area	Out to 1000 nm out from the coast.. Globally for own vessels and vessels destined for the nations port	Globally***
Need for Extra Equipment onboard Vessels	Yes	No
Start of service	2009	The first demonstrational satellite in a European system could be operational from 2010

* included in voyage messages which are only transmitted every 6 minutes
** For fishing vessels operating in the EU/EEC area.
*** Dependent on satellite constellation the system may have reduced detection probability in some high density vessel areas.

Table 2.1 Comparison of LRIT and space-based AIS

A.4 User Requirements and Data Policy



3 User Requirements and Data Policy

With a focus on maritime security the governmental institutions in Norway like coast guards, coastal administrations, and European institutions like DG FISH, DG TREN and EMSA were contacted to understand the user requirements of a space-based AIS receiver system. The information from the users and stakeholders identified was summarized into ten user requirements which could be used as a basis for the design of a European space-based Automatic Identification System for maritime security.

UR-#	Description	Requirement
UR-01	Geographic coverage	The system should allow for tracking of vessels carrying AIS in all European waters from the Barents Sea in the North to the Mediterranean in the South. It should also cover all other areas of the globe where European interests are at stake.
UR-02	Timeliness	The system should allow for hourly updates of the AIS information. The AIS messages should preferably be available on the ground in less than 30 minutes after they are received by a satellite.
UR-03	Accuracy	The system should allow for a positional accuracy of 500 meters and a timing accuracy of 1 minute.
UR-04	Capacity	The system should be able to handle several thousand ships at any one time with high detection probability.
UR-05	Validation	The system should seek to utilize any available information for validation of the positional information in the received AIS messages.
UR-06	Security	The system should seek to strike the best possible balance between an open safety-at-sea-focused system and a more closed security-focused system, bearing in mind that open information can both be used in the fight against and be a tool for illegal activity.
UR-07	Information	The system should allow for reception of both dynamic and static/voyage related information.
UR-08	Data Storage	The system should seek to store and retrieve historical data for several years, with the possibility to regain in correct timeframe, to be able to backtrack and understand historic activity.
UR-09	Flexibility	The system should be able to accommodate future changes to the AIS system, e.g. changes in frequency and/or signal format.
UR-10	Cost	The system should seek the best possible solution at an acceptable cost.

Table 3.1 User Requirements

These are the requirements for an operational service. Some of the requirements may be conflicting. The combination of UR-02 and UR-01 may require a large satellite constellation which probably will come into conflict with UR-10. A more detailed user requirements study is just started as a follow on to the TRP project.

The preliminary space-based AIS data policy assumes that the system is European, initially under the control of ESA during a development and pilot phase, subsequently transferred to an operational European entity responsible for surveillance and/or maritime security. The policy is based on considerations of data policy from the GMES initiative and existing data policies from EUMETSAT and ESA.

All data should be protected and accessible by appropriate electronic means. All access to the data should be limited to registered users and all efforts should be undertaken to protect the data, products and services against unauthorised use. The distribution of data is suggested to be within three categories.

Category 1:	The Payload data should be available for Governmental use for Maritime Security. This includes both operational use and research use.
Category 2:	The Payload data should be available to the respective owner of the vessels.
Category 3:	The Payload data should be available for private and public entities for use in Value Added Products.

Figure 3.1 shows the suggested data flow of an operational system. It is also possible that the mission control centre is divided in two, where one is responsible for the operation of the satellites in the constellation and the other is responsible for the AIS data.

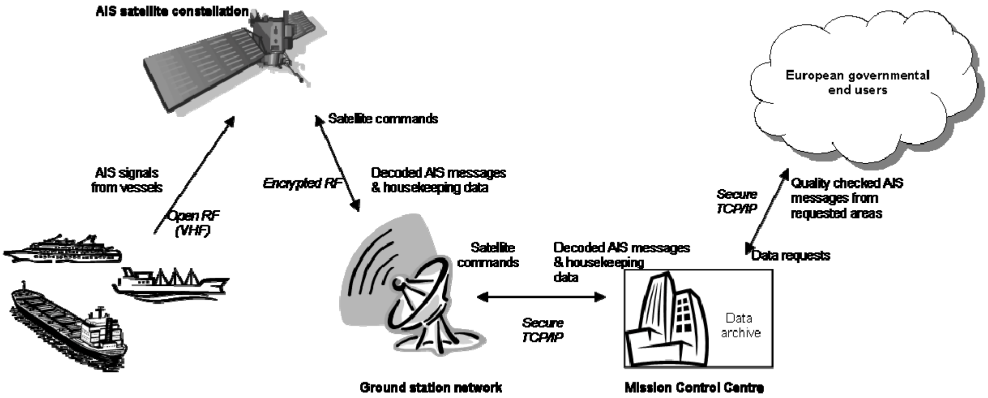


Figure 3.1 Data flow in a European satellite based AIS service.

A.5 Payload – Space-Based AIS Receiver

WP 270 Recommendations and Conclusions
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4 Payload – Space-Based AIS Receiver

Several architectures are possible for receiving AIS signals in the VHF band. Table 4.1 is a comparison of some of the architectures considered.

Receiver Architecture	Advantages	Disadvantages
Direct Conversion	Simple and inexpensive hardware implementation. Minimum of components required. Local oscillator at same frequency as received signal gives simple oscillator design. Easy to realize required amplification at baseband frequency. Low power consumption.	All selectivity has to be provided at baseband frequency. May be difficult to achieve required adjacent channel suppression. Suppression of local oscillator signal at antenna terminals may be difficult.
Superheterodyne	Proven technology and used in most current applications. High oscillator frequency will give good mirror signal suppression. Intermediate Frequency amplifiers will give high gain and good selectivity.	Increased number of components. Need LC filtering for obtaining good selectivity. Depends on filter tuning (IF) for optimum results.
Double Superheterodyne	Use two or more IF's to obtain better gain and selectivity. State of the art solution for high grade receivers.	Increased number of components and higher cost.
Software Defined Radio – SDR	Flexible regarding change of receiver parameters. New software modules can be implemented on same hardware to obtain different receiver characteristics.	Complex implementation. Relies heavily on digital signal processing to obtain same performance as superheterodynes. High power consumption due to signal processors and microprocessors needed.

Table 4.1 PROs and CONs of different receiver architectures

The most important factors for selection of receiver architecture are:

1. Probability of success for reception of the wanted signals
2. Power consumption
3. Flexibility
4. Complexity

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Receiver Architecture	Success factor	Power consumption	Flexibility	Complexity	Total
Direct Conversion	6	7	1	7	21
Superheterodyne	8	7	1	6	22
Double superheterodyne	9	6	1	5	21
SDR	9	4	8	3	24

Table 4.2 Rating of receiver architectures. Score : 1= bad 10= good.

Based on the simplified evaluation of performance and flexibility in Table 4.1 and Table 4.2, the SDR solution(Figure 4.1) is the best for a spaced based receiver. The differences are, however, marginal and all architectures are good candidates for a space based receiver. If major importance is placed on flexibility, the SDR solution is the best. This flexibility opens for different uses of the SDR, where one also can look at various modes used at certain times, e.g. one mode for areas with low vessel density and one for areas with high vessel density.

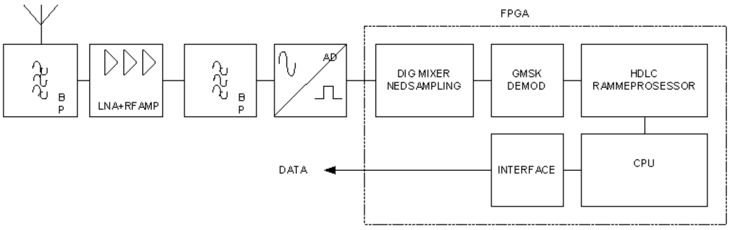

Figure 4.1 SDR receiver block diagram

In addition to the radio, the antenna is an essential part of the payload. Below the three main antenna concepts are discussed. Other concepts where also simulated during the study, but these represent the main principles considered

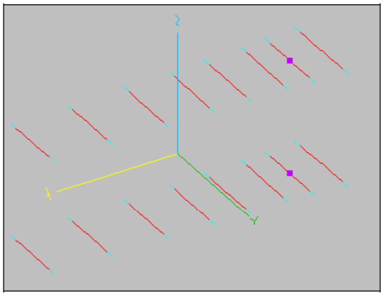

Figure 4.2 Antenna array of a large double Yagi antenna.

Figure 4.2 shows the large double Yagi array with two eight-element Yagi antennas spaced 1.2 meters apart with a boom length of 2.4 metres and with elements width of .902 meters. This is the most promising antenna configuration when looking at detection probability all around the globe. By combining the signals from the two arrays with a phase delay, one can also reduce the effect of secondary lobes, by pointing these lobes out into space. The main challenge with the use of a double Yagi array is that it would add considerable complexity to the spacecraft because of the two deployable structures needed.

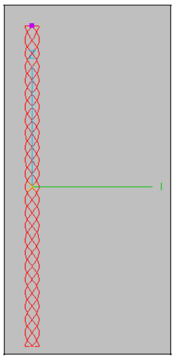

Figure 4.3 A 5-turn quadrifilar helix antenna.

Figure 4.3 shows the main quadrifilar helix antenna considered, a 5 turn with a diameter of 0.182 meters and length of 3.885 meters. This solution offers a slightly reduced field of view with a more simple design than the double Yagi. A single quadrifilar helix antenna will be easier to deploy as it can come out from the main body of the spacecraft and can be packed very compactly before launch. The field of view achieved by the quad antenna will not be as narrow as the one from the double Yagi. The antenna will also have side lobes that will receive AIS messages. In addition, the circular polarization will remove the effect of the Faraday rotation, which will increase the number of messages received. This will lower the detection probability due to increased occurrences of simultaneous arrivals of AIS messages.

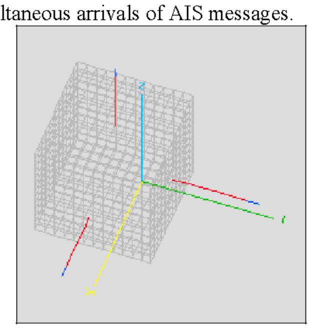

Figure 4.4 Three orthogonal monopole antennas.

Figure 4.4 shows three orthogonal monopole antennas representing the simplest solution considered. The use of three orthogonal antennas with three independent receivers would ensure independence from polarization effects like Faraday rotation, while still making use of this effect on the single antennas. This solution will also be the least complex for the spacecraft as it will have very low demands on the attitude control system. The three antenna solution will cover the largest area and thus the main challenge with this solution is simultaneous arrival of AIS messages. This solution is still competitive compared to the quadrifilar helix because of the Faraday rotation signal discrimination, and it allows for advanced signal processing on ground by using a sample and forward solution on each of the receiving chains. Combining the signal from the three antennas with respect to gain and phase could steer a low gain area to block out some interfering signals. This would increase the number of messages received in areas with high detection probability, but it is not sufficient to achieve any significant increase in the detection probability in high vessel density areas.

To understand better what can be achieved by advanced signal processing, this is the most attractive solution for a technology demonstration mission. The desired design for a demonstration payload is given as a sketch of the payload electronic box as given in Figure 4.5 and payload characteristics are given in Table 4.3.

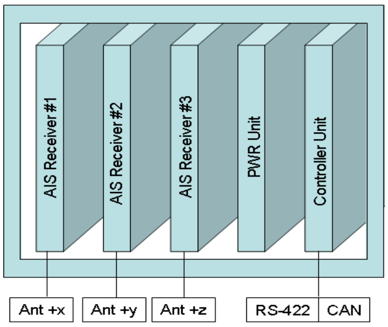

Figure 4.5 Sketch of demonstration mission payload receiver box for three orthogonal monopoles.

ID	AIS demonstration payload characteristics	
1.	Dimension (W×L×H)	150x250x150 mm (3 receivers) 150x250x75 mm (1 receiver)
2.	Power	28VDC unregulated power
3.	Payload total power consumption	15 W (3 receivers) 5 W (1 receiver)
4.	Pointing requirements	± 10 degrees
5.	Antenna requirements	Length ~0.50 m MAX (1 monopole) Weight ~ 1 kg MAX (1 monopole)
6.	Harness	0.150 kg (1 monopole)
7.	1 receiver	0.7 kg – electronics 0.5 kg – aluminium housing
8.	3 receivers	1.5 kg – electronics 1.2 kg – aluminium housing
9.	Temperature	-20°C to + 50°C

Table 4.3 Payload Design Characteristics.

A.6 Detection Probability Simulations

5 Detection Probability Simulations

A software model developed at FFI has been used to study the reception of AIS messages from low Earth orbit. It uses a global distribution of vessel densities to simulate transmission of AIS messages according to the SOTDMA scheme and the reception of messages in LEO. Hundreds of simulations have been run to test different payload configurations.

The model shows that an AIS satellite can handle at least 1200 vessels within the antenna's field of view at 95% detection probability. This result assumes only standard AIS receiver specifications with the exception of the minimum detectable signal strength. The number of vessels will increase if the receiver specifications can be improved, but a highly directive antenna is still required to achieve coverage at 40% detection probability in the most densely trafficked European waters.

Figure 5.1 shows an example of how the simulations take into account Faraday rotation as an important driver of the link budget.

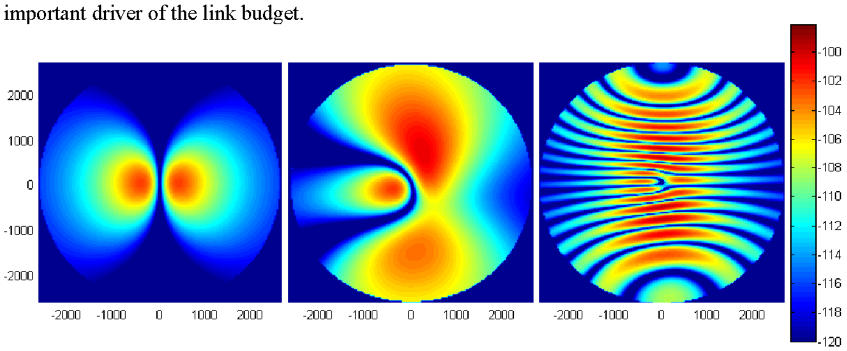

Figure 5.1 Received power (dBm) at a satellite with a horizontal dipole antenna and an altitude of 600km. All figures include polarization mismatch loss, but only the two rightmost figures include Faraday rotation. They show Faraday rotation from low and high (right figure) electron density ionospheres.

Message collisions are a significant problem whenever waters with large vessel densities are within the spacecraft field of view. Figure 5.2 shows the number of slots as a function of the number of colliding messages in a 10-second interval. The spacecraft altitude is 600km and the field of view is to the horizon. There are no slots with less than 4 message collisions and there are more than 45 slots were 10 messages collide. The received signal strengths of the messages have a range of about 30dBm depending on the antenna type.

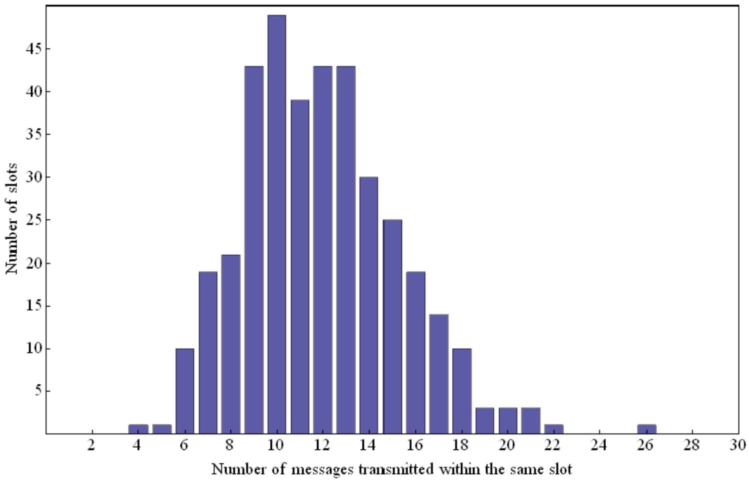

Figure 5.2 This figure shows the number of slots as a function of the number of colliding messages.

Figure 5.3 shows the detection probability after 1 day with a simple half-wave dipole antenna and a simple receiver, clearly illustrating the challenging areas in blue.

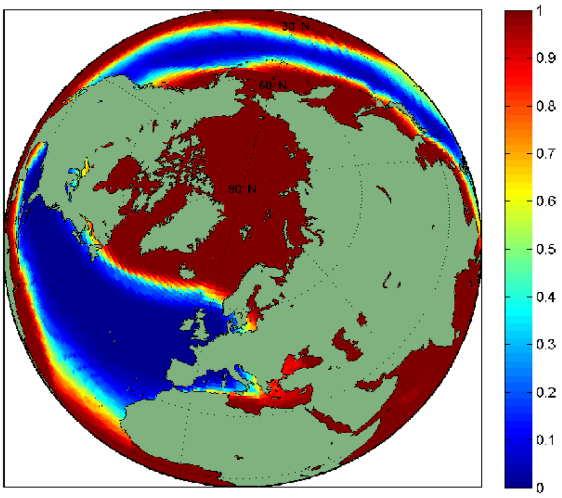

Figure 5.3 Detection probability after approximately one day (15 orbits) with a half wave dipole antenna

A combination of two directive antennas can achieve the required directivity in most ocean areas. The suggested solution is to combine the antennas with a phase difference to create asymmetrical secondary lobes, which can be oriented away from the Earth. Figure 5.4 shows the accumulated detection probability after 15 passes of a single satellite with a double Yagi antenna array.

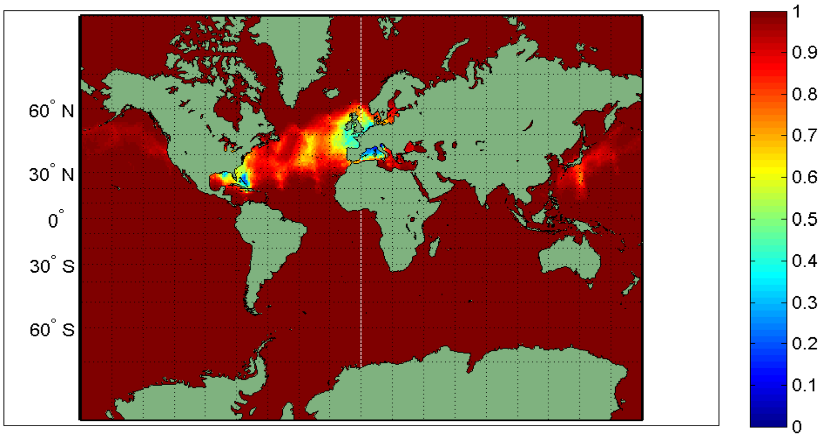

Figure 5.4 Detection probability after one day (15 orbits) using a single satellite with the asymmetric Yagi-array. This simulation used a 600km sun-synchronous orbit

Figure 5.5 shows a comparison of some of the different antenna solutions tested in simulations. While the Yagi array shows the best performance, the simpler solution of three orthogonal monopoles also looks promising, and should be the choice for a demonstration concept.

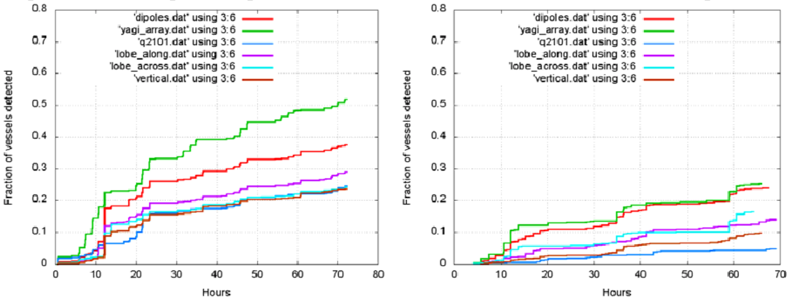

Figure 5.5 Comparison of detection probability in the North Atlantic (left) and North Sea (right) for a simple receiver on a single satellite with different antenna configurations.

Figure 5.6 shows the detection probability during 15 passes in Norwegian waters north of 62°N for satellites with 1, 2 and 3 orthogonal antennas connected to independent receivers. The orbit is sun synchronous with an altitude of 600km. The advantage of going from two to three antennas is an increase of as much as 10% points of the number of vessels detected during each pass. Although going from two to three antennas increases the payload complexity, it also increases the redundancy of the system and increases opportunities to do signal processing of the raw signals when using a digital bent pipe.

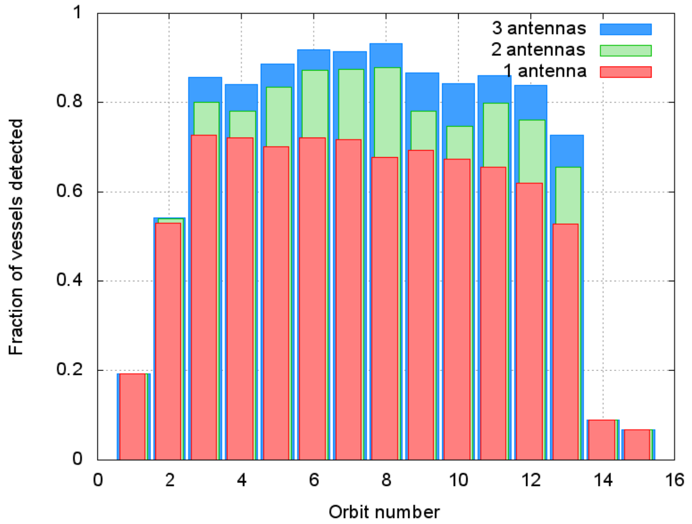

Figure 5.6 The detection probability during 15 passes in Norwegian waters north of 62°N for satellites with 1, 2 and 3 orthogonal antennas connected to independent receivers.

One possible solution for obtaining global coverage is to allocate a third AIS channel exclusively for space-based AIS. These messages will contain enough delay bits to avoid message collision from messages transmitted in different slots, and the nominal repetition rate will be decreased to one message every third minute. The total capacity of a space-based AIS sensor would increase to over 10000 vessels within the spacecraft field of view. This is sufficient to achieve almost global coverage every seventh orbit as seen in Figure 5.7.

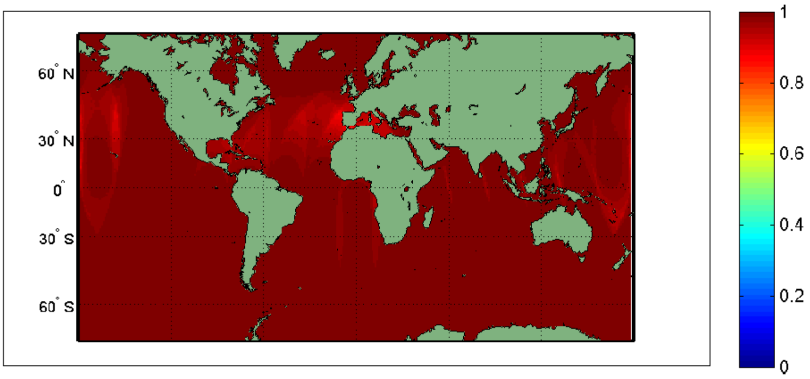

Figure 5.7 The cumulative detection probability after 7 orbits using a 3rd frequency.

A.7 Demonstration Concept

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6 Demonstration Concept

Table 6.1 gives the demonstration requirements (objectives) established in the study

DR-#	What to demonstrate	Based on	How
DR-01	Detect AIS class A vessel traffic data outside the AIS coastal base station range	User requirements	AIS receiver in space to validate the signal environment of message collisions etc.
DR-02	Detect > 90 % of the AIS Class A vessels during one pass along the Norwegian coast north of 62 degrees North.	Simulations	Compare AIS information received in space with information from AIS base stations.
DR-03	Demonstrate utilizing of the Faraday rotation for optimal vessel detection	Simulations	Simultaneously reception from antennas with two different polarizations. Showing the difference in AIS messages received.
DR-04	Estimate detection probabilities in high vessel density areas	Simulations	Do measurement campaigns in the North Sea and the Mediterranean, where results are compared with AIS data from coastal networks and possibly airborne AIS receivers.
DR-05	Validation in an area with expected detection probability >90% and with access to SAR data.	User requirements	Do a measurement campaign e.g. in the Barents Sea, combining SAR, satellite-based AIS and maybe aircraft observations.
DR-06	Demonstrate the separation of signals utilizing the Doppler effect.	Payload concept	On-ground processing where a digital channel filter is tuned to exclude signals from a specific frequency band. Compare detection probability with and without this filter
DR-07	Demonstrate the possibility of tracking vessels in open ocean areas	User requirements	Demonstrate tracking of vessel in the Pacific Ocean, South Atlantic and Barents Sea.
DR-08	Demonstrate monitoring of a selected region of interest.	User requirements	Have monitoring campaigns focusing on AIS reception in: The Barents Sea, the Mediterranean, the North Atlantic
DR-09	Demonstrate reporting <1 hour from vessel detection to data available for potential users.	User requirements	Use downlink facilities both in Arctic and Antarctic to demonstrate downlink capabilities of less than one hour, including data processing on ground and distribution to a potential user.
DR-10	Demonstrate use of firmware uploading.	Payload concept	Successfully upload new firmware in the SDR and verify operation of the payload with new firmware.
DR-11	Validate AIS signal link budget.	Payload concept	Measure the received signal strength in each AIS message and estimate the signal to noise ratio.
DR-12	Validate the SDR-based AIS receiver design in a space environment.	Payload concept	Successfully operate an SDR payload for space based AIS reception
DR-13	Demonstrate combinations of different antennas, using raw base band signals on the ground.	Payload concept	Demonstrate reception of different AIS vessels by combining the raw base band signal from two or three orthogonal antennas with different phase delays.
DR-14	Demonstrate further development of signal separation algorithms on the ground.	Payload concept	Develop new decoding algorithms based on an oversampled version of the base band signal from both the AIS channels
DR-15	Demonstrate different on-board decoding algorithms.	Payload concept	Upload firmware images with new algorithms developed on ground.
DR-16	Demonstrate the possibility of using maritime VHF channel 28, 162.000 MHz as a possible third AIS channel for space based reception	Payload concept	Do a campaign of global mapping of interference on 162.000 MHz and demonstrate switching one of the AIS receive channels from 162.025 MHz or 161.975 MHz to 162.000 MHz
DR-17	Demonstrate correlation of real detection probabilities and the simulations	Simulations	Compare detected AIS information in coastal areas with information from AIS base stations. Compare the resulting detection probabilities with the probabilities given in the simulations. Update the simulations.
DR-18	Demonstrate global mapping of the signal strength and interference at the AIS frequencies	Simulations	Measure signal (interference) level in all timeslots for both AIS channels for as long as is needed to give a reasonable global mapping. (12 consecutive hours). Such a demonstration campaign should be repeated on a regular basis (monthly/weekly)
DR-19	Identify precursor needs in terms of specifying definitions for a full operational system	Mission purpose	Be a step towards an operational system, giving answers to limitations and possibilities for an operational system.
DR-20	Demonstrate evolution of global received AIS traffic density over the mission lifetime	Simulations	Have monthly campaigns where AIS messages are received from all parts of the globe within 48 hours.
DR-21	Validate co-channel interference mitigation techniques	Payload concept	

Table 6.1 Description of demonstration requirements (objectives)

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Table 6.2 looks at how different antenna and receiver architectures are able to fulfil the demonstration requirements. BP is bent pipe while DBP is digital bent pipe or sample and forward.

DR-#	Double Yagi	Helix	Single Dipole	Two Dipoles	Three dipoles	Corner reflector	SDR	BP	DBP
DR-01	X	x	x	x	x	x	x	x	x
DR-02	0	0	0	0	x	0	x	x	x
DR-03	0	0	0	x	x	0	x	x	x
DR-04	X	x	x	x	x	x	x	x	x
DR-05	X	x	x	x	x	x	x	x	x
DR-06	n/a	n/a	n/a	n/a	n/a	n/a	x	x	x
DR-07	X	x	x	x	x	x	x	0	x
DR-08	X	▨	▨	▨	▨	▨	x	0	x
DR-09	n/a	n/a	n/a	n/a	n/a	n/a	x	0	x
DR-10	n/a	n/a	n/a	n/a	n/a	n/a	x	0	0
DR-11	X	x	x	x	x	x	x	x	x
DR-12	n/a	n/a	n/a	n/a	n/a	n/a	x	0	0
DR-13	0	0	0	x	x	0	0	x	x
DR-14	n/a	n/a	n/a	n/a	n/a	n/a	0	x	x
DR-15	n/a	n/a	n/a	n/a	n/a	n/a	x	0	0
DR-16	X	x	x	x	x	x	x	0	x
DR-17	n/a	n/a	n/a	n/a	n/a	n/a	x	x	x
DR-18	n/a	n/a	n/a	n/a	n/a	n/a	x	0	0
DR-19	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DR-20	X	x	x	x	x	x	x	0	0
DR-21	n/a	n/a	n/a	n/a	n/a	n/a	x	x	x

X	Requirement can be fulfilled
n/a	Not applicable
0	Requirement cannot be fulfilled
▨	Requirement can be partly fulfilled

Table 6.2 Demonstration requirement matrix for different antenna and receiver options.

The result from Table 6.2 shows that a concept using three dipoles would satisfy all demonstration requirements. For the receiver design, the software defined radio would need to be supplemented with a BP or DBP. Since the DBP can be implemented just using a different setup of the SDR, this was the natural choice. The DBP mode requires more internal bandwidth and storage capacity, but can be used worldwide, while a BP would only have worked during contact with a ground station.

Looking at ground stations, the Svalbard and TrollSat stations in the Arctic and Antarctica are very attractive to use because both stations have access to the satellite in 10-15 orbits every day and thus there will be only a short delay from observation anywhere on Earth till downlink of data to ground. In addition, Guildford and Redu were identified as potential ground stations covering central Europe. Figure 6.1 indicates the stations' field of view and satellite coverage from the ground.

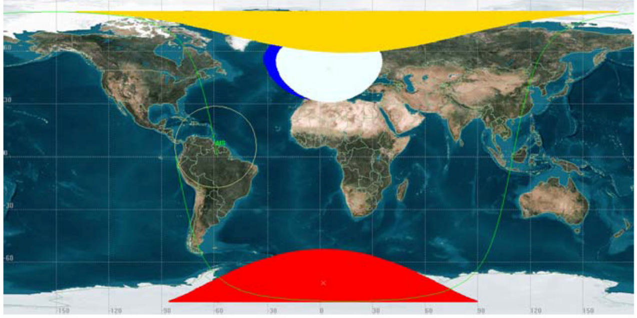


Figure 6.1 Ground Station Coverage.

Looking at the satellite platform, the SSTL-100 has been selected as heritage baseline following a trade-off in the study. Figure 6-1 shows the satellite designed in the stowed and operative configuration. The proposed solution is characterised by an extremely compact design which allows easy fairing accommodation as piggy back payload. The second view presents the platform in the operative configuration with the appendages fully deployed and the high performance solar array in final position with a slant angle of -140°.

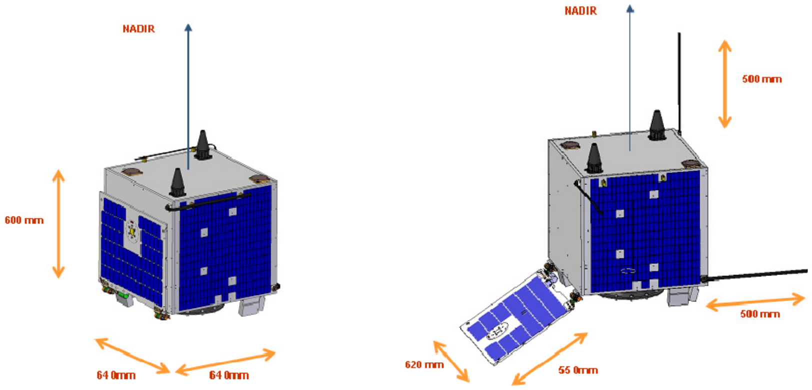


Figure 6-1: Platform Configuration: Stowed & Deployed (transparent deployed solar panel)

Figure 6-2 summarises the spacecraft block diagram.:

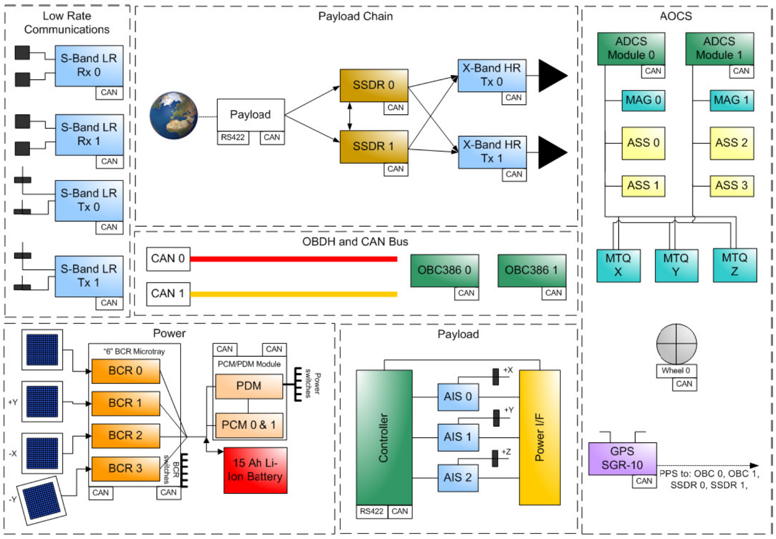


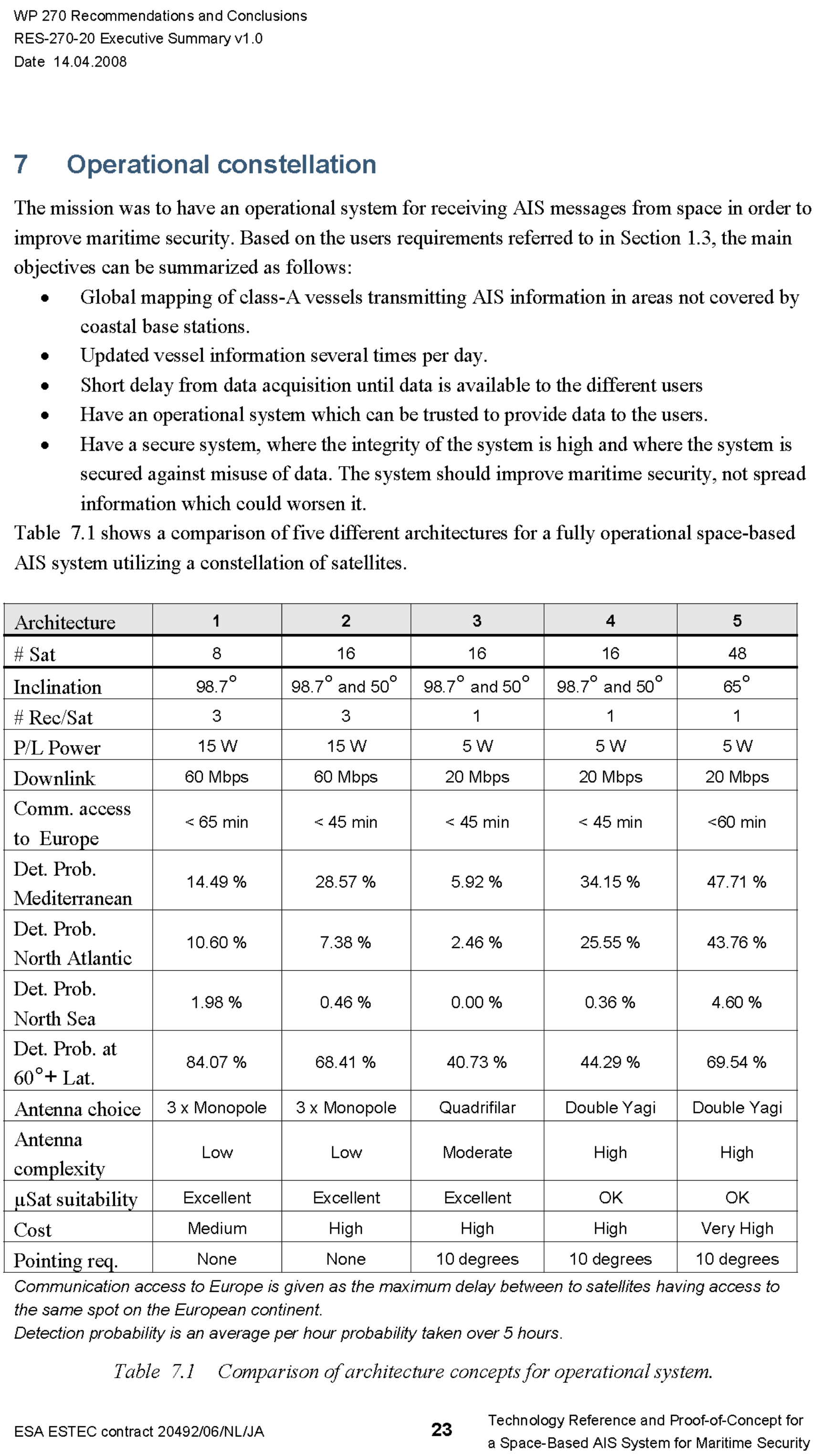
Figure 6-2: Platform Block Diagram

The mass budget is presented in the following Table 6.3.

Sub-system	Total mass [kg] NO margin	Total mass [kg] margin
AOCS	5.4	5.5
Power	11.0	11.3
Comms	11.0	11.4
Propulsion	0.0	0.0
OBDH	4.8	4.9
Environment	0.4	0.4
Structure	9.4	9.9
Harness	5.0	5.3
Payload	5.2	5.7
Sub-system total	52.1	54.4
System margin (10%)	-	5.4
Dry mass	52.1	59.8
Propellant	0.0	0.0
Launch mass	52.1	**59.8**

Table 6.3 Demonstration mission: Spacecraft mass budget.

A.8 Operational constellation



7 Operational constellation

The mission was to have an operational system for receiving AIS messages from space in order to improve maritime security. Based on the users requirements referred to in Section 1.3, the main objectives can be summarized as follows:

- Global mapping of class-A vessels transmitting AIS information in areas not covered by coastal base stations.
- Updated vessel information several times per day.
- Short delay from data acquisition until data is available to the different users
- Have an operational system which can be trusted to provide data to the users.
- Have a secure system, where the integrity of the system is high and where the system is secured against misuse of data. The system should improve maritime security, not spread information which could worsen it.

Table 7.1 shows a comparison of five different architectures for a fully operational space-based AIS system utilizing a constellation of satellites.

Architecture	1	2	3	4	5
# Sat	8	16	16	16	48
Inclination	98.7°	98.7° and 50°	98.7° and 50°	98.7° and 50°	65°
# Rec/Sat	3	3	1	1	1
P/L Power	15 W	15 W	5 W	5 W	5 W
Downlink	60 Mbps	60 Mbps	20 Mbps	20 Mbps	20 Mbps
Comm. access to Europe	< 65 min	< 45 min	< 45 min	< 45 min	<60 min
Det. Prob. Mediterranean	14.49 %	28.57 %	5.92 %	34.15 %	47.71 %
Det. Prob. North Atlantic	10.60 %	7.38 %	2.46 %	25.55 %	43.76 %
Det. Prob. North Sea	1.98 %	0.46 %	0.00 %	0.36 %	4.60 %
Det. Prob. at 60°+ Lat.	84.07 %	68.41 %	40.73 %	44.29 %	69.54 %
Antenna choice	3 x Monopole	3 x Monopole	Quadrifilar	Double Yagi	Double Yagi
Antenna complexity	Low	Low	Moderate	High	High
µSat suitability	Excellent	Excellent	Excellent	OK	OK
Cost	Medium	High	High	High	Very High
Pointing req.	None	None	10 degrees	10 degrees	10 degrees

Communication access to Europe is given as the maximum delay between to satellites having access to the same spot on the European continent.
Detection probability is an average per hour probability taken over 5 hours.

Table 7.1 Comparison of architecture concepts for operational system.

As can be seen from the table, none of the architecture options meet the user requirement of hourly update rates with 100 % detection probability in the chosen areas. This may be because of the conservative simulations and payload detection probability properties assumed in this project. Thus the first natural step should be to get more knowledge on actual detection probabilities through a demonstration project.

Looking at the numbers in the table, one can see that the double Yagi is the only antenna solution with significant detection probability in both the Mediterranean and the North Atlantic. The narrower field of view, which increases the detection probability, also requires more satellites in the constellation to cover the same areas as the antenna solutions with field of view to the horizon. This and the inclination is also the reason why the detection probability in areas of relatively low vessel density, like north of 60° latitude, is higher for the triple monopole solutions than for the other solutions. This would also suggest that a demonstration satellite should focus on this solution as it is the most flexible, has the simplest antenna solution, has the highest detection probability in low vessel density areas, and has a nonzero detection probability in high vessel density areas. The downside is a higher demand on power and downlink capacity, but if this is a problem, a demonstration mission does not need to operate continuously and can preserve energy for use in parts of the orbits or during a dedicated measurement campaign. A demonstration satellite could also accept to downlink data over several orbits if the downlink requirements are too difficult to achieve.

It is also clearly evident that the use of circular polarisation as in the quadrifilar helical solution gives the worst detection probability in all the given areas

Figure 7.1 shows the double Yagi constellation with 48 satellites

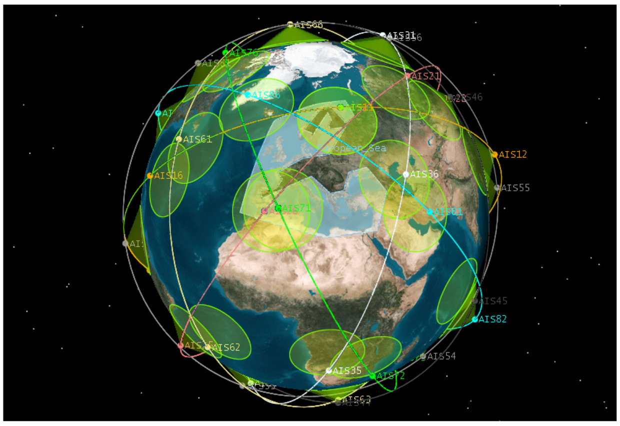


Figure 7.1 Double Yagi, 48 satellites constellation

A.9 Conclusion

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8 Conclusion

The study shows that space-based AIS is feasible in many areas of the globe, but that the challenge still remains in areas with high vessel density like the North Sea. As an operational system will depend on the willingness from stakeholders to commit to such a project, the first step should be to conduct the proposed demonstration mission to test the concept and establish the best mitigation techniques for simultaneously received messages.

A phase A mission study for the demonstration mission should be started as well as a development study for bringing the payload from the current technology readiness level 3 to the required technology readiness level 5 for on-orbit demonstrations. These studies could be started at the same time if the payload developer was included also in the mission study. The major steps for the payload would be to improve the algorithm used for GMSK decoding and establish a system of three receivers which also can handle simultaneous sampling in a DBP mode.

It is strongly recommended to go through a demonstration mission before planning a full operational system, unless someone in the meantime can prove that they have solved all problems with simultaneous arrival of AIS messages over busy European waters. A thorough understanding of the limitations of a system is important for any user within the maritime security domain, as the information or missing information provided by the system will effect security related decisions if the system is used operationally.

While a double Yagi antenna will improve detection probability it would also need more satellites to cover the same areas as simple monopole or dipole antennas. So far, simulations show that only a 3rd dedicated AIS frequency for space reception would give a true global coverage, but then, even with simple antennas.

List of acronyms

AIS	Automatic Identification System
BP	Bent Pipe
DBP	Digital Bent Pipe
DG FISH	Directorate General for Fisheries and Maritime Affairs
DG TREN	Directorate General for Energy and Transport
EMSA	European Maritime Safety Agency
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FOV	Field of View
GMES	Global Monitoring for Environment and Security
GMSK	Gaussian Minimum Shift Keying
LEO	Low Earth Orbit
LRIT	Long Range Identification and Tracking
SDR	Software Defined Radio
SOTDMA	Self Organizing Time Division Multiple Access
VHF	Very High Frequency