AIS System Study for Maritime Safety:

Executive Summary

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Author:	P. Simionato	TPZ	
Verified:	P. Simionato	TPZ-SAS	
Approved:	A. Scorzolini	TPZ-AG	

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1. AIS PROJECT OVERVIEW

1.1 Project Context and Background

The Automatic Identification System (AIS) is a maritime safety and vessel traffic system developed by the International Maritime Organization (IMO) and the International Telecommunications Union (ITU).

The AIS was introduced as a mandatory anti-collision system for IMO SOLAS (Safety Of Life At Sea) vessels: primarily merchant vessels over 300GT and passenger vessels on international voyages. The AIS is used by ships and traffic services to identify and locate vessels: the AIS transfers data over the VHF (Very High Frequency) link and enables AIS equipped vessels and shore-based stations to send and receive identification information that can be displayed on an electronic chart, computer display or compatible radar. This information can help in situational awareness to assist in collision avoidance and also providing location and additional information on buoys and lights. The AIS is widely recognized as an indispensable tool for maritime administrations especially along the coast lines so the numbers of AIS equipped vessels and transmitting Base Stations (BS) along the coast is expected to rapidly increase worldwide.

The AIS utilizes 2 dedicated VHF channels to transmit and receive data and the radio coverage range is dependent on the height of the antennas; it is possible to "see" around bends and behind islands if the landmasses are not too elevated. As being a terrestrial-based system, the actual AIS is limited to identify vessels up to 40 nautical miles far from the coasts and in same case from highly elevated base stations the coverage area may be up to 60-80 nautical miles.

Global maritime surveillance capability is one of the key elements to improve the security of people and infrastructure, the safety of life at sea, and to preserve the maritime environment: the worldwide coverage is strongly required from AIS users but being the ships velocity very slow the information on the traffic distribution could be refreshed and updated not continuously but periodically.

Recent studies have investigated the possibility of receiving AIS signals also from the space (up to 1000 Km): a constellation of satellites using the same AIS transponders on the ships but with a dedicated satellite AIS receiver could assure an AIS worldwide coverage. The SAT AIS could provide a strategic infrastructure in order to increase the maritime awareness and in particular the maritime surveillance: it could cover existing gaps of the terrestrial AIS providing global coverage, it could be integrated with LRIT (Long Range Identification and Tracking) data increasing the vessel detection capability and it could be integrated with Earth Observation data in order to identify not-cooperative or suspicious vessels.

From the Integrated Maritime Policy, it is evident how also the AIS reception from satellite is considered as an attractive option. However, the above mentioned Policy highlights a technical limitation because of the difficulty of distinguishing individual ships if more than one is transmitting at the same time. A study on this problem of collision shall be carried on, together with new system design devoted to increase the performances of legacy systems, extend their coverage capability and provide the Users community with an additional data source to overcome problems related to the limited coverage capabilities of terrestrial systems.

The availability of AIS data could be then extended from coastal seas to the entire globe, giving the possibility to go towards a more interoperable surveillance system to bring together existing monitoring and tracking systems used for maritime safety and security, protection of the marine environment, fisheries control, control of external borders and other law enforcement activities.

1.2 The "AIS System Study for Maritime Safety" Scope

The scope of this study was to define the characteristics of a worldwide space-based AIS system, carrying out the mission design with a possible architecture and with associate cost model. Starting from User Requirements and from some Use Cases in specific Key Areas (with related traffic distribution model) a set of scenarios and associated system requirements have been defined. The study has achieved, after an end to end system performance analysis, the definition of a technically optimized space-based AIS system compliant with the consolidated user requirements, moreover a feasibility analysis was performed to embark Earth Observation (EO) sensors as a non-cooperative information source to complement AIS data.

The AIS study was carried out by a team led by Telespazio (TPZ) with Carlo Gavazzi Space (CGS), EDISOFT, Information Technologies Services (ITS) and ELMAN as industrial partners with a well assessed experience in the maritime fields, especially in the AIS aspects.

2. AIS USE CASES, USER REQUIREMENTS AND SCENARIOS

2.1 Use Cases

Specific Use Cases have been identified in order to increase the understanding on service characterization on specific areas:

- **Atlantic**. The Atlantic Ocean is frequently recognized as an urban ocean. Satellites AIS may detect vessels when they are still out of range from the coastal systems
- **Africa Indian**. The area is strongly affected by piracy. Many countries and organization are interested in technologies which may help contrasting piracy.
- **Arctic**. Melting of the Arctic ice cover has allowed new shipping routes.
- **Mediterranean**. Maritime transport is of fundamental importance, particularly to Europe and the rest of the world.

The table below lists the key requirements for potential Satellite AIS applications related to specific area of interest.

Applications	Minimal Reporting time (95% of ships)	Maximum delay
Africa Indian Use Case		
Fishing surveillance	1-2 hours	3 hours
Piracy fighting	1 hour	1-2 hours
Hazardous Cargo monitoring	1 hour	1-2 days
Commercial vessel monitoring	3 hours	4 hours
Atlantic Use Case		
Commercial vessel routes tracking	3 hours	4 hours
Environmental disasters and/or violations	1 hours	1-2 days
Illegal Fishing	1-2 hour	3 hours
Arctic Use Case		
Fishing surveillance	1-2 hours	3 hours
Hazardous Cargo monitoring: vessel tracking application	2-3 hours	4 hours
Hazardous Cargo monitoring: oil spill detection	1 hour	1-2 days
Commercial vessel monitoring	3 hours	4 hours
Mediterranean Use Case		
Fishing surveillance	1-2 hours	3 hours
Vessel Traffic System	6 hours	8 hours
Commercial cargo monitoring	3 hours	4 hours

Tabella 1: Use Case Service Requirement

The User requirements, and the Uses Case applications in specific key areas have been the main inputs for designing the space-based AIS system.

2.2 User requirement Consolidation

Information collected from Core Users, concerning their needs and demands from a satellite-based AIS system, was mapped onto technical and qualitative requirements for the present study specifications matching. The fulfilment of the stated requirements is fundamental to properly for designing the space-based AIS system and will cover the AIS needs worldwide including as a minimum:

- Services and applications to be provided (including service characterization).
- Vessels distribution and vessels characterization.
- Required service performances (e.g. reporting time interval, ship detection probability) in the identified use cases.
- AIS data collection, operational requirements and utilization policy.
- Possible data fusion requirements.

The information collected to derive the Users Requirements has been based on direct contacts with users (Interview/questionnaire) and on the experiences with the relevant users involved in Maritime Security Services. This can represent a criticality to derive the system requirements and system architecture design. The final requirements were consolidated with the user requirements defined by Steering Committee.

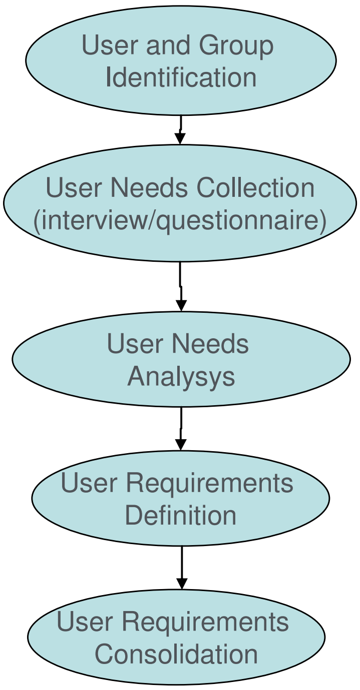


Figura 1: User Requirement Definition

2.3 Key User Requirements

The key User Requirements are listed in the table below:

Requirement	Definition	Value
Time update interval	Time interval between the availability in the data archive centre of the AIS data from 2 consecutive AIS messages sent by a specific vessel, which are correctly detected.	• max 3 hours (mandatory) • max 1 hour (desiderable)
Timeliness	Time interval between detection of the AIS message (N) by one of the satellites of the space segment and the availability of the AIS data retrieved from the message (N) in the data archive centre on ground. It comprises the time required for processing the AIS message and retrieving the data content on board the satellite, and the time for transmitting the data relevant to the received message to the closest ground station.	• max 1 hour (mandatory) • max 30 min. (desiderable)
Detection	Detect all Class A(*) and Class B (**) vessels transmitting AIS signals	•(*) mandatory for all Class A •(**) desirable for all Class B
Coverage	Detect the AIS messages transmitted by vessels	• Worldwide

Tabella 2: Key User Requirements

Moreover the AIS system should assure the sustainability of the traffic growth during the SAT-AIS mission lifetime (15 years).

2.4 System scenarios

Starting from User Requirements and the Use Cases with related traffic distribution model a set of scenarios and associated system requirements have been defined. Specific requirements are defined following the Regulatory Issues. The System requirements are grouped as follows:

- Requirements regarding mission and functional requirements, aspects on Space, Ground, Service and Launch Segments, and that are applicable to all the selected scenarios;
- Requirements characterized by specific targets in terms of complexity, cost and performances.

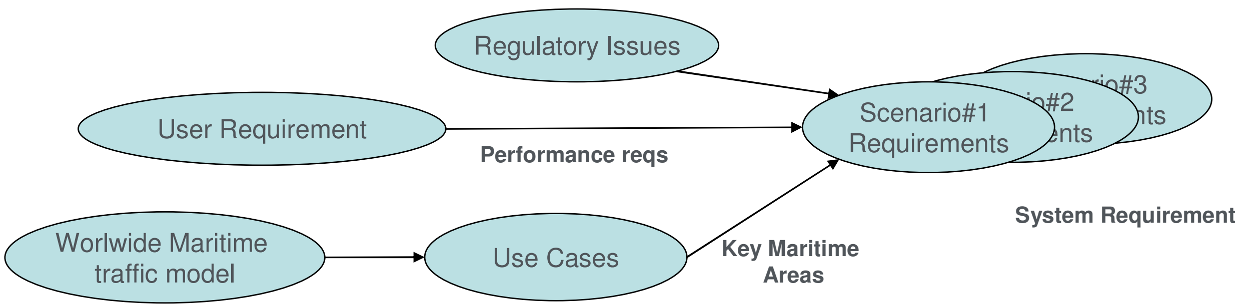


Figura 2: System Requirement Definition

Each System Scenario was identified by choosing a set of user requirements to be fulfilled. In particular, the cost is different for each scenario, and regulates the configuration of the overall system: data output performances and distribution, flexibility and modularity of the system, complexity and performances of the satellite and its payload, and the locations of the Ground Segment. The area covered is always global.

The constellation architecture design is strongly related to the ship probability detection allowable by the Payload, mainly related to the number of passages over the same area during the required Time Update Interval.

3. AIS SYSTEM DESIGN AND BASELINE DEFINITION

3.1 AIS Mission

The following figure shows the elements of the AIS mission:

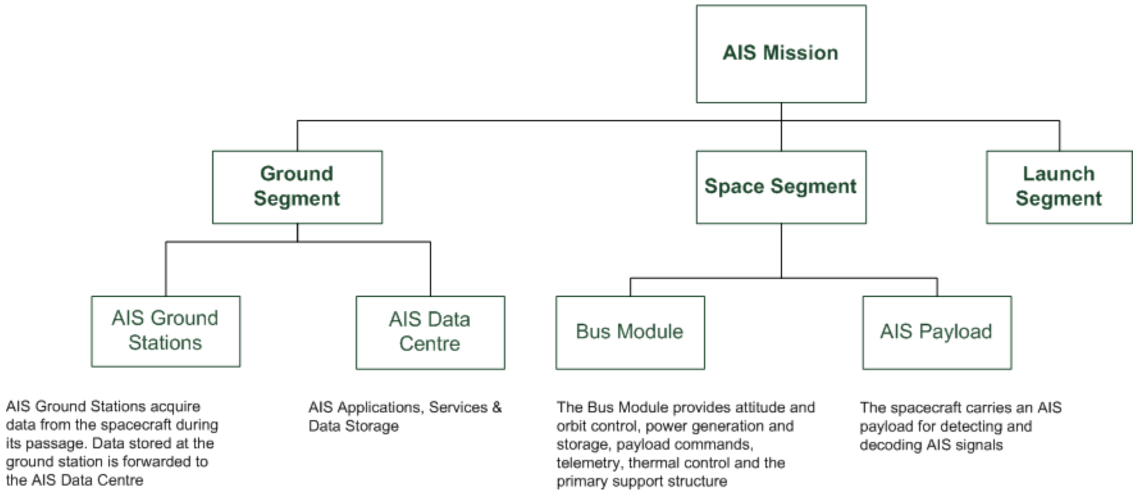


Figura 3: AIS Mission Elements

The Space Segment consists of a constellation of satellites in a low-earth orbit. Each spacecraft in the constellation consists of a Bus Module and an Automated Identification System for ships (AIS) payload. In essence, the AIS payload receives the AIS messages from the ships in a wide swath and downlinks the data to the Ground Segment. The Bus Module is the primary support platform, which provides attitude and orbit control, power generation and storage, exchange of commands and telemetry with the Ground Segment, and thermal control.

In regard to the allocation of the detection and decoding capabilities the Onboard processing option was considered. All received AIS signals are pre-processed at the LEO satellite by means of a Processing Unit, which detects and decodes the signals to extract the related message segment. The extracted message segments (Decoded AIS Data) are down linked to the AIS Ground Stations. Since the decoded message segments can include classified information that must be kept secure, encryption can be employed prior to modulation. In this case the Ground Station includes a decryption module to decrypt the received data to recover the original decoded message segments.

The Ground Segment is based on the existing Ground Segment. It consists of a Ground Control System, AIS Data Ground Stations and the AIS Data Centre. The Ground Control System receives the AIS data and telemetries from the satellites through the AIS Data Ground Stations and is in charge of the basic constellation operations (TT&C). The AIS Data Centre collects and stores the data received and represents the gateway to external users by implementing the application and service layers. A Digital Communication Network that provides communication between the Ground Segment components.

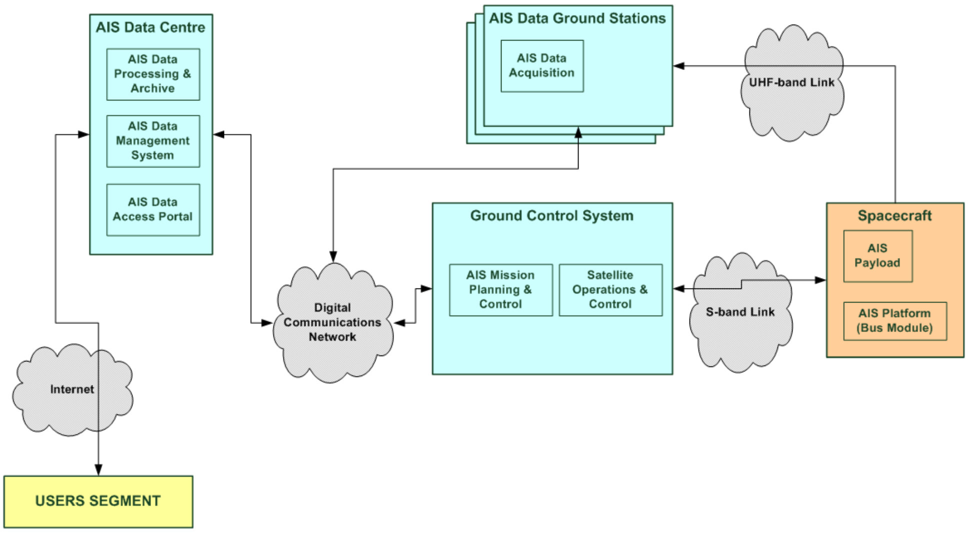


Figura 4: AIS Functional System Overview (AIS Only)

The Ground Control System and the AIS Data Centre is located at Fucino. The AIS Data Ground Stations element consists of 4 Polar Ground Stations as listed in the chart below.

Facility	Lat	Long	Height	Network
'Svalbard'	78,2	15,4	501,3	'Part of ESTRACK Augmented stations'
'Troll'	-72	3,5	1270	'Considered on a previous Satellite AIS study'
'Poker Flat'	65,1	-147,5	212	'Part of ESTRACK stations'
'Mc Murdo'	-77,9	166,7	7	'Considered in a previous AIS study'

Tabella 3: AIS Data Ground Stations

3.2 AIS Functional Overview And Concept Of Execution

The following figure shows a functional overview of the Sat AIS system. The diagram describes the interfacing entities (systems, configuration items, users, etc.).

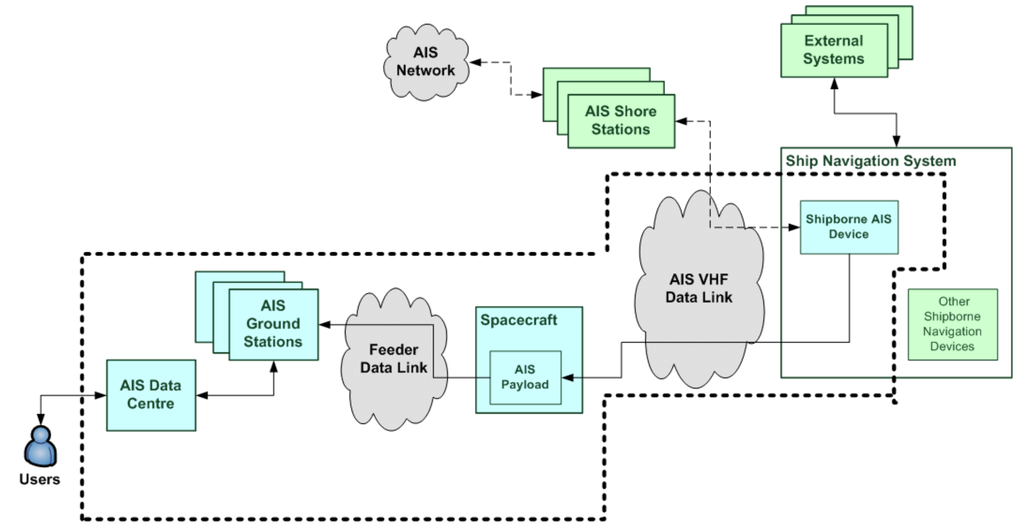


Figura 5: AIS System

The following figure shows the concept of execution among the system functions concerning the timeliness and time update interval requirements. It includes diagrams and descriptions showing the dynamic relationship of the functions, that is, how they will interact during system operation.

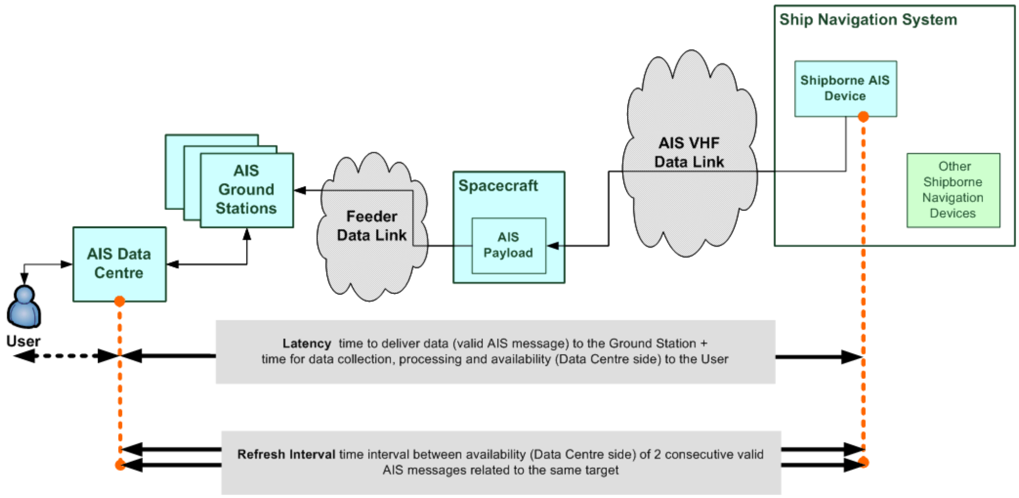


Figura 6: AIS Concept Of Execution

3.3 AIS System Overview

The following figure shows the main the main elements of the Sat AIS system.

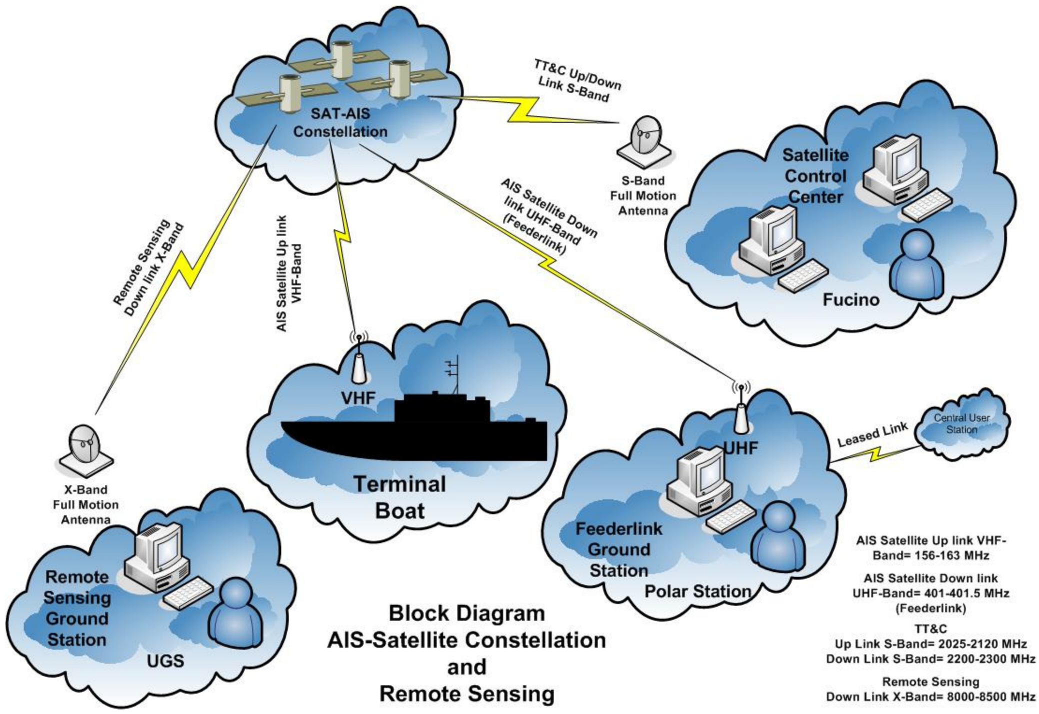


Figura 7: AIS System Overview

3.4 System Design Methodology

The system design was based on a top-down analysis, supported by end-to-end and sub-system level simulations. The analysis through simulations comprises many key aspects including the assessment of on-ground covered area, establishment of uplink and downlink, pattern analysis of the traffic originating from or terminating to the ground stations, characterization of the main system performance(Timeliness, Time Update Interval, and Detection Probability).

The following paragraphs describe are dedicated to the main tasks performed for the overall mission and system high level design.

3.4.1 AIS Constellation Design

Different constellations based on both Walker and SOC configuration models were analysed, resulting at the end in five constellation to be traded off. The characteristics of such constellations are summarised below:

- SOC constellation, based on polar orbits, constituted by 4 planes with 4 satellites per plane. The performances are the best in terms of revisit time but the spacecraft design could be a bit more complex.
- SSO-based Walker, which favour simplicity in the platforms design and in turn a greater reliability. System end-to-end performances are worse than SOC but in any

case within the requirements. The following SSO-based configurations were considered:

- SSO2: 6 satellites on 6 planes, with very low performances in terms of revisit time (about 90 minutes), but with the pros of a simple constellation, allowing multiple launches, and of very reduced costs.
- SSO4: 10 satellites on 5 planes, with higher performances (revisit time < 40 minutes over the high traffic areas) but more expensive due to more satellites and more launches, even if multiple ones.
- SSO6: 9 satellites on 3 planes, with 3 consecutive passes over the same area which should increase probability of detection, and allowing multiple launches.

The trade-offs are shown in the table below. The total score of each constellation type is determined as the weighted sum of the scores associated to each criterion.

Criteria	Weight %	SOC	Sun-synchronous configuration			Optimized for areas
			SSO2	SSO4	SSO6	
Number of Spacecrafts involved	5%	0.38	1.00	0.60	0.67	0.38
Achievable refresh time	5%	1.00	0.29	0.36	0.29	0.53
Platform Complexity	15%	0.55	0.93	0.86	1.00	0.51
Ground Segment Complexity	5%	1.00	0.87	0.67	0.72	0.33
Reliability	20%	0.67	0.56	0.67	1.00	0.44
Constellation Maintenance	5%	0.60	1.00	0.80	1.00	0.25
Technical Risks	15%	0.32	1.00	0.62	0.75	0.25
Programmatic Risks	10%	0.53	1.00	0.71	0.81	0.37
Cost (including launch)	20%	0.23	0.75	0.54	1.00	0.17
SCORE	**100.0%**	**0.51**	**0.81**	**0.66**	**0.88**	**0.35**

Tabella 4: Constellation configuration trade-off

The SS_O6 constellation seems the best candidate for the AIS system. The satellites are phased each other to achieve a symmetric configuration that in turn allows to perform homogeneous coverage.

3.4.2 AIS Spacecraft Design

The nominal AIS satellite configuration is composed by the AIS Payload and the Bus Module. The design is made following a modular approach, in order to reduce the integration time and costs; the S/C design considers the following elements:

- AIS Payload Module
- Platform Core Module
- Solar Generator Module

A set of eligible payload configurations were identified and characterized. These configurations fall in 2 main categories: digital transparent payload and onboard demodulator.

The payload architecture depends on the configuration and the number of AIS receiving antennas. Nonetheless all the options (number of antennas and number of receivers) characterized by the same configuration have the same architecture. A trade-off analysis based on payload accommodation, mass and power budgets, expected benefits has been performed and the results are provided in following table.

PEAK POWER BUDGET [W] 20% MARGIN		ANTENNA CONFIGURATION						
		1 (1+1 Helix)	2 (1+1 Patch)	3 (2-elements Patch Array)	4 (3-elements Patch Array)	5 (4-elements planar Patch Array)	6 (3 half wave crossed dipoles)	7 (2-elements Array of crossed dipoles)
RECEIVER CONFIGURATION	1 (Onboard Demod 1 Rx)	CONFIG #0.1	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED
	2 (Onboard Demod 3 Rx)	DISCHARGED	DISCHARGED	CONF #1	DISCHARGED	CONF #2	CONF #3	CONF #4
	3 (Onboard Demod 9 TBC Rx)	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	CONF #5	CONF #6	CONF #7
	4 (Digital Transparent 2 channels)	CONFIG #0.2	DISCHARGED	CONF #8	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED
	5 (Digital Transparent 3 channels)	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	CONF #9	DISCHARGED
	6 (Digital Transparent 4 channels)	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	CONF #10	DISCHARGED	DISCHARGED
	7(Digital Transparent 6 channels)	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	DISCHARGED	CONF #11

Tabella 5: Payload configuration matrix

As far as the choice between digital transparent and onboard demodulation concerns, the former is preferable - except for the technological risks due to the digital section components in the space environment, with a particular emphasis on the FPGA - for the lower impacts on the platform design. In particular the following considerations apply:

- Power budget: digital transparent solution has higher average and peak power consumptions that impacts on solar panel as well as batteries sizing, implying a platform of a class greater than the on-board solution
- Feeder link: by analyzing the bit-rate, the bandwidth, the ground segment issues, on board transmitter complexity and cost, it seems that with the transparent payload the feeder link is more complex and expensive.

Concerning the AIS antenna, the study has focused on the following configurations:

- 2-element Array of Folded Circular Ring antennas aligned along the velocity vector
- 2x2 planar array of Folded Circular Ring antennas
- 3 crossed half wave Dipoles
- 2-elements array of 3 crossed half wave Dipoles.

The analysis was focused on the impacts on the platform and on the achievable performances (e.g. Probability of Detection) determined with system simulations.

Antennas selection impacts on the platform mainly for Solar panels and batteries sizing, Accommodation issues, Launch issues. In synthesis, referring to the above table, for the payload baseline the following configurations were considered

- Conf. #5: 4 patches antenna array and on board demodulator with 9 digital receivers.
- Conf. #6: 3 half wave crossed dipoles array and onboard demodulator with 9 digital receivers.

3.5 Simulation Tools

A Simulator Tool (SAST) was developed in order to analyse the end to end performance of a Satellite based AIS System.

The development was done essentially in Matlab®, for its proven capability in simulation tools. It was also used Basic STK® software, a tool with proven results in orbits emulations and accesses of satellites, targets and ground facilities results.

The SAST architecture was driven by the capability to validate several antennas models and also to be able to implement complex scenarios (24H run, 9 satellites, 4 GS, >69.000 Vessels). SAST was divided as 3 main blocks (with well defined interfaces):

- Scenario Generation (including the Traffic Model, Satellite Model and Ground Stations Model);
- STK engine: to emulate the constellation, vessels and ground station in order to produce the visibility data to use in the analysis of communication link performance;
- Simulator Engine: to emulate the physical and logical communication link (based on the antennas behaviour along with the SOTDMA protocol and path losses).

The following figure shows the structure of the developed simulation tool:

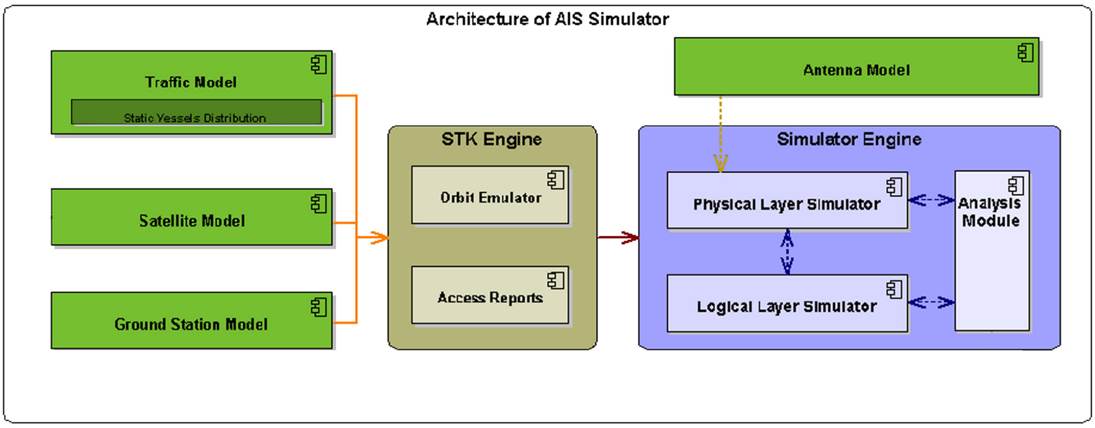


Figura 8: SAST Simulator Architecture

The following outputs are provided, which can be chosen for defined areas:

- Probability of detection for each AIS channel and for both AIS channels (for the whole constellation and per satellite);
- Revisit time per Ground Statiosn and per satellite;
- Access duration between Ground Stations and satellite;
- Number of contacts between each Satellite and Ground Stations;
- Maximum refresh time interval;
- Antenna Gain (without Polarization Losses), Faraday Rotation Plots and Antenna Total Gains including Polarization Losses;

- Global refresh time statistics for the whole constellation, ground station network and vessel distribution.

The following figures present a sample subset of the SAST outputs.

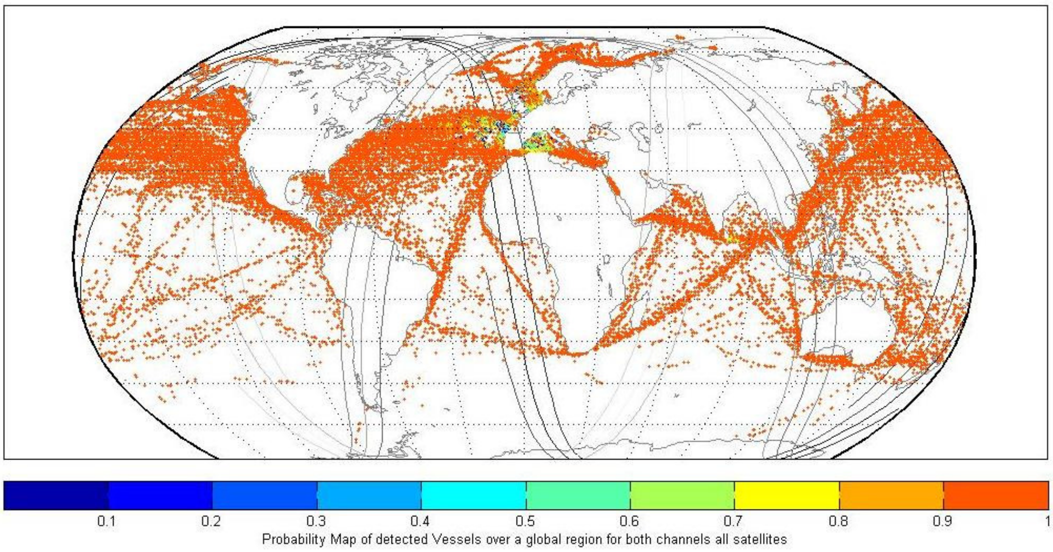


Figura 9: Scenario detection probability map for the complete constellation

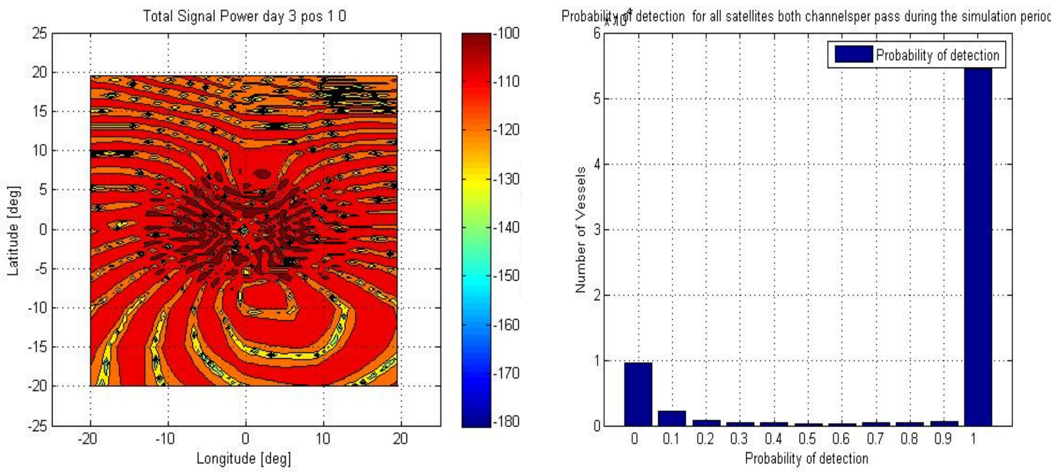


Figura 10: Total received Signal Power and Detection probability histogram

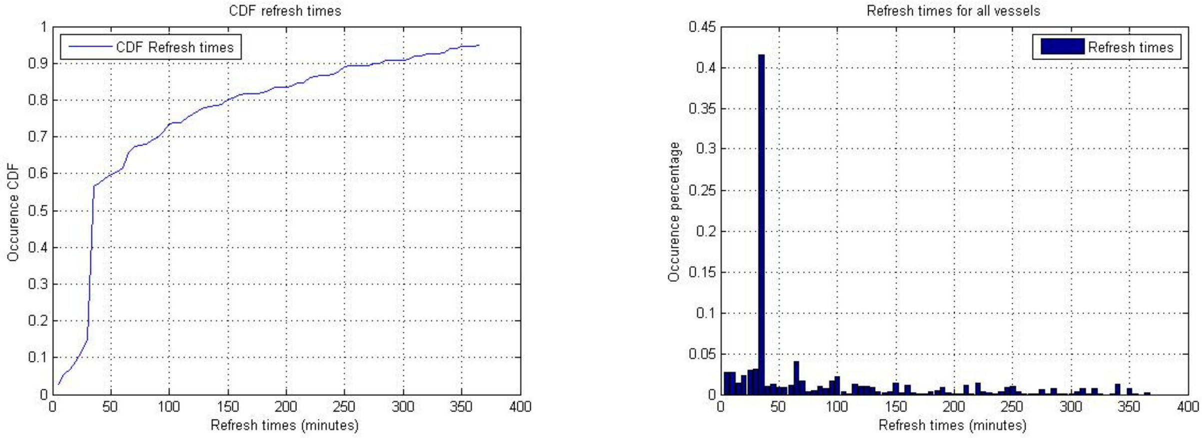


Figura 11: Refresh Time CDF and relevant histogram

4. End-to-end System performance analysis

4.1 Reference Traffic Models

A reference traffic model was generated before running the simulation test cases. The output data obtained in the computation of the total number of ships for the World Wide traffic distribution forecast 2014 is 69952 vessels. This figure is considered as the reference when running the simulations relevant to forecast year 2014.

Year/Zone	rate	2011	2013	2014	2015	2017	2019	2021	2023	2025	2027	2029
Mediterranean	13,73%	8709	9258	9545	9840	10460	11119	11819	12563	13354	14194	15088
Pacific	32,76%	20777	22086	22770	23476	24954	26525	28195	29971	31858	33863	35995
Atlantic	25,89%	16420	17454	17995	18553	19721	20963	22282	23685	25177	26762	28447
Africa /Indian	16,76%	10633	11302	11652	12014	12770	13574	14429	15337	16303	17329	18420
North Sea/Artic	10,86%	6890	7324	7551	7785	8275	8796	9350	9939	10564	11229	11936
World Wide	100,00%	63429	67423	69513	71668	76180	80976	86075	91494	97255	103378	109887

Tabella 6: Maritime Traffic - Vessels Distribution Rate & Forecast

The charts below represent in sequence the World Wide map and the borders that identify the single target zones, plus the World Wide Traffic Distribution model as implemented by the AIS System Simulator.

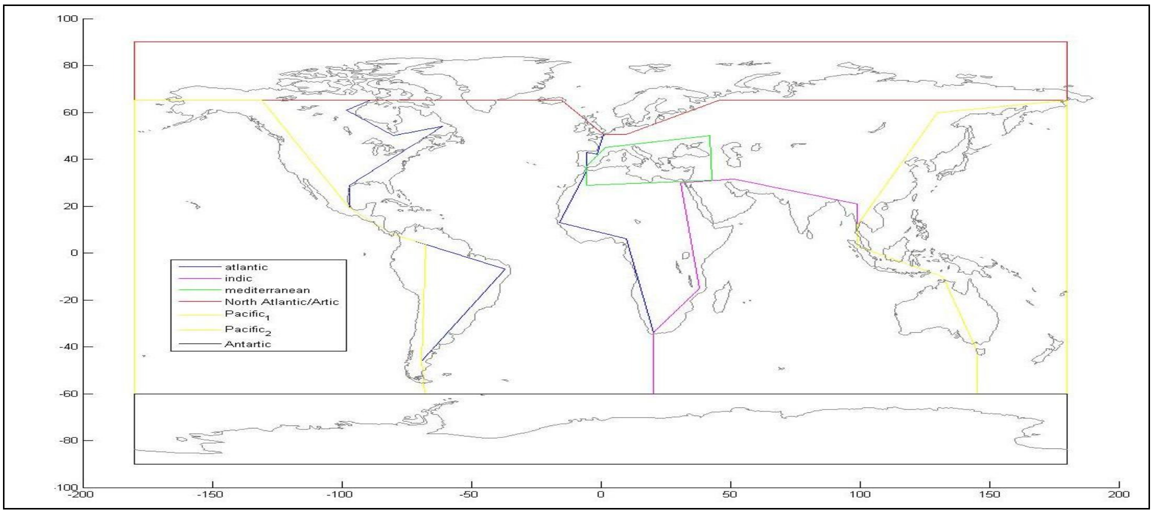


Figura 12: World Wide and Main Target Zones Map

4.2 Reference AIS Satellite Constellation

SS06 is a Low Earth Orbit (LEO) constellation comprising 9 Sun-Synchronous satellites (small to medium size) in Walker configuration 9/3/2 with an altitude of 600 Km. This SAT-

AIS constellation configuration provides a global coverage with revisit time capability of 90 minutes. The following 3D figures below show the architecture of this SAT-AIS constellation.

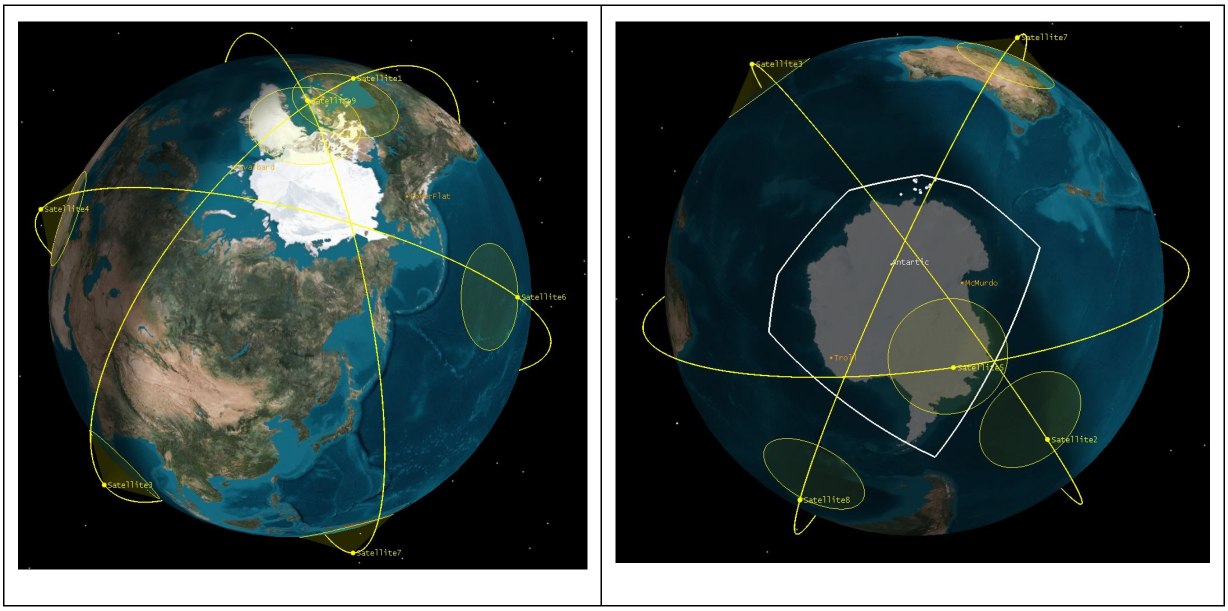


Figura 13 SS_06 Constellation

4.3 Simulation Cases

The simulation cases listed below were carried out for a World Wide vessel traffic model forecast for the year 2014 with a duration of the Antenna simulation run set to 6 hours. (W1 or W2).

The following candidate antenna systems were analysed:

- Patch_4: A 2x2 planar array of circularly polarized patches;
- 3_CrossedDipoles: 3 crossed half-wavelength dipoles;
- 2x3_CrossedDipoles: A 2-elements array of 3 crossed half-wavelength dipoles.

Case	Traffic Distribution	Forecast	Sat Network	Time Window	Antenna Type	GS Network	Scope
2	World Wide	2014	SS_02 (6 satellites)	W0		GS_03	Provide STK engine data for 24 hours
2c-1	See 2	See 2	See 2	W1	Patch_4	See 2	Analyse System Performance of Patch_4 antenna configuration for a 6-hour window
3	World Wide	2014	SS_06 (9 satellites)	W0		GS_03	Provide STK engine data for 24 hours
3a-1	See 3	See 3	See 3	W1	3Crossed Dipoles (27 patterns)	See 3	Analyse System Performance of 3Crossed Dipoles Antenna configuration for a specific 6-hour window
3b-1	See 3	See 3	See 3	W1	2x3Crossed Dipoles (27 patterns)	See 3	Analyse System Performance of 2x3Crossed Dipoles antenna configuration for a 6-hour window
3c-1	See 3	See 3	See 3	W1	Patch_4	See 3	Analyse System Performance of Patch_4 antenna configuration for a 6-hour window
3a-2	See 3	See 3 (ATL)	Sat No. 8 (See 3)	W1 (1st Orbit)	3Crossed Dipoles (full)	See 3	Analyse System Performance of 3Crossed Dipoles antenna configuration for a 6-hour window
3b-2	See 3	See 3 (ATL)	Sat No. 8 (See 3)	W1 (1st Orbit)	2x3Crossed Dipoles (9 patterns-45°)	See 3	Analyse System Performance of 2x3Crossed Dipoles antenna configuration for a 6-hour window
3c-2	See 3	See 3 (ATL)	Sat No. 8 (See 3)	W1 (1st Orbit)	Patch_4	See 3	Analyse System Performance of Patch_4 antenna configuration for a 6-hour window
3c-3	See 3	See 3	See 3	W2	Patch_4	See 3	Analyse System Performance of Patch_4 antenna configuration for a 6-hour window

Tabella 7: Simulation Cases (Vessel Traffic model forecast for year 2014)

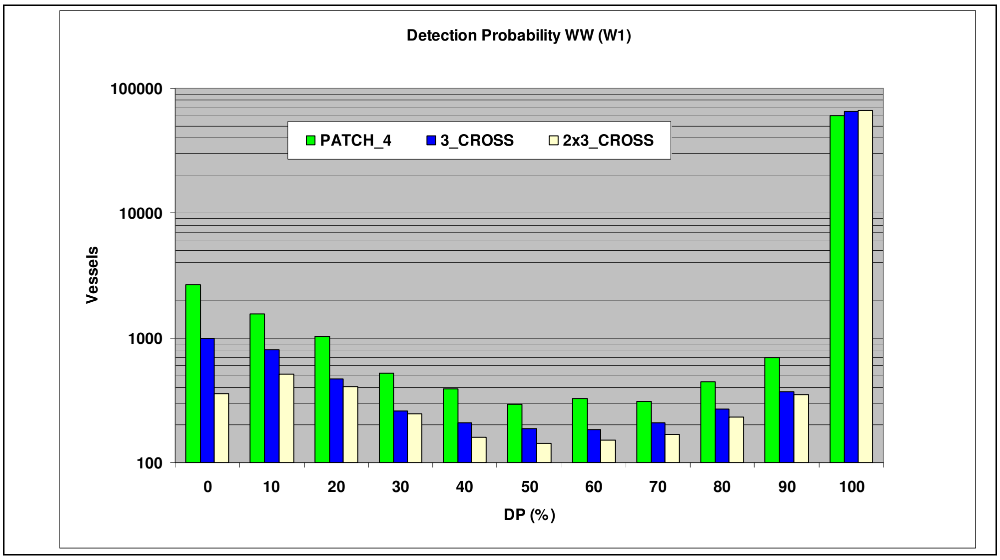
Further investigations were conducted in order to assess the capabilities of the SS_06 configuration in the operational scenario relevant to a Vessel Traffic model forecast for the year 2021. These runs were carried out for a World Wide vessel traffic model with a duration of the Antenna simulation run set to 12 hours (W3).

Case	Traffic Distribution	Forecast Year	Sat Network	Time Window	Antenna Type	GS Network	Scope
4	World Wide	2021	SS_06 (9 satellites)	W0		GS_03	Provide STK engine data for 24 hours
4c-1	See 4	See 4	See 4	W3	Patch_4	See 4	Analyse System Performance of Patch_4 antenna configuration for a 12-hour window

Tabella 8: Simulation Cases (Vessel Traffic model forecast for year 2014)

4.4 Detection Probability

The charts below summarize the performance concerning the Detection Probability capabilities according to the type of antenna. The analysis is carried out for the global World Vessel Traffic model forecast for the year 2014.

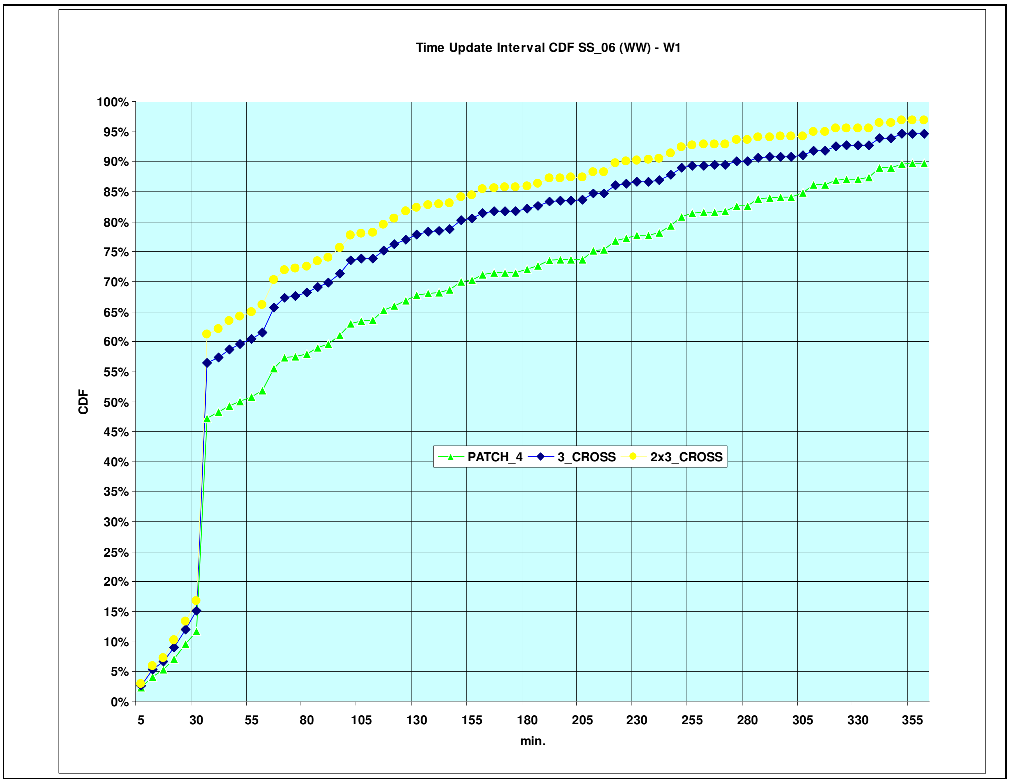


	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	ΣVess.	ΣVess. DP<>0%	%
PATCH_4	2646	1562	1029	524	390	296	327	312	447	697	60781	69011	66365	96,17
3_CROSS (+)	994	805	465	261	207	189	184	208	266	373	65059	69011	68017	98,56
2x3_CROSS (+)	355	511	402	247	160	142	150	169	232	353	66290	69011	68656	99,49
(+) redux-27 patterns														

Figura 14: Detection Probability SS_06 (WW) – W1

4.5 Time Update Interval

The charts below summarize the performance concerning the Time Update Interval capability (time between two AIS messages transmitted by the same vessel, which are correctly detected) according to the type of antenna. The analysis is carried out for the global World Vessel Traffic model forecast for the year 2014.



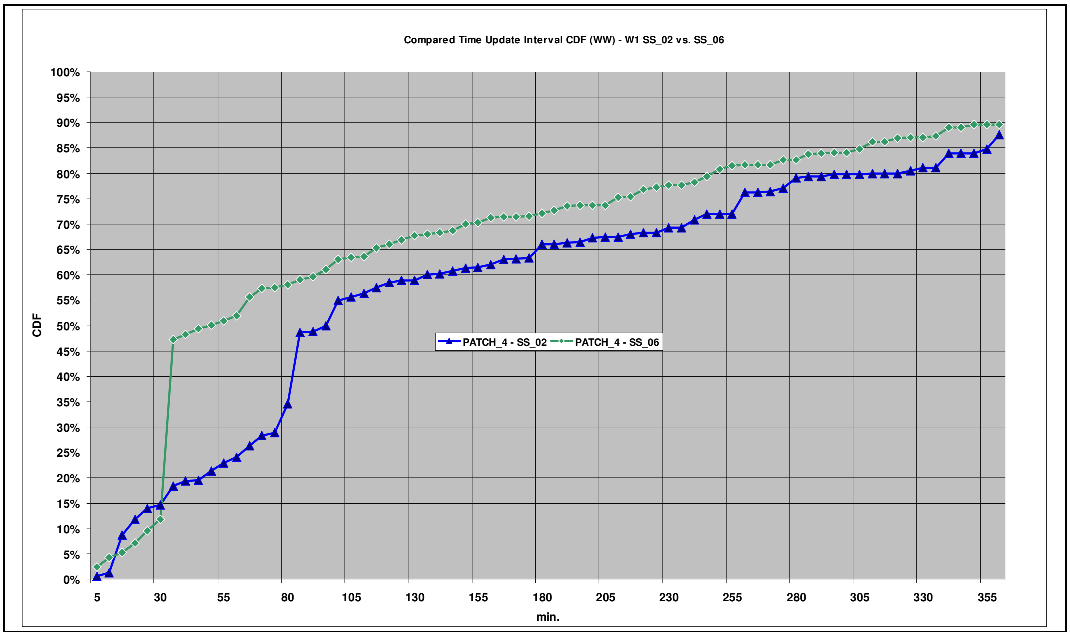
	5	30	55	80	105	130	180	230	255	305	330	355
3_CROSS (+)	2,73	15,13	60,42	68,14	73,81	77,89	82,17	86,63	89,26	91,14	92,67	94,64
2x3_CROSS (+)	3,00	16,75	64,96	72,55	78,00	82,38	85,94	90,26	92,76	94,27	95,51	96,87
PATCH_4	2,35	11,78	50,87	57,99	63,51	67,72	72,07	77,69	81,48	84,83	87,07	89,68
(+) redux-27 patterns												

Figura 15: Compared Time Update Interval CDF SS_06 (WW) -W1

Time Update Interval SS_06 (WW) – W1	% Updates [60 min]	% Updates [180 min]
3_CROSS	61,55	82,17
2x3_CROSS (+)	66,15	85,94
PATCH_4	51,92	72,07
(+) redux-27 patterns		

Tabella 9: Time Update Interval Performances SS_06 (WW)

To evaluate the Time Update Interval capability, the outcome of the test cases concerning the AIS constellation was analysed by comparing the Time Update Interval performance parameters of satellite configuration SS_02 and SS_06. In this evaluation being the Vessel Traffic, the antenna type (PATCH_4) and the Simulation time window the same; the comparison is done between two satellite configurations having 6 satellites (SS_02) and 9 satellites (SS_06).



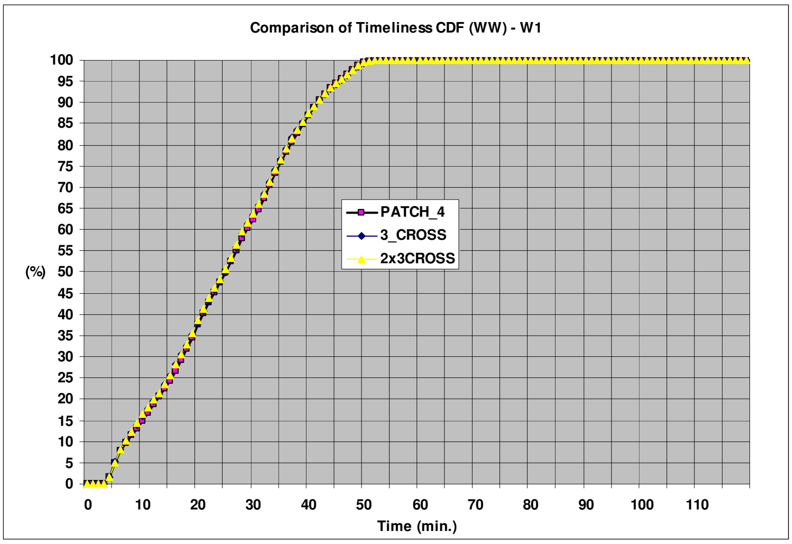
PATCH_4	5	30	55	105	130	180	230	255	305	330	355
SS_02	0,56	14,66	22,96	55,67	58,93	65,95	69,26	72,03	79,78	81,14	84,80
SS_06	2,35	11,78	50,87	63,51	67,72	72,07	77,69	81,48	84,83	87,07	89,68

Time Update Interval (WW) – W1	% Updates [60 min]	% Updates [180 min]
SS_02	24,01	65,95
SS_06	51,92	72,07

Figura 16: Compared Time Update Interval CDF (WW) - PATCH_4 W1 SS_02 vs. SS_06

4.6 Timeliness

The charts below summarize the performance concerning the Timeliness capabilities (time interval between detection of the AIS message by one of the satellites of the AIS constellation and the availability of the AIS data retrieved from the message in the data archive centre) according to the type of antenna. The analysis is carried out for the global World Vessel Traffic model forecast for the year 2014.



	Average (min.)	% (30 min.)	% (60 min.)
3_CROSS (+)	25,22	63,46	100,00
2x3_CROSS (+)	25,12	63,69	100,00
PATCH_4	25,47	62,37	100,00

Figura 17: Compared Timeliness CDF SS_06 (WW) – W1

4.7 Detection & Coverage Performances

In regard to the Vessel Traffic Coverage capabilities the outcome of the test cases concerning the AIS constellation is listed in the following charts which list the Vessel Traffic Coverage performance parameters relevant to SS_06 configuration by antenna type. Note that the figures relevant to the Σ Ships detected parameter give the number of ships in the current traffic distribution for which at least one AIS message was successfully detected.

	PATCH_4	3_CROSS (+)	2x3_CROSS (+)
Ships detected	62646 (90.78%)	66094 (95.77%)	67227 (97.41%)
Ships not detected (0)	6365 (9.22%)	2917 (4.23%)	1784 (2.59%)
Ships detected (1)	8582 (12.44%)	4973 (7.21%)	3707 (5.37%)
Ships detected (>1)	54064 (78.34%)	61121 (88.57%)	63520 (92.04%)
Messages exchanged	422224	536383	581838
Contacts x ship (*)	6,1	7,8	8,4
Contacts x ship detected (*)	6,7	8,1	8,7
Contacts x sat (*)	46913,8	59598,1	64648,7
Contacts x sat x orbit (*)	11728,4	14899,5	16162,2
Bandwidth x sat x orbit (*) [kbit/s]	4,341	5,514	5,982
Timeliness (*) [min]	25,5	25,2	25,1
(*) Average			
(+)_redux-27 patterns			

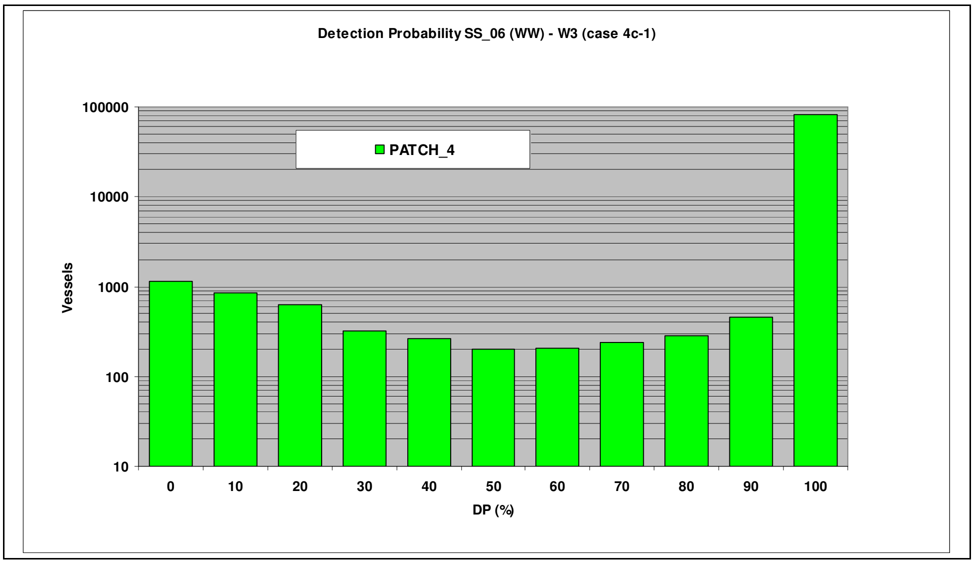
Tabella 10: Detection Performance SS_06 (WW) – W1

4.8 Performances for the 2021 World Wide Scenario

Further investigations on the end-to-end performance of the AIS System were conducted in order to assess the capabilities of the SS_06 configuration in the operational scenario relevant to a Vessel Traffic model forecast for the year 2021.

The analysis was carried out for a World Wide vessel traffic model forecast for the year 2021 with a duration of the Antenna simulation run set to W3 (12 hours).

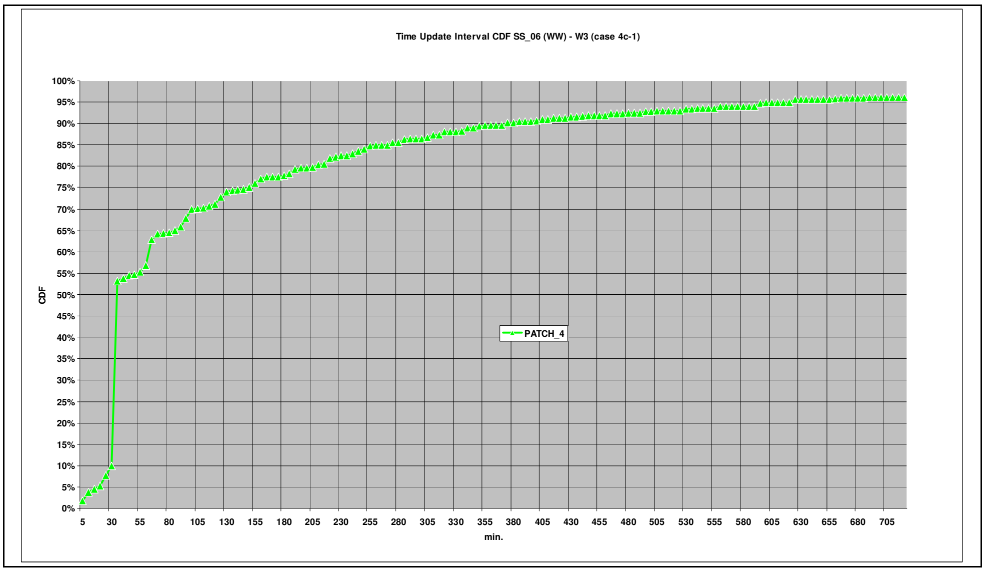
The charts below summarize the AIS Constellation performance concerning the Detection Probability capabilities specific to the PATCH_4 type of antenna.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	ΣVess.	ΣVess. DP<>0%	%
PATCH_4	1157	842	625	320	260	200	205	238	287	459	81860	86453	85296	98,66%

Figura 18: Detection Probability SS_06 (WW) – W3 (Case 4c-1)

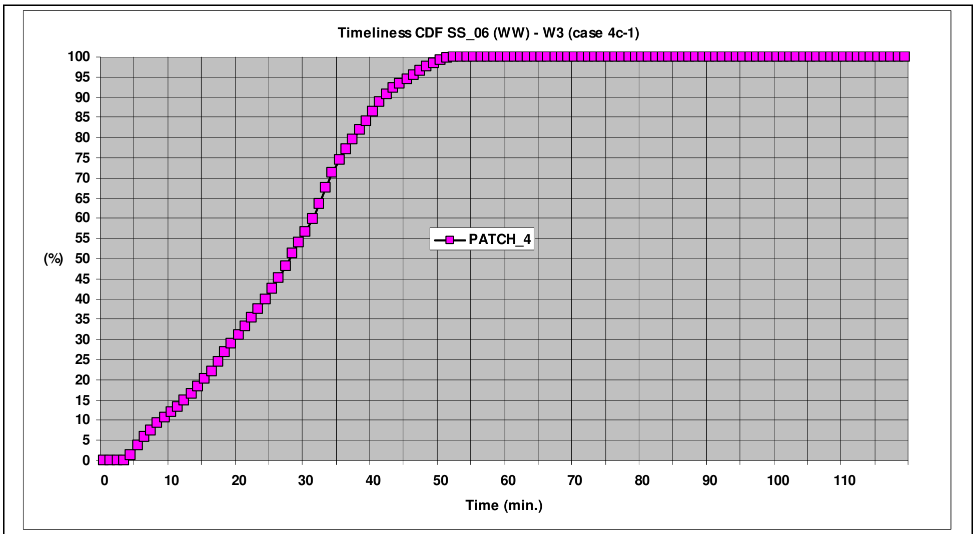
The charts below summarize the AIS Constellation performance concerning the Time Update Interval capability specific to the PATCH_4 type of antenna.



W3 (Case 4c-1)	5	30	60	130	180	230	255	305	330	360
PATCH_4	1,87%	10,01%	56,79%	74,08%	77,79%	82,43%	84,71%	86,65%	88,13%	89,52%

Figura 19 Time Update Interval CDF SS_06 (WW) - W3 (Case 4c-1)

The charts below summarize the AIS Constellation performance concerning the Time Timeliness capability specific to the PATCH_4 type of antenna.



Average (min.)	% (30 min.)	% (60 min.)
26,96	56,68	100

Figura 20: Timeliness CDF SS_06 (WW) – W3 (Case 4c-1)

4.9 Variations of Statistics

These analysis were focused on the comparison of the performances in order to assess the variation of the statistics concerning the Detection Probability and the Timeliness performances. The simulations were executed out for the global World Vessel Traffic model forecast for the year 2014 for 2 different simulation 6-hour windows (W1 and W2).

The charts below summarize the performance concerning the Detection Probability and the Timeliness capabilities specific to the PATCH_4 type of antenna.

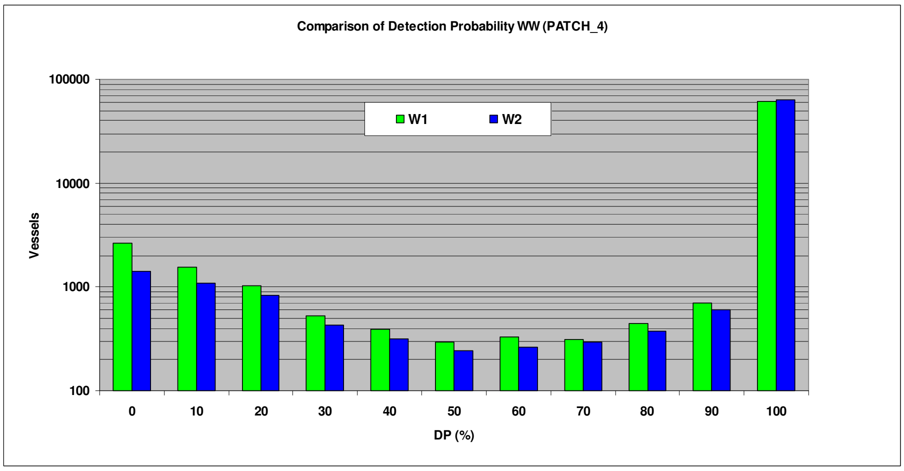
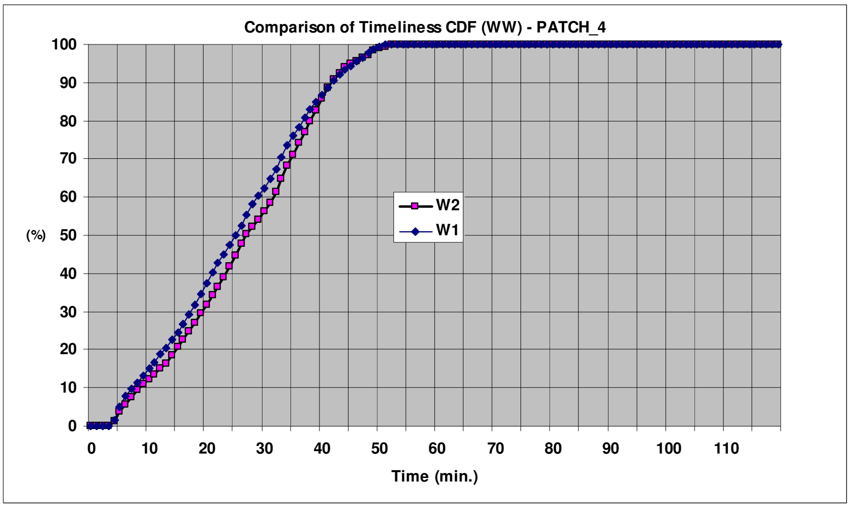


Figura 21: Compared Detection Probability SS_06 (WW) - PATCH_4



PATCH_4	Average (min.)	% (30 min.)	% (60 min.)
W1	25,47	62,37	100,00
W2	27,01	56,27	100,00

Figura 22 Compared Timeliness CDF SS_06 (WW) - PATCH_4

4.10 Coverage Analysis

A geometrical visibility analysis was carried out by evaluating the access duration and the number of contacts of the constellation with each point of a grid that covers the entire globe.

Too asses the coverage performance of AIS satellite constellation SS_06 over a global region of interest STK was used to simulate the satellite constellation in order to obtain to map the duration of the contacts between the points of a vessel grid and the constellation (9 satellites). The mapping was performed over 2 different 6-hour windows (W1 and W2) and then a comparison was made between the relevant figures of merit:

- Access Duration: the intervals during which coverage is available from a single asset;
- Number of accesses: the number of independent accesses of the assets to the points of the grid.

	W1			W2		
	Min	Max	Ave	Min	Max	Ave
Number of Access	7	35	14.228	7	35	14.230
Access Duration (sec)	434.422	734.423	592.717	440.027	734.523	592.654

Tabella 11 Results Of Coverage Analysis

Concerning the coverage performances of constellation SS_06 associated with the observation time windows, the results listed in the table above show that the figures of merit are almost the same for the two windows considered.

4.11 Conclusions And Recommendations

The outcome of the analysis indicates that from a geometrical point of view the satellite constellation SS_06 has the same coverage performance at the grid points regardless of the two considered observation time windows W1 and W2.

On the other hand, the uncertainty of the results of the statistical processes over W1 and W2 compared to the coherency of the results of the geometrical coverage indicates that the statistical processes are not sufficiently meaningful in a 6-hour simulation window.

Overall, the degree of uncertainty on the statistical meaningfulness of the results (time update interval) does not allow a definitive conclusion on the proposed technologies. A more complete analysis focused on the statistical part would require modifications on the simulation software and a significant amount of time to perform a large number of test runs.

5. AIS FIRST ELEMENT MISSION

The AIS First Element mission aims at demonstrating in flight the system performance and functionalities of the AIS system. A first part of the full mission, elements are deployed and a period of verification and tests is performed, both at element and system (reduced) level. The main mission objectives driving the design of the AIS First Element mission can be summarised as follows:

- Demonstrate the capabilities/performances of AIS system in a defined target area
- Demonstrate the technology of the AIS payload
- Flight test of the overall satellite in nominal configuration
- Test of the nominal Ground Segment architecture (even if with less elements)
- Test of the Nominal Service performance
- Cost efficient precursor -> design and development plan shared with the complete Sat-AIS system
- Eventually test of integration of a non cooperative EO Payload increasing service performances

These goals can be achieved with a single mission split into 2 sequential phases, each with different purposes and use cases, where the space segment architecture (a subset of the baseline AIS constellation) remains the same, while the ground segment grows from a non-nominal to a subset of the nominal one.

5.1 First phase as Demo Mission:

- Test the receiver performance on High Traffic Zone with a reduced visibility time window.
- Functional and performance test of the Ground Segment.
- Mediterranean Use Case
- Compliance with scaled System Mission performance requirements
- Space segment options: one, or more – e.g. two, three - satellites; the former allows to reduce short term costs and/or is preferable in case of high risks connected to the Payload development. The latter, which relates to a multiple launch possibility, can be seen as a solution to get better system performances.
- Single Ground Station, in the Arctic area (baseline Svalbard) or in the Mediterranean area, for improving AIS data timeliness and refresh time.
- Operational activities for service applications include Fishing Surveillance, Tracking and Information System, and Commercial vessel monitoring.

5.2 Second phase as First Element Mission:

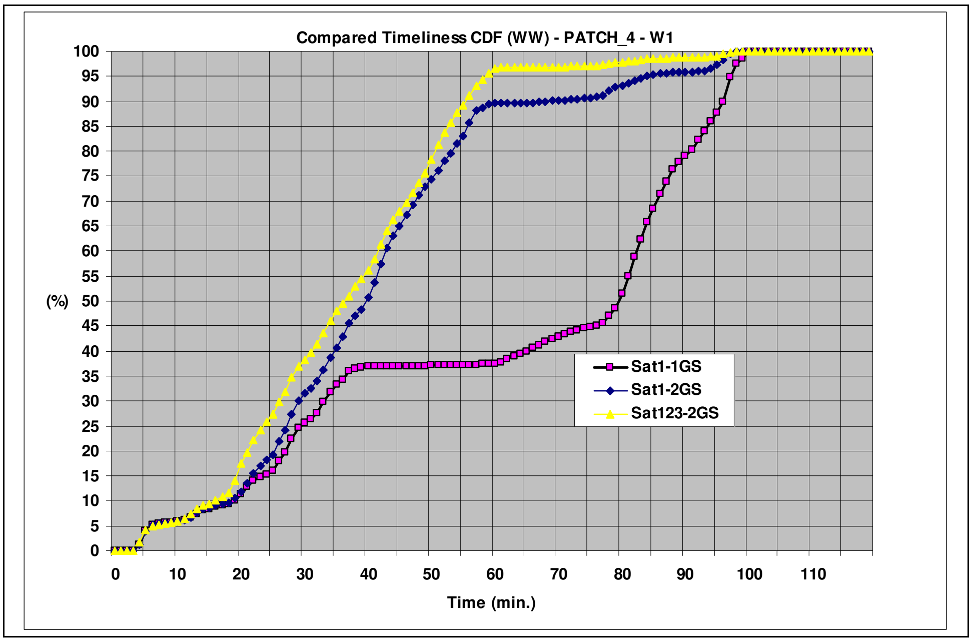
- Test the receiver performance with visibility time window comparable with complete System performance.
- Functional and performance test of the Ground Segment in near real time data acquisition and download using a final system Ground Station at the North Pole
- North Sea/Arctic Use Case:
- Compliance with scaled System Mission performance requirements
- Single Ground Station in the Arctic area (baseline Svalbard)
- Operational activities for service applications include Fishing Surveillance, Hazardous Cargo monitoring, and Commercial vessel monitoring.
- Functional and performance test of the Ground Segment in network configuration (option with 2 Ground Stations) include AIS data acquisition & processing, fusion with AIS shore station data, and user request management

5.3 Detection & Coverage Performances Of First Element Mission

The charts below summarize the performance concerning the Detection & Coverage performance and the Timeliness capabilities specific to the PATCH_4 type of antenna by Satellite Segment configuration as defined in the modular step-by-step approach for the deployment. The data presented are related to global World Vessel Traffic model forecast for the year 2014 for a simulation 6-hour window (W1).

System Detection Performances (WW) – PATCH_4 – W1	Sat1	Sat123	Sat123456789
∑ Ships detected	29211 (42.33%)	41861 (60.66%)	62646 (90.78%)
Ships not detected (0)	39800 (57.67%)	27150 (39.34%)	6365 (9.22%)
Ships detected (1)	17893 (25.93%)	12237 (17.73%)	8582 (12.44%)
Ships detected (>1)	11318 (16.40%)	29624 (42.93%)	54064 (78.34%)
Messages exchanged	43725	136938	422224
Contacts x ship (*)	0,6	2,0	6,1
Contacts x ship detected (*)	1,5	3,3	6,7
Contacts x sat (*)	43725,0	45646,0	46913,8
Contacts x sat x orbit (*)	10931,2	11411,5	11728,4
Bandwidth x sat x orbit (*) [kbit/s]	3,997	4,208	4,341
Timeliness (*) [min]	41,1 (-)	36,9 (-)	25,5 (+)
(*) Average			
(-) GS: Svallbard + Troll			
(+) GS: All 4 Ground Stations			

Tabella 12: AIS First Element Detection & Coverage Performances (WW)



System Timeliness CDF (WW) – PATCH4 – W1	Average (min.)	% (30 min.)	% (60 min.)
Sat1-1GS	62,75	25,67	37,48
Sat1-2GS	41,07	31,50	89,63
Sat123-2GS	36,86	38,29	96,54
SS_06-4GS	25,47	62,37	100,00

Figura 23: AIS Deployment Compared Timeliness CDF (WW) – W1

6. AIS COST BREAKDOWN

A preliminary analysis of the estimated costs (development, deployment and maintenance) was performed for the baseline system scenarios so as to give a rough estimation of the financial requirements (CAPEX and OPEX) to the Satellite Operator. The analysis is relevant to the SS_O6 constellation.

CAPEX elements include:

- Development: related to the cost of design, of development, of test and of validation of the AIS system including the definition of operative and maintenance activity
- Launch: related to the cost of the satellites launches
- Deployment: related to the cost of deployment of the Space and Ground Segment
- Infrastructure related to the cost for the requested infrastructure (TEMPEST/EMC/Power/Conditioning) at Ground premise including the building cost and security arrangement.

OPEX elements include:

- Deployment of the Subset and System Verification
- Subset System Validation
- Certification , Full deployment , and Full Service operations
- In regard to the Deployment the following costs are considered:
- Space Segment operations
- Ground Segment operations
- System Verification operations
- Certification Operations
- Full Service operations

6.1 First Element Costs

The estimates are based on the following assumptions:

- Space Segment consists of 1 S/C.
- EO payload (optional) costs are not included.
- For what concerns the S/C the following models are considered
  - Breadboards (where needed).
  - Engineering Model (EM, ref. ECSS Standards)
  - Flight Model (PFM) that will be subject to a protoflight qualification campaign
  - Ground Support Equipment
- S/C lifetime is 7-8 years

- Launch Costs are not included

The chart below lists the criteria driving cost estimates for the First Element Mission.

Item	Notes
System	The estimated values include the coordination of activities for all phases of the mission, design and analysis, integration, verification and qualification of the flight model, management, technical and programmatic interface with the launcher and the launch campaign.
Platform	The estimates include the design, material purchasing, development, integration and verification platform and all its subsystems for an engineering and protoflight model.
AIS Payload	The estimates include the design, material purchasing, development, integration and testing of all elements of the AIS payload engineering model and flight

Tabella 13: First Element Mission cost elements

The System cost element includes the Non Recurring activity at System Level (system design and analyses), the management and interface with all the mission segment (launcher, ground segment) and the integration, verification and qualification process including the rental of the environmental facilities test, the insurance for the satellite transportation, the launch campaign.

6.2 Full Constellation Costs

The estimates are based on the following assumptions:

- Production of a batch of 9 S/Cs having a unique configuration.
- For what concerns the S/C the following models are considered:
  - Engineering Model (EM)
  - Proto-Flight Model (PFM) that will be subject to a proto-flight qualification campaign
  - 8 Flight Models (FM), that will be subject to a flight acceptance campaign.
  - Ground Support Equipment
  - This estimate includes the different cost of the 4-patch and 3-dipole solution.

The chart below lists the criteria driving cost estimates for the full constellation.

Item	Notes
System	Includes coordination of activities for all phases of the mission, design and analysis, integration, verification and qualification of the flight model, management, technical and programmatic interface with the launcher and the launch campaign.
Platform	Includes design, material purchasing, development, integration and verification platform and all its subsystems for an engineering and proto-flight model.
AIS Payload	Includes design, material purchasing, development, integration and testing of all elements of the AIS payload engineering model and flight
EO Payload	Not included

Tabella 14: Full Constellation cost elements

6.3 Launch Costs

Launch cost is a key parameter for the choice of constellation deployment. Besides coverage and data output considerations, cost of developing and launching numerous spacecrafts on different orbital planes is an important aspect to take into account.

For what concerns the launch cost (ROM), the estimates account for 3 launches, and are assumed as result of a negotiation with the launcher provider for performing the overall number of launches needed to deploy the full AIS constellation and do not include the LEOP-related services.

6.4 Ground Segment Cost Analysis

The estimates are based on the following assumptions:

- Security requirements are not considered.
- Cost of Mission Planning is not included.
- Cost of AIS Service Segment is not included.
- Infrastructure Costs are not included except where noted.
- Antenna (full motion) costs are quoted for the R/F part only.
- Provided estimates are Rough Order of Magnitude (ROM).

The chart below lists the criteria driving cost estimates for the Ground Segment.

Item		Notes
Ground Control System	SOC	HW and SW costs concerning the development cycle (design, procurement, development, integration and verification). Personnel costs (development cycle).
	SCC	HW and SW costs concerning the development cycle (design, procurement, development, integration and verification). Personnel costs (development cycle). Full Motion 10 m diameter S Band Antenna (infrastructure cost included).
	NCC + NMC	HW and SW costs concern the development cycle (design, procurement, development, integration and verification) plus Personnel costs (development cycle).
AIS Data Ground Stations	Svalbard Troll Poker Flat McMurdo	Full Motion 5,4 m diameter UHF Band Antenna. (infrastructure cost,1 Baseband Subsystem included)
EO Data Ground Stations (optional)		Full Motion 5 m diameter UHF Band Antenna (infrastructure cost included). Cost of Baseband Subsystem is not included.
AIS Data Center		Not included
Digital Communication Network		Associated OPEX not included.

Tabella 15: Ground Segment Costs

Item	Notes
UHF Band Antenna	Full Motion 5,4 m diameter antenna. This item is per single antenna and includes infrastructure cost.
S Band Antenna	Full Motion 10 m diameter antenna. This item is per single antenna and includes infrastructure cost.
X Band Antenna	Full Motion 5 m diameter antenna. This item is per single antenna and includes infrastructure cost.
Ground Control System (HW+SW)	HW and SW costs related to the Ground Control System development cycle (design, procurement, development, integration and verification).
Ground Control System (Manpower)	Personnel costs related to the Ground Control System development cycle.

Tabella 16: Ground Segment Elements Cost