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Satellite Automatic Identification System (SAIS) Performance Modelling and Simulation

Progress Findings Report

Garrett Parsons, James Youden and Chris Fowler

The scientific or technical validity of this Contract Report is entirely the responsibility of the Contractor and the contents do not necessarily have the approval or endorsement of Defence R&D Canada. The initial version of this report was completed in March 2012.

Defence R&D Canada – Ottawa

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Satellite Automatic Identification System (SAIS) Performance Modelling and Simulation

Progress Findings Report

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Abstract

An Automatic Identification System (AIS) capability on the RADARSAT Constellation Mission (RCM) will enhance the Canada First Defence Strategy goals of conducting national and continental operations and defending Canada. Key to understanding this is the ability to model and simulate satellite AIS (SAIS) performance characteristics. This report provides an overview of a statistical model implemented by C-CORE to evaluate SAIS performance. Included is a discussion on the approach and methodology employed with results presented for the specific case of the proposed AIS payload on the RCM. The model is driven by a global ship density map (GSDM) developed as a part of this project. GSDM's are generated based on data provided by DRDC for this purpose including both SAIS data (from exactEarth) and data from the Maritime Safety and Security Information System (MSSIS). C-CORE has implemented a basic model corresponding to previous analytical and stochastic model approached reported in the literature by the International Telecommunication Union (ITU), Norwegian Defence Research Establishment (FFI) and London Research and Development Corporation (LRDC). Simple cases for RCM have been run and initial results show that standard model results (no provision for signal de-collision) indicate significant decreases in probability of detection as the number of ships in the field of view increases, while the enhanced model (with provision for de-collision techniques) shows much more favourable results. Further AIS model enhancements and improved vessel identification capability with AIS and synthetic aperture radar (SAR) sensors co-located on a satellite platform is also discussed.

Résumé

La capacité du Système d'identification automatique (SIA) dans le cadre de la mission de la Constellation RADARSAT (MCR) accentuera les objectifs de la Stratégie de défense Le Canada d'abord (SDCD) consistant à mener des opérations nationales et continentales ainsi qu'à défendre le Canada. La capacité à modeler et à simuler les caractéristiques de rendement du SIA par satellite est essentielle à la compréhension de cet énoncé. Le présent rapport donne un aperçu du modèle statistique mis en œuvre par C-CORE pour évaluer le rendement du SIA par satellite. Vous trouverez ci-joints un document de discussion sur l'approche et la méthodologie employées ainsi que les résultats présentés pour le cas spécifique de la charge utile du SIA proposée pour la MCR. Le modèle est dicté grâce à une carte de la densité globale des navires conçue dans le cadre de ce projet. Les cartes de la densité globale des navires sont produites à partir de données fournies par Recherche et développement pour la défense Canada à cet effet, y compris les données du SIA par satellite (provenant d'exactEarth) et les données du Système d'information sur la sécurité et la sureté maritimes (MSSIS). C-CORE a mis en œuvre un modèle de base correspondant au modèle analytique et stochastique antérieur envisagé mentionné dans la littérature par l'Union internationale des télécommunications (UIT), l'institut norvégien de recherche pour la défense (Norwegian Defence Research Establishment [FFI]) et la société London Research and Development Corporation (LRDC). Des scénarios simples pour la MCR ont été exécutés, et les résultats préliminaires démontrent que les résultats du modèle standard (sans le nécessaire pour corriger la collision des signaux) indiquent des diminutions importantes dans la probabilité de détection étant donné que le nombre de navires dans le champ de visée augmente, tandis que le modèle amélioré (avec le nécessaire pour les techniques de correction de la collision des signaux) démontre des résultats beaucoup plus favorables. Il est également question d'améliorations additionnelles au modèle du SIA et d'une capacité améliorée d'identification des navires au moyen de capteurs du SIA et de capteurs de radar à synthèse d'ouverture (SAR) installés ensemble sur une plateforme satellitaire.

Satellite Automatic Identification System (SAIS) Performance Modelling and Simulation: Progress Findings Report

Chris Fowler; Garrett Parsons; James Youden; DRDC Ottawa CR 2013-094; Defence R&D Canada – Ottawa; December 2013.

Introduction: The AIS is an International Maritime Organization (IMO) mandated safety system designed as a line-of-sight (LOS) collision avoidance system based on low power, very high frequency (VHF) transponder broadcasts. Under the IMO's Safety of Life at Sea (SOLAS) convention, AIS transponders are required carriage for internationally voyaging ships with gross tonnage of 300 tons or more. There are over 70,000 ships worldwide with AIS transponders installed. While the prime purpose of the system is collision avoidance, broadcast information is very useful for surveillance and security purposes. Typical shore-based and vessel mounted receivers are limited to LOS reception ranges on the order of 40 nautical miles. The advent of AIS receivers on satellites eliminates this range constraint providing global coverage.

This document provides a progress findings report on the development of a SAIS statistical performance model. This model will be used to assess the feasibility of the design of an AIS receiver payload on the RCM. The report provides an overview of existing model approaches and outlines the approach and methodology applied to the statistical model implementation to date. Development of a baseline GSDM is a key requirement of this work and the report outlines the approach taken to derive the GSDM based on available satellite and terrestrial AIS data sources.

Results: The model is driven by a GSDM developed as a part of this project. GSDM's are generated based on data provided by DRDC for this purpose including both SAIS data (from exactEarth) and data from the MSSIS. Two GSDM's were developed using different methods and were compared. Both maps show similar densities overall, but the selected GSDM contained a greater number of total ships and a higher maximum ship density. GSDM's developed from these limited data sources are comparable to those presented by other sources and are used for the purposes of this work.

A space based AIS performance model was developed and verified against similar models published by the FFI, J.K.E Tunaley, and the ITU. The developed model was able to reproduce the probability of detections achieved by the other models when similar parameters are used. The derived model was then run using RCM-specific parameters to generate preliminary performance results. Initial results show that standard model (no provision for signal de-collision) outcomes indicate significant decreases in probability of detection as the number of ships in the field of view increases. The enhanced model (with provision for de-collision techniques) shows much more favourable results.

Significance: A method for generating a GSDM from available AIS data from different sources was defined. Due to limitations in the available AIS data, the density map may not reflect the actual global ship densities. However, the GSDM is judged to be sufficient for use with the AIS performance model.

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The developed satellite based AIS performance model is able to achieve the same results as existing models. This verification is important before the model is further extended to simulate an AIS system on RCM.

Future plans: Future efforts on the performance model include options for additional AIS satellites and the isolation of a particular SAR swath within the field of view. To aid in the analysis of the combined AIS and SAR detection capabilities, the SAR ship detectability information will be incorporated into the performance model. The ability to simulate AIS message transmissions and detection is advantageous in the analysis of non-uniform characteristics as exist in ship distributions and terrestrial interference. An algorithm for the Monte Carlo simulation of the AIS message detection is currently being developed.

The GSDM will be updated with new AIS data as it becomes available. The current AIS data set spans from August to March, so new data outside of this period will capture any seasonal changes in the global ship traffic.

Satellite Automatic Identification System (SAIS) Performance Modelling and Simulation: Progress Findings Report

Chris Fowler; Garrett Parsons; James Youden ; DRDC Ottawa CR 2013-094 ; R & D pour la défense Canada – Ottawa ; décembre 2013.

Introduction ou contexte : Le SIA est un système de sécurité exigé par l'Organisation maritime internationale (OMI) et conçu comme un système d'évitement des collisions entre navires à visibilité directe qui utilise les transmissions de transpondeurs de très haute fréquence (VHF) et de faible puissance. En vertu de la Convention internationale pour la sauvegarde de la vie humaine en mer de l'OMI, les navires qui sillonnent les eaux internationales et dont le tonnage brut est de 300 tonnes ou plus doivent être équipés de transpondeurs du SIA. On compte plus de 70 000 navires équipés de transpondeurs du SIA dans le monde. Alors que ce système vise essentiellement à éviter les collisions, la transmission d'information est fort utile dans le cadre d'opérations de surveillance et de maintien de la sécurité. Habituellement, la portée de réception des récepteurs côtiers et des récepteurs présents à bord des navires se limite à celle en visibilité directe, soit 40 milles marins. L'arrivée de récepteurs du SIA basés sur des satellites élimine cette contrainte de portée et permet d'obtenir une couverture globale.

Le présent document contient un rapport de constatations sur l'élaboration d'un modèle de rendement statistique pour le SIA. Ce modèle sera utilisé pour évaluer la faisabilité de la conception d'une charge utile du récepteur du SIA pour la MCR. Le rapport donne un aperçu des approches du modèle existant et décrit brièvement l'approche et la méthodologie employées dans le cadre de la mise en œuvre du modèle statistique jusqu'à maintenant. La conception de la carte de la densité globale des navires dite de référence est un impératif majeur de ce travail, et le rapport décrit brièvement l'approche employée pour adapter la carte de la densité globale des navires du SIA satellitaires et terrestres disponibles.

Résultats : Le modèle est dicté par la carte de la densité globale des navires conçue dans le cadre de ce projet. Les cartes de la densité globale des navires sont produites à partir de données fournies par Recherche et développement pour la défense Canada à cet effet, y compris les données du SIA par satellite (provenant d'exactEarth) et les données du Système d'information sur la sécurité et la sûreté maritimes (MSSIS). Deux cartes de la densité globale des navires ont été conçues selon des méthodes différentes et ont été comparées. Les deux cartes montrent des densités semblables, mais la carte de la densité globale des navires retenue comportait un nombre total de navires plus important et une densité maximale des navires plus grande. Les cartes de la densité globale des navires se comparent à celles présentées par d'autres sources et sont utilisées aux fins de ce travail.

Un modèle de rendement du SIA dans l'espace a été conçu puis a fait l'objet de vérifications par comparaison avec des modèles semblables publiés par le FFI, J.K.E Tunaley et l'UIT. Le modèle conçu a permis de reproduire la probabilité de détections obtenue au moyen d'autres modèles lorsque des paramètres semblables sont utilisés. Le modèle adapté a ensuite été exécuté au moyen de paramètres propres à la MCR afin de produire des résultats préliminaires sur le rendement. Les résultats préliminaires démontrent que les résultats du modèle standard (sans le nécessaire pour

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corriger la collision des signaux) indiquent des diminutions importantes dans la probabilité de détection étant donné que le nombre de navires dans le champ de visée augmente. Le modèle amélioré (avec le nécessaire pour les techniques de correction de la collision des signaux) démontre des résultats beaucoup plus favorables.

Importance : Une méthode a été établie pour produire une carte de la densité globale des navires à partir des données du SIA disponibles provenant de diverses sources. En raison du peu de données du SIA disponibles, il est possible que la carte de la densité ne reflète pas les densités globales de navires réelles. Toutefois, on considère que la carte de la densité globale des navires suffit en ce qui concerne son utilisation avec le modèle de rendement du SIA.

Le modèle de rendement du SIA par satellite qui a été conçu est capable de produire les mêmes résultats que les modèles existants. Cette vérification est importante avant que le modèle soit développé davantage en vue de simuler un SIA dans le cadre de la MCR.

Perspectives : Les travaux qui seront effectués sur le modèle de rendement comprennent des options pour des satellites supplémentaires du SIA et l'isolation d'une fauchée précise du SAR à l'intérieur du champ de visée. Pour faciliter l'analyse des capacités jumelées du SIA et du SAR, les données de détectabilité des navires du SAR seront intégrées au modèle de rendement. La capacité à simuler des transmissions de messages du SIA et leur détection est avantageuse pour ce qui est de l'analyse des caractéristiques non uniformes telles qu'elles existent dans la répartition des navires et l'interférence terrestre. On travaille actuellement à la conception d'un algorithme destiné à la simulation de Monte-Carlo de la détection des messages du SIA.

La carte de la densité globale sera mise à jour à partir des nouvelles données du SIA à mesure qu'elles deviendront disponibles. L'ensemble actuel de données du SIA couvre la période d'août à mars; par conséquent, les nouvelles données recueillies en dehors de cette période refléteront les changements saisonniers pour l'ensemble de la circulation maritime.

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1 Introduction

The Radar Data Exploitation (RDE) Group of Defence Research and Development Canada – Ottawa (DRDC Ottawa) is investigating the feasibility of implementation and the capability to enhance identification of ships in the maritime approaches to Canada, including the Arctic. The Department of National Defence / Canadian Forces (DND/CF) is also concerned about other Maritime Areas Of Interest (AOIs) worldwide. This report outlines work done to date on performance modelling and simulation of an Automatic Identification System (AIS) sensor payload for the Canadian Space Agency (CSA)-led RADARSAT Constellation Mission (RCM).

In 2000, as a part of the Safety of Life At Sea (SOLAS) convention, the International Maritime Organization (IMO) added AIS to the shipboard navigational carriage requirement for a number of ship categories. These include ships of 300 tons (gross) or greater that travel internationally, cargo ships of 500 tons gross or greater, and all passenger ships. The requirement came into full force for these ships on December 31, 2004 and the system is known as "Class A" AIS. After this date, all ships in service in the said categories are mandated to operate their AIS equipment continuously, except where international agreements allow navigational data to be protected. In 2007, "Class B" was introduced for small craft, including pleasure vessels.

AIS was conceived mainly as a collision avoidance system and is based on regular very high frequency (VHF) transmission and reception of short binary messages containing information about the ship's identity, position, speed and course. The United Nations Conference on Trade and Development (UNCTAD) report, "Review of Maritime transport 2011," reports the worldwide commercial fleet of seagoing vessels in service as of January 2011 to be 103,392 [1]. In a presentation to IMO Nav 57, exactEarth (eE) reports a current worldwide deployment of AIS transponders on 65,000 vessels [2]. The AIS systems are based on Time Domain Multiple Access (TDMA). This means that short messages are sent during specific time slots. To avoid confusion when the signal traffic is high, schemes are adopted to ensure that signals are not transmitted simultaneously by different ships into the same time slot. For Class A, this is a self-organizing method called SOTDMA. In this method, a transceiver actively searches for an appropriate empty slot before transmitting. For Class B, a transceiver first listens to a slot to determine if anyone is using it and, if free, proceeds to transmit. This is known as Carrier-Sense TDMA (CSTDMA).

Although the AIS capability was developed for line-of-sight (LOS) applications, there is worldwide interest in having a beyond line-of-sight (BLOS) capability based on AIS receivers onboard primarily, polar orbiting satellites. The current shore-based AIS systems are limited by LOS distance (i.e., roughly 40 nautical miles). Satellite-based systems would eliminate this constraint and provide global coverage. However, satellite-based AIS (SAIS) systems also suffer from the collision of AIS messages when many ships are in the satellite's field of view.

When AIS is operated as a terrestrial system, the SOTDMA protocols ensure that signals from different ships do not interfere with one another. However, the number of time slots is limited to 2,250 on each of two VHF channels and these slots are reassigned every 60 seconds. Therefore, in an area of very high shipping density, some signals may be dropped. The system is configured so that the weaker signals in the far range are omitted. This effectively reduces the size of a self-organized cell and has little effect on the collision avoidance aspect of the system. When signals

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are received by space-based platforms with large fields of view (FOVs), the number of messages may easily exceed the number of message slots available. This issue of message collision is a significant issue for SAIS receivers.

It is anticipated that an AIS capability on RCM will enhance the Canada First Defence Strategy goals of conducting national and continental operations and defending Canada. An AIS payload co-located with space-based radar is expected to enhance identification of vessels of interest in maritime approaches in a timely manner by significantly reducing the number of unidentified detected vessels in an operational AOI. The purpose of this study is to provide support for or contrary to this hypothesis.

The tasks associated with this investigation include:

- 1. Development of a model that will incorporate statistical models from space-based AIS data sources and simulate the major factors affecting the quality of the AIS radio frequency link;
- 2. Identify issues and expected performance associated with the combination of space-based AIS and RADARSAT-2 vessel detection data; and
- 3. Establish the expected performance for AIS on RCM.

The actual work completed under this project will be decided on a task by task basis by the contract technical authority, and as such, may be revised.

Section 2 of this report presents the development of a baseline ship density map for use in the performance model, which is discussed in Section 3.

2 Global Ship Density Map

The objective of this activity was to augment existing ship density models using space-based AIS data. The developed global ship density map (GSDM) will be used as an input to a statistical model of an AIS system on RCM, which will be developed in later tasks.

Specifically, the goals are to:

- 1. Provide a baseline GSDM that consists of the expected number of Class A AIS ships within specific spatial regions, and
- 2. Update the baseline GSDM with the space-based AIS data provided by DRDC Ottawa.

Sub-Section 2.1 presents the results of an investigation into possible sources of global ship density data, from both non-AIS and AIS sources. Non-AIS sources are preferred to reduce any potential bias that may be inherent in AIS-based systems. Sub-Section 2.2 discusses the generation of GSDMs based on the eE AIS datasets purchased by the Canadian Space Agency (CSA) and made available to DRDC Ottawa. Sub-Sections 2.3 and 2.4 examine the results of the density map generation and summarizes the work.

2.1 Investigation of Baseline Global Ship Density Data

In order to develop an unbiased global ship density baseline, various data sources were investigated. However, it was discovered early on, that non-AIS sources did not have the breadth of information required. As a result, alternate AIS systems were included in the research. Identified sources for non-AIS and AIS global ship density data are listed in Table 1. This table does not include the eE AIS dataset purchased by the CSA.

Name	Comments
Automated Merchant Vessel Reporting program (Amver)	Non-AIS. Voluntary system used for search and rescue. The Amver website states that, on average, about 4000 ships are recorded by the system each day. The ship density maps are posted online, but access to the data used to generate the maps is limited to search and rescue use only. See http://www.amver.com/density.asp .

Table 1:	Baseline	global	ship	density	sources
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Name	Comments
World Meteorological Services Voluntary Observing Ships (WMO VOS)	Non-AIS. Voluntary system used for ships to provide weather reports. The WMO VOS website states that currently only about 4000 ships participate globally. There is a ship density map available online based on WMO VOS data collected for a period of 12 months beginning in Oct-2004. See <u>http://www.vos.noaa.gov/vos_scheme.shtml</u> <u>http://www.nceas.ucsb.edu/globalmarine/impacts</u> .
Historical Temporal Shipping (HITS) database	Non-AIS. Uses historical data collected from many different sources. For United States Department of Defence use only, was used in two DRDC CORA reports [3], [4] through a data sharing agreement.
Norwegian Defence Research Establishment (FFI)	AIS based. FFI has developed a global ship density map, which could be purchased. They have spent considerable time developing the map (over six months) and it is generally regarded as being of high quality.
IHS Fairplay	AIS based. IHS Fairplay offers AIS services. A global ship density map would have to be purchased if it exists, or generated from purchased AIS data.
PASTA-MARE project	European Union (EU) project about satellite based AIS. The resulting GSDM is available free online in ShapeFile format and was created from both satellite and terrestrial AIS data (satellite data from Pathfinder and Orbcomm between 01-Jan-2010 and 31-Mar-2010). See https://webgate.ec.europa.eu/maritimeforum/content/1603.

2.2 Development of GSDM from AIS Data

The AIS data used to create the GSDM includes both SAIS and terrestrial AIS (TAIS). The SAIS data comes from eE and consists of four AIS datasets as described in Table 2. The eENorth dataset covers mainly the north-western hemisphere and eECanada covers the water regions around Canada. eEViewer data is manually captured on a semi-daily basis (typically Monday to Friday) and only the last ship position for an observed maritime mobile service identity (MMSI) was retained. This dataset is still being acquired (as of the writing of this report) and the GSDM will be updated as new data becomes available. The temporal coverage of the AIS data is shown in Figure 1 and Figure 2 shows the cumulative number of valid, unique MMSI's versus the number of days of data in the AIS datasets. The spatial coverage for each dataset is shown in

Figure 3 to Figure 6. Only the eEGlobal and eENorth datasets are contiguous, the others have gaps in their acquisitions.

The TAIS dataset, also listed in Table 2 and shown in Figure 7, is from the Maritime Safety and Security Information System (MSSIS). It provides almost-global coastal coverage with notable gaps near India and Vietnam.

The AIS datasets listed in Table 2 cover the time period from August to March (i.e., fall and winter). Ship information in the spring and summer is missing. Similarly, AIS data from the PASTA-MARE project falls within this same time period. Shipping routes that are only active in the spring and summer months will not be properly represented in a GSDM based on the data in Table 2. For example, Canada's Northwest Passage is only navigable when the passage is ice free, which is in the summer months.

Dataset Name	Spatial Cover	Date Range	Number of days
eEGlobal	Global	13-Jan-2010 to 23-Mar-2011	70
eENorth	Mainly north-western hemisphere	08-Sep-2010 to 12-Jan-2011	126
eECanada	Waters near Canada	27-Aug-2011 to 23-Oct-2011	58
eEViewer	Global	08-Nov-2011 to 16-Feb-2012	37 (currently)
MSSIS	Coastal, almost global	01-Aug-2011 to 20-Oct-2011	42

Table	2:	List	of AIS	datasets
1 000 00		2000	0,111~	



Figure 1: Temporal distribution of AIS datasets



Figure 2: Cumulative number of valid, unique MMSI's per day for each AIS dataset

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Figure 3: eEGlobal coverage



Figure 4: eENorth dataset coverage



Figure 5: eECanada dataset coverage



Figure 6: eEViewer dataset coverage



Figure 7: MSSIS dataset coverage

The development of a GSDM from the available AIS data was created using two different methods. Both methods use a map grid spacing of 1° latitude by 1° longitude. Method 1 uses the following steps:

- 1. Pre-process the AIS data: AIS data is provided in a variety of formats and require preprocessing. The AIS messages from eEGlobal, eENorth, eECanada, and MSSIS were first decoded using a modified C program available online from [1]. This C decoder was modified to output the AIS data into text files separated by day. eEViewer snapshot data is in the form of a decoded CSV file and is re-formatted to match the output of the C decoder.
- 2. Create density map from SAIS data:
 - a. Read eight days of AIS data for a particular dataset (eEGlobal, eENorth, eECanada, or eEViewer). Reading in several days' worth of data is necessary to account for the fact that the satellites cannot cover the entire world in one day. Increasing the number of days of data will result in more ships in the density map, while decreasing the number of days will lessen the number of ships observed. Eight days was chosen as a reasonable compromise between maximizing the number of ships observed and having the minimum amount of data to create a useable density map.
 - b. Keep data with valid MMSI: The MMSI is the unique identification of the ship. Valid MMSI's (from [6]) for ships are nine digit numbers where the first three digits range between 201 and 775. It should be noted that some ships use MMSI's outside this range and are dropped.
 - c. Keep only valid latitude and longitude positions: There are cases where the ship reports a position of 91° N, 181° E which is interpreted as being a bad value. All other positions reported by ships have a decimal latitude and longitude and are

between $+/-90^{\circ}$ latitude or $+/-180^{\circ}$ longitude. There are fewer of these errors than with bad MMSI's. Messages deemed to have bad positions are dropped.

- d. Create subset density map: The last valid ship position reported in the eight day interval is added to the subset density map.
- e. Repeat steps 2a, b, c, and d until all AIS data in the dataset has been imported, resulting in multiple subset density maps.
- f. Average the subset density maps for the dataset. Assume areas with zero density were observed but no ships found (the average includes cells with zero density).
- 3. Repeat Step 2 for each of the SAIS datasets, resulting in four dataset density maps.
- 4. Repeat Step 2 for the MSSIS dataset. It is only necessary to use one day of data to create a subset density map as the MSSIS system provides a near global snapshot on a daily basis.
- 5. Combine the dataset density maps into the final GSDM. Different combination methods were evaluated and the final outcome was reached by averaging the four SAIS density maps and then taking the maximum of this and the MSSIS density map. This avoids the bias introduced by missed messages in high volume coastal areas for satellite based data as compared to the terrestrial data available near shore. In this step, it is assumed that a cell with zero density was not observed, and therefore is not included in the calculation. This was done to accommodate the combination of density maps with different spatial coverage (such as the eECanada and eEGlobal datasets).

Figure 8 illustrates this procedure and the resulting GSDM from Method 1 is shown in Figure 9.



Figure 8: Method 1 density map generation chart



Figure 9: GSDM based on Method 1

The steps to produce a GSDM using Method 2 are:

- 1. Pre-process the AIS data as in Step 1 of Method 1.
- 2. Read all AIS data from all datasets. Keep only the valid MMSI and positions (as was done in Step 2b and 2c of Method 1).
- 3. Sort the AIS data by MMSI. For each MMSI:

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a. Get the last reported position per day (*n* positions) and update the density map by 1/n at each reported position. This ensures that a single ship will only contribute one to the GSDM. Updating the density map based on the last position each day was used because this is how the eEViewer dataset is formatted. The other datasets typically provide the positions of the ships at a higher frequency.

A diagram of this procedure is shown in Figure 10, and Figure 11 shows the resulting GSDM.



Figure 10: Method 2 density map generation chart



Figure 11: GSDM based on Method 2

2.3 GSDM Results

The GSDM's in Figure 9 and Figure 11 were plotted using the same logarithmic scale for comparison purposes (i.e., the logarithmic scale was used to highlight the cells with lower ship densities). Some common statistical parameters for the GSDM's are given in Table 3. Note that the column 'Total Ships' is not the actual total number of ships for Method 1; it is merely a summation over the density map. Due to the combination of subset and dataset density maps, it is not possible to get the actual number of ships; therefore the summation is used as an estimate. The minimum and average values in Table 3 do not include cells with zero density.

The main differences between the two methods occurs because the second method collects a ship position at the end of each day, while the first method acquires the last ship position in an eight day period (i.e., for the SAIS data only; the MSSIS is still collected as the last position each day). The maximum density obtained by Method 2 is significantly higher than in Method 1. This occurs in European waters near the Belgium-Netherlands border at approximately 52° latitude by 4° longitude. This grid square (52°-53° latitude by 4°-5° longitude) covers a spatial area of approximately 7,600 km² containing 2,738 vessels. As a reality check, information obtained from the live AIS data at <u>www.marinetraffic.com</u> indicates that there are 2,694 ships in a 10,000 km² area in the same location.

The AIS data used to generate the GSDM's contains errors in some position reports that lead to incorrect ship densities. This effect is most evident over the land areas of Figure 9 and Figure 11, although some of these are valid messages from rivers and inland water bodies. One method to account for the position errors is to remove the ships that only contain a few position reports in all the AIS data. This assumes that the errors are from a random process rather than a recurring error from specific ships. The removal of the ships is straightforward for Method 2 as all AIS data is sorted by MMSI and processed as one dataset. The Method 1 GSDM cannot be filtered in this way because the AIS datasets are kept separate until the final combination. Instead, density cells

that reported only one ship in one of the subset density maps were removed from the dataset density maps.

Table 5 lists statistics after filtering the Method 2 GSDM. The 'Min ship report threshold' column indicates the number of position reports a ship must exceed to be included in the density map. For example, a threshold of one means that any ship with only one position report in all the AIS data will be removed. The GSDM for the filtered Method 1 and Method 2 results are shown in Figure 12 and Figure 13.

Filtering of the Method 1 GSDM has eliminated a significant number of density cells, and the percent of global coverage is reduced to 28.58% compared to 42.56% for the unfiltered case. The total number of valid, unique MMSI remained similar and the maximum density was the same. Filtering of the Method 2 GSDM only slightly reduced the coverage but had a large effect on the total ships and maximum density. Removing the ships with only one position report in all AIS data has reduced the maximum number of ships from 107,764 to 87,411. This value is much closer to the generally accepted actual number of Class A ships worldwide, 75,000.

Method	Total Ships	Min Density (Ships/1° grid square)	Max Density (Ships/1° grid square)	Average Density (Ships/1° grid square)	% of Global Coverage	Lat, Lon of Max Density Cell (Degrees)
1	59012	0.02381	890.81	2.1282	42.56	52, 4
2	107764	0.003636	2738.27	3.1634	52.28	52, 4

Table 3: Comparison of Method 1 and Method 2 GSDMs

Table 4: Method 1 GSDM statistics after filtering by ship reports

Total Ships	Min Density (Ships/1° grid square)	Max Density (Ships/1° grid square)	Average Density (Ships/1° grid square)	% of Global Coverage	Lat, Lon of Max Density Cell (Degrees)
58582	0.04762	890.81	3.1458	28.58	52, 4

Min Ship Report Threshold	Total Ships	Min Density (Ships/1° grid square)	Max Density (Ships/1° grid square)	Average Density (Ships/1° grid square)	% Coverage	Lat, Lon of Max Density Cell (Degrees)
1	87411	0.0036364	2451.3	2.7975	47.95	52, 4
2	83613	0.0036364	2221.3	2.6789	47.90	52, 4
5	76824	0.0036364	1644.3	2.4652	47.82	52, 4
10	70076	0.0036364	1124.3	2.2535	47.72	52, 4

Table 5: Method 2 GSDM statistics after filtering by minimum number of ship position reports



Figure 12: Method 1 GSDM after filtering by ship reports



Figure 13: GSDM from Method 2, ignoring MMSI with only one position report in all AIS data

2.4 GSDM Summary

The GSDM's presented in this section were developed to be the baseline ship density for the performance modelling discussed in Section 3. Given the limited data sets available for GSDM development, the results are believed to show a reasonable representation of global ship density. Qualitatively, the GSDM's generated are comparable to other AIS-generated ship density maps openly published and will be used for the purposes of this project. GSDM's will be updated with new AIS data as it becomes available during the course of the project.

The work on the GSDM was performed in parallel with the development of the performance model. The Method 1 GSDM (without filtering) was generated first, and therefore used as the baseline for the work in this report.

As of March 2012, it has been decided that the Method 2 GSDM should be used going forward. Subsequent analysis will use GSDM's generated using Method 2 based on the most current data sets available.

3.1 Overview

3.1.1 Background

There have been many studies and reviews on the potential of satellite reception of AIS messages. Notable among these have been the modelling and simulation work done by the FFI (see, for example [7], [8] and [9]), and the stochastic model presented by J.K.E. Tunaley ([10], [11] and [12]). An overview of satellite detection of AIS messages, including a discussion of the work mentioned above, has been given by the ITU ([13] and[14]).

Beyond the basic models that have been developed for the satellite reception of AIS messages, of interest here is the detection of AIS messages that has been reported by COM DEV and their subsidiary eE. An overview of their work has been given, for example, by D'Souza and Martin [15], and more recently by D'Souza [16]. An interpretation of the performance presented in the latter work has been given by Tunaley [12] based on a stochastic model.

3.1.2 Parameters

The basic parameters of AIS are summarized in Table 6, as presented by the ITU [13]. Of note here are the message slots of length 256 bits transmitted in 26.7 ms, with 2250 time-slots in each frame. The message interval varies from 2 s to 6 min depending on the dynamic status of the ship, with the average interval for all ships being about 7 s [13].

The ITU [13] has also summarized the nominal signal parameters and effective link margin, as shown in Table 7 and Figure 14. For a satellite altitude of 950 km considered within the ITU report, a margin of 10 dB is obtained out to about 500 km from the sub-satellite point.

AIS parameters	Values
Frequencies	161.975 and 162.025 MHz
Channel bandwidth	25 kHz
Platforms	Class A ships, Class B ships, coastal stations, navigation aids
Power	12.5 W (Class A); 2 W (Class B)
Antenna type ⁽¹⁾	$\frac{1}{2} \lambda$ dipole
Antenna gain ⁽¹⁾	2 dBi with cosine-squared vertical elevation pattern; Minimum gain = -10 dBi
Receiver sensitivity	-107 dBm for 20% packet error rate (PER) (minimum) -109 dBm for $\leq 20\%$ PER (typical)
Modulation	9600 bits GMSK
Multiple access mode	TDMA (self-organizing, random, fixed and incremental)

Table 6: Overview of shipboard AIS technical parameters, from [13]

AIS parameters	Values		
TDMA frame length	1 min; 2250 time-slots		
TDMA slot length	26.7 ms; 256 bits		
Message types	22 types		
Message length	1 to 5 slots with 1 slot being the dominate type		
Periodic message interval	2 s to 6 min transmit intervals		
Required D/U protection ratio	10 dB at PER = $20\%^{(2)}$		

⁽¹⁾ Typical parameters not defined in Recommendation ITU-R M.1371. ⁽²⁾ Parameter specified in IEC 61993-2.

Parameters	
Geometry	
Satellite altitude (km)	
Minimum transmit elevation angle (degrees)	0
Satellite antenna off-axis angle (degrees)	60.5
Maximum slant range (km)	3 281
Power	
Transmit power (dBm)	41.0
Transmit gain (dBi)	
Transmit cable & miscellaneous losses (dB)	
Free space propagation loss at maximum range (dB)	
Polarization mismatch loss (dB)	
Satellite antenna gain at the horizon (dBi)	
Satellite RF line/filter losses (dB)	
Received power at satellite (dBm)	
Satellite sensitivity for 20% PER (dBm)	
Net margin (dB)	8.3

 Table 7: Ship-to-satellite link budget at maximum range [13]
 [13]



Figure 14: Ship-to-satellite link margin vs. surface distance from sub-satellite point [13]

3.2 Modelling Approaches

Four approaches to modelling the satellite detection of AIS messages have been used. A socalled analytical method uses basic probability analysis over the various regions of the FOV to derive probability of detection expressions for various scenarios, and has been extensively developed by FFI [8], [9]. The problem has also been considered by Tunaley [12] in terms of random transmission of messages described by Poisson statistics, yielding results in agreement with the analytical method. More detailed analyses based on simulation of the transmission and detection characteristics have been performed, for example, by FFI [9] and ITU [13]. For most straightforward scenarios, the simulations yield results similar to the other approaches, although simulations remain a useful method to verify non-uniform behaviour within the AIS analyses.

3.2.1 Analytical models

FFI has developed two approaches, the first dealing with relatively small antenna footprints (< 800 km) and a second extended model. The first approach assumes only one type of message collision considering the maximum relative propagation delay for messages among different ship transmitters of 2ms. The second approach considers larger satellite antenna footprints including a second type of messages collision caused by relative delays among messages coming from vessels in the FOV which are longer than the maximum value allowed by self organized cells.

The first FFI approach [7] defines the detection probability, P, for a given ship within the observation area as:

$$P = 1 - \left[1 - \left(1 - \frac{N_{tot}}{75M\Delta T}\right)^{M-1}\right]^{\frac{T_{toto}}{\Delta T}}$$
(1)

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where M is the number of organized areas (size 40x40 nm was used for modelling), N_{tot} is the total number of ships, ΔT is the reporting interval and T_{obs} is the observation time.

The second FFI approach [8] defines ship detection probability as:

$$P = 1 - \left[1 - g^{\frac{-(1 - s)N(tor)}{2T - m_{tot}\Delta T}}\right]^{\frac{T_{obs}}{\Delta T}}$$
(2)

where s is the overlap factor depending on the sensor's altitude and FOV, N_{tot} is the total number of ships, n_{ch} is the number of independent channels used for transmission, ΔT is the reporting interval and T_{obs} is the observation time.

The ITU analytical model is based on identifying the instances when message signals may collide at the receiver, as shown in Figure 15 of the ITU [13]. Zone 0 corresponds to the region in which the self-organizing capability of the TDMA signal would prevent collisions with the signal under consideration. In contrast, Zones 1 and 2 correspond to the regions where there is no coordination of the signal transmission, and therefore the signals may collide, with Zone 1 being limited to the area in which the maximum propagation delay is less than 2 ms so that only a single time slot is affected, and Zone 2 is the remaining area within the field of view in which the propagation delay is greater than 2 ms so that two time slots will be affected by a signal collision.



Figure 15: Illustration of time-slot collision zones [13]

The probability that at least one AIS message is detected out of *M* transmitted is then:

$$P_{M,N} = 1 - \left[1 - \left(1 - \frac{k\left(\frac{T}{MT}\right)}{2}\right)^{N-1}\right]^{M}$$
⁽³⁾

where N is the total number of ships within the FOV, τ is the time for the message transmission, ΔT is the period of the message transmissions, and k is 0, 1, or 2 according to the zone of interference as illustrated in Figure 15.

3.2.2 Stochastic model

Tunaley [10] has described the probability of detection of an AIS message in terms of a Poisson random process, with the mean rate of message transmission, λ . Thus, the probability of at least one correct AIS message being received is:

$$\mathbf{p} = \mathbf{1} - \left(\mathbf{1} - \mathbf{q}^{-h_{0}(1-q)(1-q)}\right)^{\frac{T_{obs}}{\Delta T}}$$
(4)

where τ is the time for the message transmission, ΔT is the period of the message transmissions, and T_{obs} is the time during which the AOI is being viewed. The parameter q is the probability that a message is uncorrupted by another single message, and s is an overlap factor that accounts for the three zones of interference as outlined in Figure 15. For small values of the argument, $\lambda \tau (1 - q)(1 + s)$, the expression for the detection probability obtained by Tunaley is identical to that given by the analytical model above.

3.2.3 Simulations

Simulation of the satellite reception of AIS signals is useful for verifying the detection behaviour, and is especially useful for analyzing non-uniform characteristics. The Monte Carlo simulation is based on characterizing the ship distribution, the message transmissions, propagation, and reception. Additional factors, such as interference from terrestrial sources may be included. Both FFI and ITU, as well as COM DEV, have simulated the behavior of AIS satellite reception under various assumptions.

An example of the results obtained from the ITU [13] for the basic scenario of uniform ship distribution and random AIS transmissions is shown in Figure 16, along with the corresponding results from the analytical model.



Figure 16: AIS satellite detection baseline curve using simulation method [13]

The ITU report [13] has also considered the various interference effects, from both Class A and Class B signals, and the effects of non-uniform ship distribution. The results for various observation times are presented in the report, and a few figures are reproduced here for reference. Figure 17 shows the probability of detection for an AIS signal considering Class A interference only, while Figure 18 includes interference from Class B signals. The results shown in Figure 19 are based on the global ship distribution, and illustrate one example of the detection probability for the North Atlantic shipping lanes.

Interference from terrestrial sources is considered in the review by the ITU [13], in particular VHF public correspondence stations (VPCS) and land mobile radio (LMR). Since these signals generally have higher signal levels, they can readily swamp the AIS signals at the satellite receiver. Successful reception of AIS signals in this instance therefore depends on the duty cycle of the terrestrial source, such that the AIS message can be received between terrestrial transmissions.



Figure 17: AIS satellite detection (One-and-six-satellite scenarios) [13]



Figure 18: Detection probability in a mixed Classes A and B environment (One satellite; 12 h observation period) [13]



Figure 19: Detection statistics using worldwide ship data (Target ship located 1000 km off coast of New York, NY, USA) [13]

The reception of standard AIS messages at a satellite may be improved by using one or more enhanced methods. The satellite antenna pattern can be altered to focus on a reduced FOV, although this, in general, will also limit the observation time, thereby offsetting potential gains in reduced message collisions. One can also take advantage of the difference in the Doppler shift from the ships in varying parts of the satellite footprint to separate colliding messages, or use the differences in the polarization from Faraday rotation to separate messages along different propagation paths. The redundancy in the AIS messages from a given ship can be used in a correlation processor to help separate such messages from noise, and may be of particular value in excluding the lower power Class B signals.

3.2.4 Satellite Specific AIS — Message 27

To improve the detection of AIS messages received by satellites, new message parameters have been proposed to help overcome the message collisions. These proposed changes, which would define a new Message 27, are summarized in ITU-R M.2169 [14]. They include transmitting the messages on two channels (75 and 76) that are restricted to maritime use, and reducing both the message length to 96 bits and the reporting interval to 3 min. This standard would be limited to Class A vessels only, and furthermore a transmission would be suppressed if a vessel is within range of an AIS base station. The timeline for the introduction of this standard, including the upgrade of existing AIS transmitters, has been recently addressed at the World Radiocommunication Conference 2012.

An example of the probability of detection for the satellite specific AIS, as determined by the ITU [14], is shown in Figure 20. These results show that the detection is around an order of magnitude better than that for the standard AIS messages.



Figure 20: Detection statistics with 3^{rd} AIS satellite channel (assuming uniform ship distribution) [14]

3.3 Model Implementation

The initial model implementation relies on the global ship distribution, the satellite orbit and resulting footprint, and the calculation of the probability of AIS detection according to the models outlined in the previous section. The options for input therefore include the specific global ship distribution database, the satellite to be considered (or alternatively specified orbit parameters) and the analytic or stochastic model to be calculated. The output can either be the general probability of detection curves as a function of the number of ships, or the probability relevant to a specific area of interest.

3.3.1 Model Verification

The implementation of the above models has been verified against the results presented in the published literature, most notably the FFI, ITU and Tunaley reports. Examples of comparisons between the model results produced here and those given in other reports are shown in the figures below. Table 8 provides a summary of parameters used for each case represented in the discussion below.

Parameter	FFI-1328 approach [7]	FFI-4390 approach [8]	ITU-2084 approach [13]	Tunaley approach [11]
Altitude, km	600	600	950	-
Field of view diameter, km	148, 370, 741, 1111, 1481	5334	3281	>5000
Size of organized areas, nmi	40x40	-	-	-
Reporting interval, ΔT (s)	10	6	7	6
Observation time, T_{obs} , (s)	Specified in Figure	Specified in Figure	818	900 and 816
Overlap factor, s	-	0.6362	-	0.7
Number of independent channels, n_{ch}	-	2	-	2
Number of messages transmitted by a given ship, $T_{obs} / \Delta T$	-	-	117	150
Time of message length, ms	26.7	26.7	26.7	26.77
Factor to describe the intra-system interference, <i>k</i>	-	-	1.6	-

Table 8: Summary of model parameters used in Figure 21 to Figure 28

Figure 21 and Figure 22 show the C-CORE model results and those from the first FFI approach [7], respectively. The results show ship detection probability as a function of the total number of ships for various swath widths.



Figure 21: Probability of detection, C-CORE implementation of FFI first approach



Figure 22: Probability of detection from FFI report [7]

Similarly, using the second FFI approach [8], the C-CORE implementation output is shown in Figure 23, while the corresponding output reported in the paper is shown in Figure 24. In this case, the results show ship detection probability curves as a function of the total number of ships within the observation area for various observation times.



Figure 23: Probability of detection, C-CORE implementation of FFI second approach



Figure 24: Probability of detection reported by FFI [8]

Figure 25 and Figure 26 illustrate, respectively, the C-CORE model results and those from the ITU report [13], and show the variation of AIS probability of detection with varying observation times, based on either one or six satellites observing a specific area during a single pass or over timeframes of 4 or 12 hours. The actual observation times are shown in the legend of Figure 25, and correspond to the respective scenarios listed for Figure 26.



Figure 25: C-CORE model output using the ITU approach



Figure 26: AIS satellite detection (one and six satellite scenarios)



Figure 27: C-CORE results for Tunaley implementation



Figure 28: Probability of detection against number of ships from [11]

Figure 27 and Figure 28 illustrate the comparison between the current and published results of the statistical model developed by Tunaley [11] to characterize the COM DEV results of D'Souza [16]. The parameters here are specified by Tunaley [11], and in particular include a 6-s message transmission interval and a 10-min observation time. The parameters that have been derived from the COM DEV data are a γ_0 of 0.2683 and a q of 0.904.

The third example in Figure 29 is based on the results of an analysis of the properties of the proposed Message 27, as given in the ITU M.2169 report [14]. The message transmission interval is three min, as well as a six min interval. Both results for the single channel cases

appear to be quite close to that presented in the ITU graph in Figure 30. The results for the twochannel case appear to vary by roughly 5% to 10%. At this time, the reason for this variation is unclear, although the exact parameters and methodology used to generate the ITU results are not given in that report.



Figure 29: C-CORE result for Message 27 use



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Figure 30: Detection statistics with 3^{rd} AIS satellite channel (assuming uniform ship distribution) [14]

3.3.2 RCM Results

Examples of the footprint for a RCM satellite based on an altitude of 600 km and a corresponding FOV with a radius of 2,663 km are shown in Figure 31 to Figure 34. These illustrate typical ship densities for the Arctic and the West and East Coasts of Canada. The number of ships in the footprint is about 800 for the Arctic region, including many ships around Iceland and Greenland, and is respectively 2,900 and 3,100 for the West and East Coasts.

The probability of detection curves for an RCM satellite is shown in Figure 35. These correspond to the analytical and statistical models discussed in the previous section. The results obtained from these two methodologies are indistinguishable in this case. An average message transmission interval of seven seconds is used here. The observation time within the satellite footprint is taken as five min and 10 min, the former being that used in the specification of the COM DEV receiver, and the latter being the approximate average time of visibility within the RCM footprint.

The detection of AIS messages using the COM DEV receiver and processor has been reported, for instance, by D'Souza [16]. In this case, the de-collision of AIS messages is represented by the γ parameter. These results have been analyzed by Tunaley [11] in terms of a stochastic model, where the probability of detection is given by:

$p = 1 - (1 - \gamma_0 s^{-\lambda \tau_0 (1 - q) t_{1+s})} \frac{T_{q2s}}{\Delta t}$

(5)

where, γ_0 is the probability of receiving an uncorrupted message at the receiver input, and q is the

probability that a single message will be uncorrupted by reception of another message. The results of the Tunaley model for an RCM satellite are shown in Figure 36. The average message transmission interval is seven seconds and the observation time is five min. The probability of detection for the standard receiver as shown in the previous figure is reproduced here for reference.



Figure 31: Example of ship densities for a RCM footprint in the north



Figure 32: Example of ship densities for a RCM footprint in the north (zoomed view)



Figure 33: Example of ship densities for a RCM footprint in the Pacific



Figure 34: Example of ship densities for a RCM footprint in the Atlantic



Figure 35: C-CORE model implementation result for RCM



Figure 36: Comparison of enhanced model implementation vs. standard model for RCM

Of interest also is the potential improvement achieved through the introduction of a satellite specific AIS signal, namely Message 27. Figure 37 shows the probability of detection for Message 27 as transmitted on channels three and four, with an improvement in the detection of

about an order of magnitude. In this instance, the number of ships within the satellite footprint that will be transmitting Message 27 will often be reduced since any ships within range of a coastal AIS base station will not transmit Message 27. It should be noted that the message transmission period of three minutes means that the number of repeat messages transmitted within the observation time is limited, especially for restricted times such as the five-min timeframe shown here. This is evident in the probability of detection curves of Figure 37, where the curve for the five -min observation time decreases significantly more quickly than that for the 10-min observation time.



Figure 37: Ship detection probability with the introduction of Message 27

4 Further Model Development

At present, there are several efforts ongoing to extend the current implementation. The main areas of activity include:

- 1. Updates to the GSDM;
- 2. Furthering the simple model implementation to include non-uniform characteristics;
- 3. Further validation exercises; and
- 4. Additional analysis pertaining to RCM.

The intent is to get the model to a state that of usability that do not require extensive code modification to implement model runs for various scenarios. The current model implementation is being extended to include a user interface allowing input of user specified AIS satellite parameters and other variables to produce model outputs for specific use cases. This will provide end users with a more useful tool for further work beyond the scope of the current project. Details pertaining to each of the activities listed above are discussed in the following Sub-Sections.

4.1 GSDM

As indicated in Sub-Section 2.4, the GSDM will be compiled using the Method 2 filtered approach. The intent is to update the GSDM on a regular basis going forward, based on the availability of new data. Implementation of the GSDM is configured to easily ingest new data to facilitate this. DRDC Ottawa personnel are actively acquiring new data from the MSSIS and eEViewer sources. This new data will be utilized to update the GSDM once the current acquisition activity is completed. It is expected that additional data acquisition efforts will be conducted in the future for use in GSDM updates.

4.2 Non-uniform Characteristics

The ability to simulate AIS message transmissions and detection is advantageous in the analysis of non-uniform characteristics such as exist in ship distributions and terrestrial interference. An algorithm for the Monte Carlo simulation of the AIS message detection is currently being developed. The planned simulation capabilities will include a basic simulation of random AIS transmissions from a uniform ship distribution in the satellite FOV. This will be extended to include non-uniform ship distributions. Ship distributions are based on the cell densities as defined in the GSDM. It is assumed that there are no message collisions within a given cell. A further extension of this will be to vary the AIS transmission frequency within each cell based on ship activity. For each cell, a percentage of ships will be assumed to be at port (i.e., reduced transmission frequency) and the remainder will be moving with AIS transmissions occurring at a higher frequency. External noise sources will also be included in the simulation. The initial implementation of this will be based on power level and duty cycle for known interference

sources located around the globe. Interference sources will be represented as point sources within a given cell. Additional functionality to allow stepping of the satellite FOV across a region of interest for the scenarios listed above is also planned.

4.3 Validation

Two validation approaches are ongoing to further confidence in the model results. The first approach will look at eEGlobal data for a single sensor. Data taken for a single sensor pass to determine the number of ships and the model run on this basis. This is compared to the baseline density map. This is then repeated for a series of passes and sensors. The initial results from this validation method were not as definitive as expected. Data were isolated for a single pass of the AprizeSat-3 (AS3) satellite on February 26, 2012 and analyzed for two selected FOVs covered in the pass representing areas of low and medium ship density as per the GSDM. The low density location was over the Gulf of Mexico. Results for the low density area show an expected number of ships from the GSDM to be 233 with the number of ships detected in the single pass being 40. Similarly, the results for the medium density area are 4,067 ships expected from the GSDM and 428 detected. AS3 contains a standard AIS receiver with no enhanced processing capabilities.

Given the absence of enhanced processing on AS3, the results found for the medium density area are not surprising and could even be considered fairly good. Expected performance with over 4,000 ships in the FOV gives a probability of detection of zero based on the standard ITU model. Surprisingly, the performance in the low density area is less than expected. With only 233 ships expected in the FOV, the expected probability of detection is 100%, but, only 40 ships were detected.

Further consideration of this result, especially for the low density area highlights a number of potential issues with this validation approach. The result is for a single snapshot for a single sensor. We are comparing the actual result to a GSDM that is developed using a significant data set containing several sensors over an extended period of time and shows an average number of vessels to be expected. Although extensive, the GSDM dataset is still very much limited. As such, the snapshot captured by AS3 may be abnormal due to a seasonal or time of day variation in ship traffic or the non-uniform distribution of ships in the FOV may be an issue. In the absence of an independent source of ground truth data, it is difficult to assess performance on this single pass data. Further analysis using additional passes will be carried out to provide a better assessment of this validation method and determine if this approach is reasonable going forward.

The second validation approach being investigated looks at the probability of redetection for satellite passes close in time. Similar to the first approach, data from a single sensor are used. Two passes close in time are then used to find MMSI's common to both passes. Initial efforts used data from AprizeSat-4 (AS4) obtained on March 2, 2011. From this data, the initial pass showed 17, 322 messages decoded with 5,419 of these from unique MMSI's. The second pass showed 14,523 messages decoded with 5,170 unique MMSI's. Between the two passes, 2,473 MMSI's were repeated for a re-detection rate of 45.6%. These numbers are for two complete cycles. Re-detection rates for specific FOVs were not analyzed. Indications from the analysis show that very few messages are decoded in areas of high ship density, likely due to the number

of signal collisions occurring in these areas. Further details and results pertaining to this approach will be determined as the work progresses.

4.4 RCM Analysis

Initial model runs using RCM specific parameters are described in Sub-Section 3.3.2. As model enhancements are implemented, additional scenarios will be run for RCM. Ongoing activities include analysis of expected FOVs based on the GSDM to determine areas of high and low density and the corresponding numbers of ships expected, analysis of expected times of visibility and corresponding probabilities of detection as a function of these parameters. Once the full model implementation is in place, runs for specific use cases will be conducted for scenarios identified in consultation with DRDC personnel. Primary scenarios will be based around performance in maritime approaches in Canada's AOI's.

Furthermore, an area of interest within the satellite footprint will be considered to enable the selection of a region corresponding to a SAR swath. This will later be combined with SAR probability of ship detection calculations to help in the analyses of the combined AIS and SAR detection capabilities.

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List of acronyms

AIS	Automatic Identification System
AOI	Area of Interest
Amver	Automated Merchant Vessel Reporting program
BLOS	Beyond line-of-sight
CSA	Canadian Space Agency
CSTDMA	Carrier-sense time domain multiple access
еE	Exact Earth
FFI	Norwegian Defence Research Establishment
FOV	Field of view
GSDM	Global ship density map
HITS	Historical Temporal Shipping
IMO	International Maritime Organization
ITU	International Telecommunication Union
LMR	Land Mobile Radio
LOS	Line of sight
MMSI	Mobile service identity
MSSIS	Maritime Safety and Security Information System
RCM	RADARSAT Constellation Mission
RDE	Radar Data Exploitation
SAIS	Satellite based automatic identification system
SOLAS	Safety of life at sea
SOTDMA	Self-organizing time domain multiple access
TAIS	Terrestrial based automatic identification system
TDMA	Time domain multiple access
VHF	Very high frequency
VPCS	VHF public correspondence stations
WMO VOS	World Meteorological Services Voluntary Observing Ships

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An Automatic Identification System (AIS) capability on the RADARSAT Constellation Mission (RCM) will enhance the Canada First Defence Strategy goals of conducting national and continental operations and defending Canada. Key to understanding this is the ability to model and simulate satellite AIS (SAIS) performance characteristics. This report provides an overview of a statistical model implemented by C-CORE to evaluate SAIS performance. Included is a discussion on the approach and methodology employed with results presented for the specific case of the proposed AIS payload on the RCM. The model is driven by a global ship density map (GSDM) developed as a part of this project. GSDM's are generated based on data provided by DRDC for this purpose including both SAIS data (from exactEarth) and data from the Maritime Safety and Security Information System (MSSIS). C-CORE has implemented a basic model corresponding to previous analytical and stochastic model approached reported in the literature by the International Telecommunication Union (ITU), Norwegian Defence Research Establishment (FFI) and London Research and Development Corporation (LRDC). Simple cases for RCM have been run and initial results show that standard model results (no provision for signal de-collision) indicate significant decreases in probability of detection as the number of ships in the field of view increases, while the enhanced model (with provision for de-collision techniques) shows much more favourable results. Further AIS model enhancements and improved vessel identification capability with AIS and synthetic aperture radar (SAR) sensors co-located on a satellite platform is also discussed.

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Performance Modelling; AIS; Ship Density; RADARSAT Constellation Mission; RADARSAT-2

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