Modeling the Impact of Blue Force Tracking on the Automatic Identification System Very High Frequency Data Link

A Project Report

Submitted to the Faculty

of the

UNITED STATES COAST GUARD ACADEMY

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

in

Electrical Engineering

by

DeCarol A. Davis, Cadet First Class

Projects in Electrical and Computer Engineering
25 April 2008

Reviewed By:

LCDR Robert Oatman, Project Advisor

LCDR Daniel K. Pickles, Class Coordinator

Professor Keith C. Gross, Chief, Electrical & Computer Engineering Section

Abstract

This report assesses the impact of using the Automatic Identification System (AIS) Very High Frequency Data Link (VDL) to support Blue Force Tracking (BFT) for United States Coast Guard (USCG) afloat assets in the port and near-coastal operating environment. BFT is a general term used to define the next generation command and control data communications between CG shore units, CG boats and cutters, and port partner resources. First generation BFT prototypes leveraged the AIS VDL because the network is widely used, cost-free, and readily available. Prior to deploying an enterprise-wide BFT solution, program managers at USCG Headquarters requested additional information on any potential impacts the system might have on the AIS VDL, noting that current prototypes failed to follow necessary protocols for ensuring that CG operations do not consume too much of the AIS VDL and disrupt the transmissions of commercial users. This report summarizes the findings of a simulation for the port of New York. Results show that although BFT has a noticeable impact on the AIS VDL, it does not overload the channel's capacity. Moreover, preliminary findings suggest that the AIS VDL could support additional data communications necessary to facilitate enhancements to BFT.

Table of Contents

Introduction page 1

Background page 2 page 2

Objective page 6

System Design page 8

Figure 1: Daily Vessel Loading for New York's AOR page 9

Table 1: Blue Forces Operating in New York Harbor page 11

Figure 2: Design Solution Flow Chart page 12

Results page 13

Figure 3: Baseline Average Slot Distribution page 13

Figure 4: Baseline Slot Capacity page 14

Figure 5: Baseline Slot Availability page 15

Figure 6: Slot Availability w/ Blue Force Loading (Stage 2) page 16

Figure 7: Slot Availability w/ Blue Force Loading (Stage 3) page 17

Conclusions page 18

References page 19

Bibliography page 20

Appendices page 21

Appendix A: Business Case page A-1

Appendix B: Functional Requirements page B-1

Appendix C: Design Specification page C-1

Appendix D: Project Management Plan page D-1

Appendix E: Support Plan page E-1

Appendix F: Slot Availability Plots page F-1

Introduction

Following the events of September 11, 2001, the need to enhance maritime domain awareness (MDA) and secure the nation's borders from terrorist activity rose high on the United States' agenda. To improve interagency coordination and organization, Blue Force Tracking was proposed as a situational awareness tool to promote communication between United States Coast Guard (USCG) shore units, CG boats and cutters, and port partner resources. This improvement, coupled with other sensor and communications products, took aim at developing heightened levels of MDA.

The USCG Headquarters Integrated Systems Division (CG-641), the project sponsor, proposed the implementation of BFT over the Automatic Identification System (AIS) Very High Frequency Data Link (VDL) because the network was widely used, cost-free, and readily available. The problem in using the AIS VDL for CG operational needs was that current BFT prototypes failed to follow necessary protocols for ensuring that CG operations do not consume too much of the AIS VDL and disrupt the transmissions of commercial users. Prior to deploying a CG wide BFT solution, program managers at CG-641 requested additional information on any potential impacts the system might have on the AIS VDL. The focus of this report was to assess the impact of BFT over the AIS VDL.

The impact of BFT was measured by observing the effects of Blue Force vessel loading on the AIS VDL's slot capacity. The AIS VDL is composed of a finite number of slots that are reserved by users through Self-Organizing Time Domain Multiple Access relying on GPS timing signals. Using the UAIS Simulation Software developed by the U.S. Coast Guard Research and

Development Center, the channel's slot availability could be determined by simulating slot usage. For the purposes of this project, slot availability was defined as the number of slots unreserved and ready during any given minute over the course of a day. Slot usage was modeled under three different scenarios. The project stages are as follows:

1. A baseline stage modeling the operation of Class A vessels over the AIS VDL without Blue Forces
2. A stage modeling the operation of Class A vessels over the AIS VDL with Blue Forces only transmitting 1-slot position reports
3. A stage modeling the operation of Class A vessels over the AIS VDL with Blue Forces transmitting 5-slot broadcasts in addition to1-slot position reports.

Decisions for the design solution were made with the intent to create an operational picture from which future capabilities of the AIS VDL could be discussed. *Results show that although BFT has a noticeable impact on the AIS VDL, it does not overload the AIS channel*. At a minimum, 45.7% of the AIS VDL is available to support additional operational requirements, and at most, Blue Forces (i.e., all CG and port partner afloat resources) will make up 25% of New York's vessel AIS VDL traffic. The project results also show that the Coast Guard could realistically employ the AIS VDL for additional data communications in support of BFT operational needs that would require more of the AIS channel.

Background

Blue Force Tracking (BFT) is a situational awareness tool designed to improve interagency coordination and enhance communications between CG shore units, CG boats and cutters, and

port partner resources. BFT operates in real time, allowing the Coast Guard to view information pertaining to its units almost simultaneously from when the information was output [1]. Currently, the Coast Guard is exploring several prototypes for BFT including AIS BFT, cellular-based BFT, and over-the-horizon, satellite-based Iridium BFT [2]. BFT systems have generated considerable interest because they represent a major step forward in establishing a complete network-centric command for the Coast Guard, offering point-to-point communication between all Blue Forces, whether U.S. Coast Guard or port partner units [3]. CG-641 is focusing its efforts toward AIS BFT because the network is widely used, cost-free, and readily available.

The problem in using the AIS VDL for BFT is that current prototypes fail to follow necessary protocols for ensuring that CG operations do not compromise the integrity of the AIS by disrupting the primary requirement of the system, i.e., safe navigation for commercial vessel movements. This issue has been formally recognized in a formal legal opinion delivered by Rear Admiral W. D. Baumgartner, Judge Advocate General, on July 28, 2006. Given the sensitive nature of Coast Guard and port partner operations, a primary requirement of any BFT system is to ensure the security of operational data, be it location of forces, operational areas/overlays or high interest vessel data. This need for the Coast Guard to protect sensitive information in transit necessitates encryption. The Coast Guard's current solution for encrypting position report transmissions over AIS consumes two slots, double the amount of space necessary to transmit a normal AIS position report for a Class A vessel. This issue, as defined in the aforementioned JAG memo, has been characterized as "politeness, in which "politeness" constitutes noninterference over the AIS VDL by limiting one's slot usage [4]. Current CG BFT prototypes are exceeding the 1-slot slot capacity for position reports. To address this concern the USCG

Command and Control Engineering Center and CG-641 developed new protocols for AIS data communications in support of BFT. These new protocols, also known as message types have been formally recognized and approved by the international AIS governing bodies and are outlined in the International Telecommunication Union (ITU) standards ITU-R M.1371-2 [4] [5] [6].

Message Types standardize the way in which the slots are used over the AIS VDL. Under the original protocol, the CG prototypes use Messages 6 and 8 to transport encrypted Coast Guard information. Both Message Types are binary, where Message 6 consists of an addressed binary message and Message 8 consists of a broadcasted binary message. The new AIS BFT message types, Message 25 and Message 26 are also defined as one-slot multi-purpose binary messages and multi-slot multi-purpose binary message, respectively. Message 25, the one-slot multi-purpose binary message, allows for a one-slot encrypted position report rather than the previous two-slot position report of Message 6. Message 26 will similarly allow the CG to leverage the AIS VDL to send encrypted multi-slot transmissions, which include text messages and overlays (search patterns and vessel of interest position reports). With Messages 25 and 26, Blue Forces can more "politely" operate over the AIS VDL, not occupying more slots than necessary to transmit encrypted messages. To assess the impact of Messages 25 and 26, the slot use protocols of the AIS VDL must be understood.

The USCG Navigation Center defines AIS as the following:

> "The AIS a shipboard broadcast system that acts like a transponder, operating in the VHF maritime band, that is capable of handling well over 4,500 reports per minute and updates as often as every two seconds. It uses Self-Organizing Time Division Multiple Access

(SOTDMA) technology to meet this high broadcast rate and ensure reliable ship-to-ship operation" [7]

AIS was originally required on ships by the SOLAS International Convention for the Safety of Life at Sea 1974 to promote maritime safety [8]. AIS allows you to select a ship on the display and observe the ship's name, latitude, longitude, course over ground, true heading, rate of turn, speed over ground, classification, call sign, registration number, Maritime Mobile Service Identity, and other important information [9]. The transmission of this data is known as a position report. An advantage of AIS allows you to call any ship over VHF radiotelephone by name, rather than by geographic means or relative positions.

AIS was originally designed for large, commercial Class A vessels. "Class A" is an AIS term and is used to describe commercial users who have "Shipborne mobile equipment intended for vessels meeting the requirements of IMO [International Maritime Organization] AIS carriage requirement" [7]. Position and timing information, necessary for timing slot usage on the AIS VDL, is normally derived from an integrated or external GPS receiver. Other information which is broadcasted by the AIS transponder is electronically obtained from shipboard equipment through standard marine data connections. The AIS transponder transmits and receives over two VHF frequencies to avoid signal interference problems and to allow channels to be shifted without a loss of communications between ships [9]. Each of the AIS frequencies is comprised of 2250 slots per minute or 'frame', making a total of 4500 available slots per minute over the AIS VDL channels. The impact of BFT over the AIS VDL can be calculated by measuring slot usage. Assessing the impact of BFT slot usage over the AIS VDL will help engineers to

determine whether or not there is capacity on the AIS VDL channels for Messages 25 and 26 to be employed.

Objective

The goal of this project is to assess the impact of BFT on the AIS VDL. The U.S. Coast Guard desires to expand its use of the AIS VDL to improve situational awareness and MDA. This plan for BFT enables the Coast Guard to inexpensively and effectively communicate over the AIS channel with other Coast Guard units as well as local, state, and federal agencies without being tracked by over the AIS VDL by other AIS users. To find more information regarding project significance and reasons for research, refer to the Business Case in Appendix A.

The objective was achieved by measuring the effects of Blue Force vessel loading on the AIS VDL's slot availability. The functional requirements were that these measurements had to cover the scope of a max-loaded scenario, model the effects of the new operational requirements defined in Messages 25 and 26, and be completed in an eight month time span to meet the 25 April 2008 deadline. Additional information regarding functional requirements can be found in the Functional Requirements document, Appendix B.

The AIS channel is composed of a finite number of slots that are reserved by users through Self-Organizing Time Domain Multiple Access relying on GPS. Using the UAIS Simulation Software developed by the U.S. Coast Guard Research and Development Center, the channel's slot availability could be determined by measuring the slot usage of three different stages.

The first stage was a baseline of the AIS VDL's capacity, modeling the operation of Class A vessels over the AIS VDL without Blue Force vessel loading. The second stage was a model of

Class A vessels operating over the AIS VDL with Blue Forces only transmitting 1-slot position reports every 15 seconds per the STEDS protocol for Messages 25 and 26. The final stage modeled the operation of Class A vessels over the AIS VDL with Blue Forces transmitting 5-slot broadcasts in addition to the 1-slot position reports.

Decisions for the design solution were made with the intent to create an operational picture from which future capabilities of the AIS VDL could be discussed. With regard to the Coast Guard missions, this project proposes to analyze and quantify only the specific Coast Guard operational requirements defined in the STEDS requirements: position reports, text messages, overlays (specifically security zones and search patterns), and vessel of interest data.

Sector New York's area of responsibility (AOR) was the only port analyzed because of the project's time constraints, but New York's high vessel traffic characteristic makes it an effective baseline for researching the channel capacity of the AIS VDL. Further research can increase the fidelity of results found in this project and better determine the AIS VDL's capability across the nation.

The three stages in the design solution were chosen to provide a baseline for comparison, to isolate the impact of Blue Forces acting as they already do, and to assess the impact of the Blue Forces using the new operational requirements. The results will be interpreted by only looking at one of the two AIS frequencies. This approach makes the data easier to read and compile, and upon testing, there was a deviation of less than 2% with the number of slot available for Class A's on each frequency. Assuming that the slots used are representative on the Blue Forces impact, the decision to use slot availability to determine the effects of loading narrows the scope of the AIS VDL but allows a more focused analysis of the Blue Force's impact on the AIS VDL.

There were several constraints in obtaining the project's objective. The input data for the simulations were representative of Class A vessel densities for three selected days in 2007. This does not account for future potential VDL loading increases due to greater numbers of vessels. The primary purpose of this project was to assess Blue Forces impact on Class A vessels; therefore, only Class A data was used. The simulations do not account for eventual addition of Class B vessel reporting. To give the project operational focus, scenarios are taken from actual NAIS daily archives at the selected locations, and include broadcasts from any vessel "heard" by specified receiver on a given day. This includes any anchored vessels, which have very low report rates. To see more details regarding the decisions and constraints of the project, refer to the Design Specification and the Project Management Plan found in Appendix C and D, respectively.

System Design

Using the UAIS Simulation Software developed by the U.S. Coast Guard Research and Development Center, the impact of Blue Force vessel loading on the AIS VDL's slot availability could be observed. Slot availability is the AIS VDL's channel capacity as defined by the number of slots unreserved and ready for use at a given minute during the course of a day. Slot availability was examined at three stages. Slot availability was examined at three stages. They include:

1. A baseline scenario modeling the operation of Class A vessels over the AIS VDL without Blue Forces
2. Scenario 1 with the addition of Blue Forces transmitting 1-slot position reports every 15 seconds

3. Scenario2 with the additional loading created by having 18 of the Blue Forces transmitting one 5 slot messages every hour

For each of these stages, the slot availability was observed for three different days. The input data for these days was generated from actual data recorded in NAIS logs in 2007 for the Sector New York's AOR. The NAIS data used in the simulation software comes from 3 antennas that cover Sector New York's AOR. The decision to use actual data, rather than arbitrarily loading the VDL and assessing its limits, gives the project operational validity and insight by modeling what has actually been observed on the water.

The three days selected for study represent increasing levels of loading. The 90th percentile is a day for which the total number of vessels transiting within AIS range of Sector New York is such that 90% of the time there will be equal to or fewer vessels. For example, if the 90th percentile day vessel count value is 300, 90% of the time New York would have daily vessel counts equal to or less than 300. The selected days include 05 October 2007 (90th percentile), 02 August 2007 (95th percentile), and 25 September 2007 (99.9th percentile). The number of vessels transmitting in the New York AOR for each day is shown in Figure 1, where 25 September 2007 represents that maximum (99.9th percentile) loading scenario.

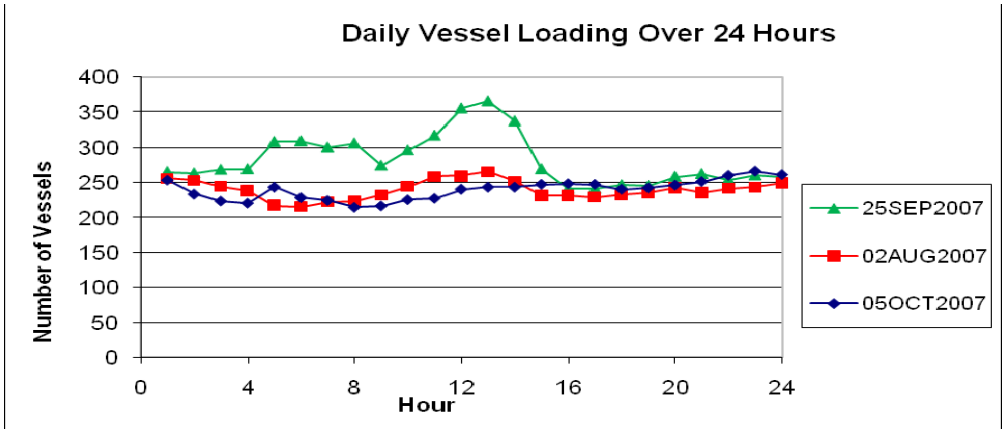

Figure 1: Daily Vessel Loading for New York's AOR

Each project stage required the inputs of the simulation software to be modified. The modifications were for the following parameters: (1) The day used to generate .mpo input file, which dictates how many Class A users will be loaded on the AIS VDL, how they will be dead reckoned in the simulation, and how they will reserve slots); (2) The number of Blue Forces to load in the scenario; (3) The speed and location of the Blue Forces; (4) The transmission rate (or interval) for the Blue Forces; (5) The number of slots that each Blue Force will use upon transmission. Figure 2 represents a flow diagram of the steps take to modify the input to the software and retrieve results for analysis. For additional information regarding the technical procedures for manipulating inputs, refer to the Support Plan found in Appendix E.

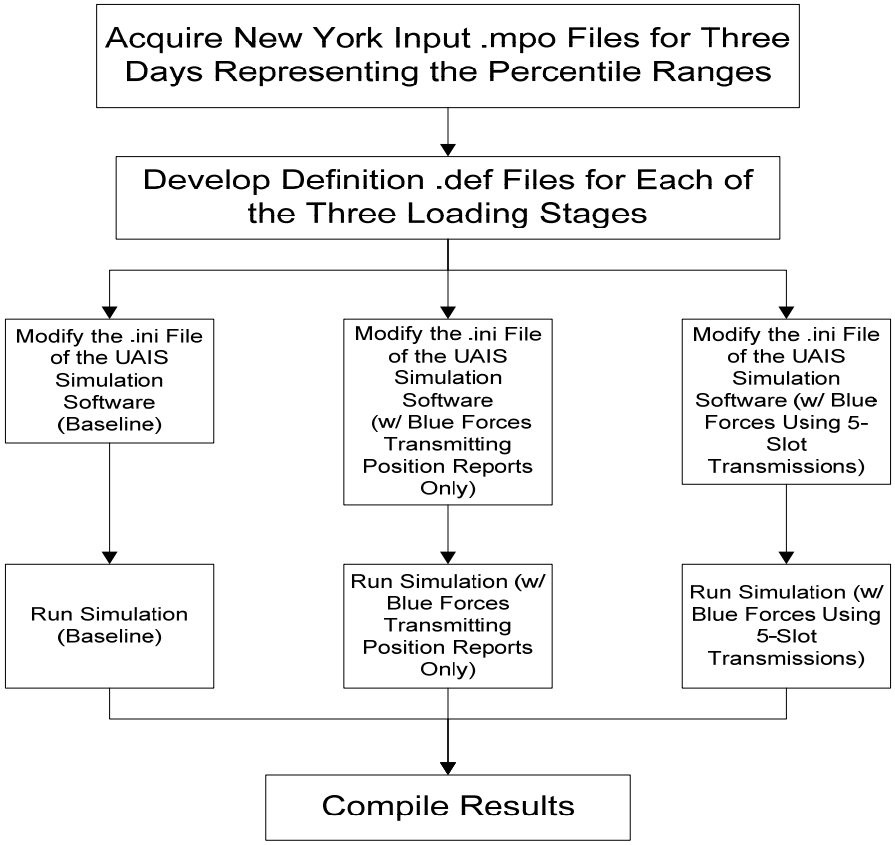

Figure 2: Design Solution Flow Chart

For Stage 1, the baseline, the three specified days were the only necessary specification because there were no Blue Forces loaded in the scenario. For Stage 2, the software was modified to run the three days with 61 Blue Forces traveling zero knots located at select positions in New York Harbor and transmitted 1 slot for position reports every 15 seconds. The UAIS Simulation Software was originally designed to develop protocol for Class A vessels only. This limitation meant that the locations for Blue Force loading had to be defined by using information gathered from New York's Vessel Traffic Service (VTS) experts, SAR Controllers, Command Center Watch Standers, and Operations Officers. Although the Blue Forces were defined to travel at zero knots, slots are used according to the interval defined for transmission in the .ini input file.

For Stage 3, the final simulation stage, the software was modified to run the three days with 61 Blue Forces transmitting 1-slot for position reports every 15 seconds, eight Blue Forces transmitting 5-slot text messages every hour, and ten Blue Forces transmitting 5-slot overlays every hour. In the BFT protocol, Blue Forces are permitted to use between on and five slots. In addition to the 1-slot position reports, five-slot broadcasts were the only transmissions used in Stage 3 because assuming 5-slot usage generated the max-loaded operational scenario. This scenario can be visualized as trying to model the effects of BFT over the AIS VDL on a day such as September 11, 2001, where all Coast Guard units and port partners are on the water in high traffic situations.

The number of 5-slot transmissions used to load the scenario was created by analyzing data obtained through multiple methods such as conference calls with key personnel and operational records. Members of the key personnel included Vessel Traffic Service (VTS) experts, SAR Controllers, Command Center Watch Standers, and Operations Officers. The types of operations

documents that were used were OPSUM, SAR Logs, SAR Stats, OPCEN Status Boards, VTS Activity Reports, and LE Logs. The number of Blue Force vessels selected – 61 Blue Forces – was also generated from VTS reports, OPSUMs, and conference calls with Command Center Watch Standers. Table 1 illustrates the minimum, average, and maximum number of Blue Forces and port partners available to New York.

Blue Forces Operating in New York Harbor			
Type of Vessel	**Min # of Vessels Daily**	**Max# of Vessels Daily**	**Avg # of Vessels Daily**
Coast Guard (87's or 110')	**1**	**3**	**2**
Coast Guard Small Boats	**4**	**28**	**4**
Coast Guard Auxiliary	**1**	**10**	**4**
Port Partners	**12**	**20**	**12**
Total BFT Assets	**18**	**61**	**22**

Table 1: Blue Forces Operating in New York Harbor

To assess the impact of the Coast Guard's text message and overlay applications, the impact using 5 slots versus 1 slot were examined to ensure that there were enough slots available for the Coast Guard to employ these new operational requirements reliably. A distribution summary of the contiguous slots available was also generated to insure that there were enough 5-slot baseline occurrences to meet operational needs. A bar chart illustrating the number of contiguous slots available on average and at a minimum for each of the three days can also be found in the results of this report.

The results from this design were used to develop a recommendation to CG-641 as to whether or not the AIS VDL has the capacity to perform new operational requirements without negatively affecting Class A AIS users.

Results

The first step in achieving results was to establish a baseline of slots being used by Class A vessels and model the slot distribution of the AIS VDL. A model of the slot distribution can be seen in Figure 3.

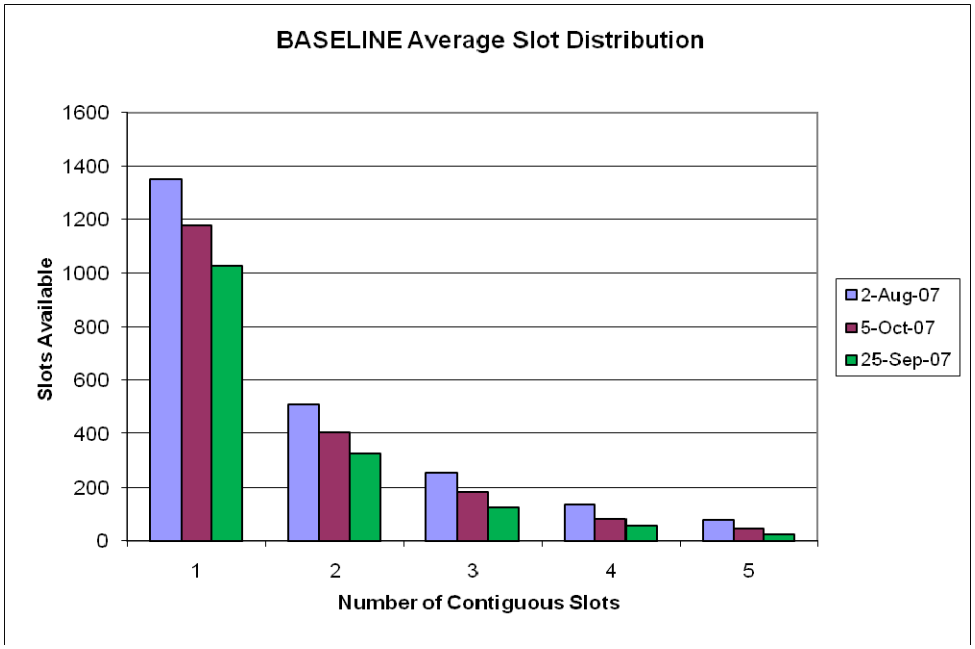

Figure 3: Baseline Average Slot Distribution

The proposal for operational requirements over the AIS VDL developed by CG-641 consists of transmitting text messages and overlays, which require multiple slot transmissions. In most practical operational scenarios, the length of text necessary to provide meaningful communications, will dictate the maximum allowable slots, i.e., 5. Similarly, the composition of

most overlays will necessitate 5 slots in order to adequately define the geographic boundaries and any complementary descriptions. The distribution summary seen in Figure 3 was generated to ensure that there were enough 5-slot baseline occurrences to meet operational needs. On 25 September, the maximum loading scenario, there was an average of 27 5-slot availabilities per minute while a maximum of 18 per hour are needed to meet Coast Guard needs based surveys and research.

Stage 1 of the simulation process provided a baseline of the slots available on the AIS VDL on a given day per minute prior to any loading. Figure 4 below illustrates the maximum number of slots consumed per day.

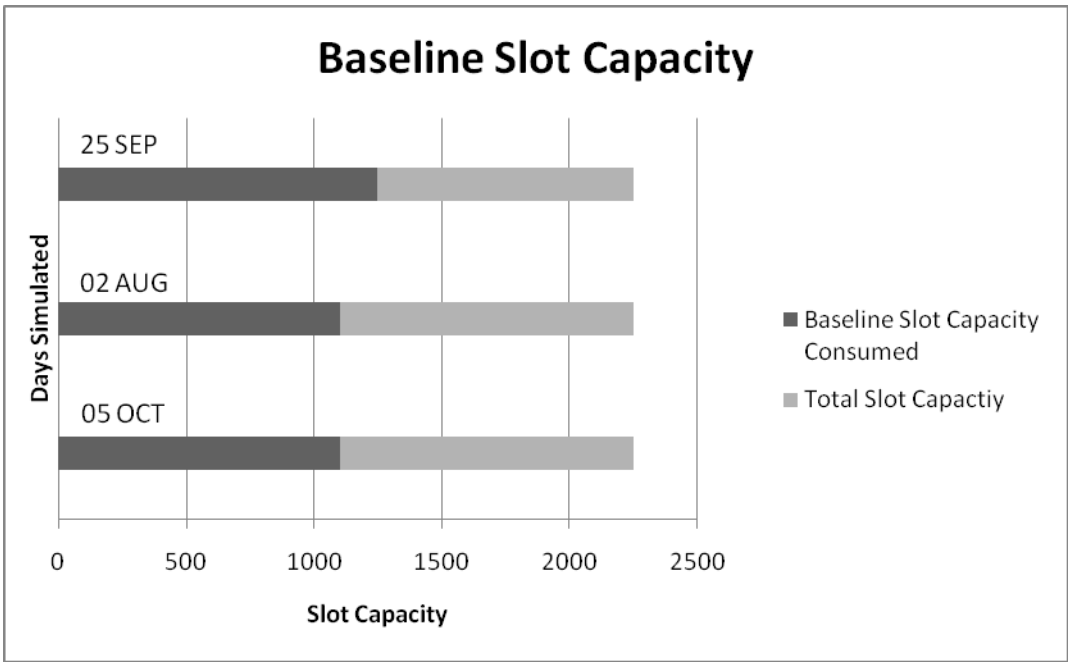

Figure 4: Baseline Slot Capacity

From Figure 4, there was 55.6% of the AIS VDL consumed on 25 September 2007, 48.9% consumed on 02 August 2007, and 48.9% consumed on 05 October 2007.

Three curves representing a baseline of slots available throughout the day based on percentage of the AIS VDL can be seen in Figure 5. The green curve representing 25 September 2007 shows that there are at least 1000 slots available per minute 100% of the time.

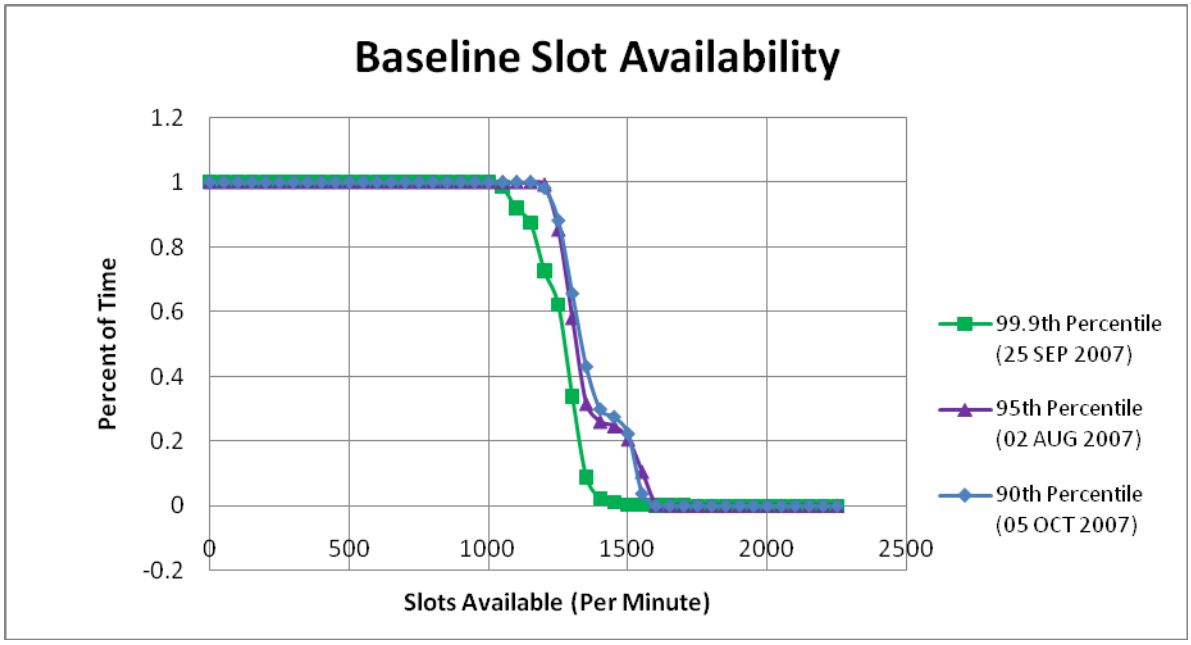

Figure 5: Baseline Slot Availability

From these results, there is an average of 50% of the AIS VDL still available. At a minimum, there is 42.2% of the AIS VDL available for additional operational requirements. With Blue Forces making up 25% of New York's vessel traffic, a slot capacity of 45.7% over the AIS VDL was hypothesized to meet USCG needs. Results from Stage 2 and 3 simulations validate this hypothesis.

The results from the Stage 2 simulation are the effects of loading the AIS VDL with Blue Forces broadcasting 1-slot transmissions only, which are position reports, and the results from Stage 3 are the effects of loading the AIS VDL with Blue Forces broadcasting 5-slot transmissions in

addition to the 1-slot position reports to model the effects of overlay and text message applications. To observe the effects of loading at Stage 2, the impact of Blue Forces transmitting position reports only was compared to the baseline as seen in Figure 6. The slot availability results for 25 September 2007 were used because this day represents that maximally loaded scenario.

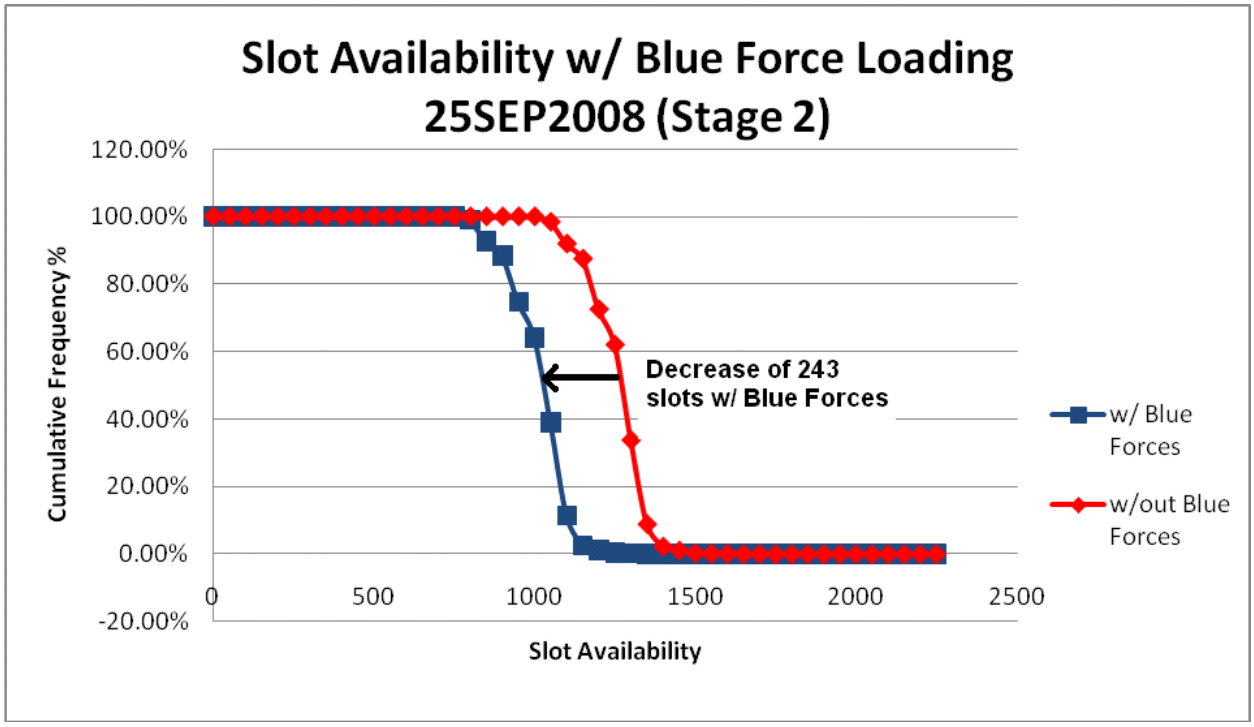

Figure 6: Slot Availability w/ Blue Force Loading (Stage 2)

In Figure 6, the blue curve labeled "w/ Blue Forces" is shifted to the left, which is closer to the y-axis at zero slots available. The leftward shift shows that 243 slots were consumed by Blue Forces, a 24.3% decrease in the number of slots available. As this curve shifts to the left, less slots are available over the AIS VDL, meaning there is less capacity for the AIS VDL to meet its operational requirements. The difference between the "w/out Blue Forces" curve and the "w/ Blue Forces" curve illustrates the impact of BFT. Although this impact is significant, there are

still 757 slots available *per minute* over the AIS VDL. Figure 7 shows that the slots available for the Stage 3 loading scenario vary from Stage 2 by only 7%.

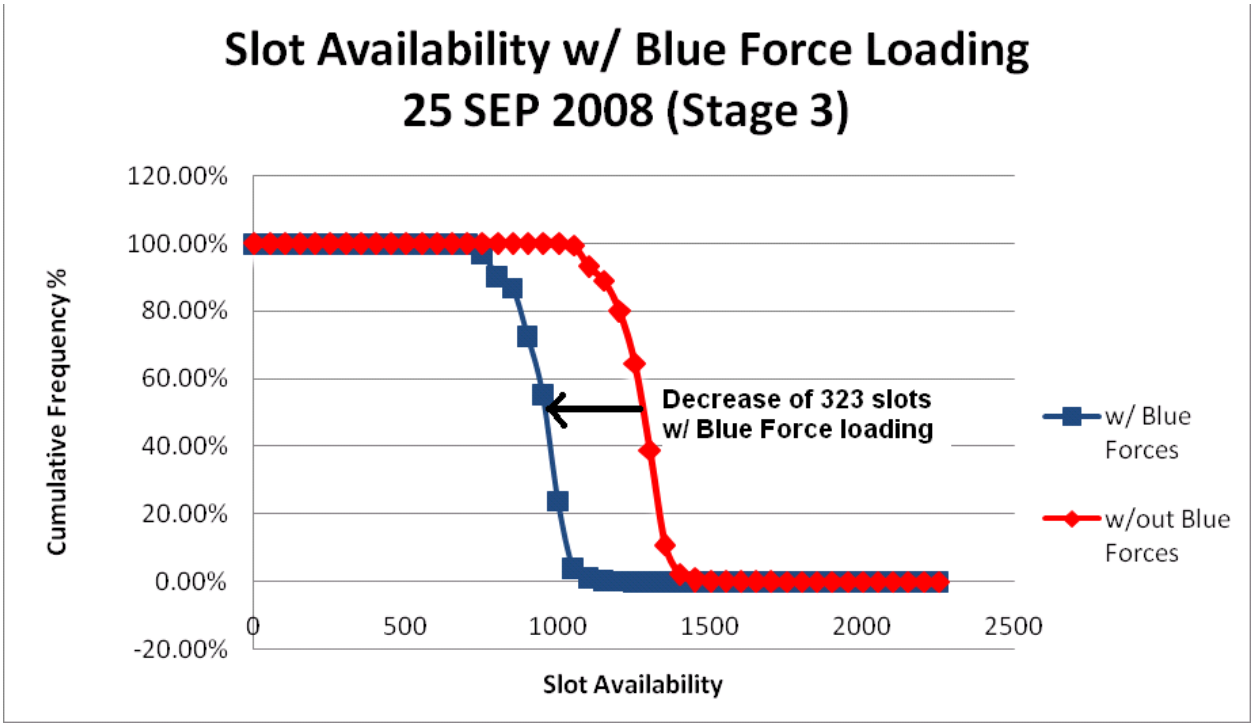

Figure 7: Slot Availability w/ Blue Force Loading (Stage 3)

In Figure 7, the blue curve labeled "w/ Blue Forces" is shifted to the left, showing a 32.3% decrease in the number of slots available. This leftward shift shows that 323 slots were consumed by Blue Forces using multiple slot transmissions. From the 25 September 2007 data, there are always at least 677 slots available per minute it is revealed that the AIS VDL has the capacity for the additional loading proposed by CG-641. At the very least given maximum loading and the addition of new operational requirements, there would be at least 677 slots still available per minute, leaving 30% of the AIS VDL in reserve.

Slot availability plots for all three days simulated can be found in Appendix F. *These results conclude that although BFT has a noticeable impact on the AIS VDL, it does not overload the channel's capacity*. The Coast Guard may be able to employ the AIS VDL in New York for additional data communication requirements.

Conclusions

The focus of this report was to assess the impact of BFT over the AIS VDL. The problem in using the AIS VDL for CG operational needs is that the current BFT prototypes fail to follow necessary protocols for ensuring that CG operations do not consume too much of the AIS VDL and disrupt the transmissions of commercial users.

The impact of BFT was measured by observing the effects of Blue Force vessel loading on the channel's slot availability at three stages. The first stage was a baseline of the AIS VDL's capacity, modeling the operation of Class A vessels over the AIS VDL without Blue Force vessel loading. The second stage was a model of Class A vessels operating over the AIS VDL with Blue Forces only transmitting 1-slot position reports every 15 seconds per the STEDS protocol for Messages 25 and 26. The final stage modeled the operation of Class A vessels over the AIS VDL with Blue Forces transmitting 5-slot broadcasts in addition to the 1-slot position reports.

The greatest challenge of the project was translating the operational requirements defined in the new protocol for Messages 25 and 26 into usable inputs for the UAIS Simulation Software. The software was originally designed solely for the purpose of validating specifications for Class A vessels using AIS. The software was not designed with the intent to load Blue Forces nor simulate vessels transmitting with multiple slots. Modeling more recent data, analyzing more

ports, and further research could increase the fidelity of results found in this project and better determine the AIS VDL's capability across the nation.

Results show that BFT has a noticeable impact on the AIS VDL but does not overuse the channel's capacity. At the very least given maximum loading and the addition of new operational requirements, there would be at least 677 slots still available, leaving 30% of the AIS VDL in reserve. The project results show that the Coast Guard would also be able to employ the AIS VDL for additional operational needs.

References

[1] B. Siemiatkowski. (2007, Dec. 03). [Online] Available e-mail: Re: CGA EE Capstone Project.

[2] J. Pike (2004, Dec. 07). Homeland Security: Automatic Identification System [Online]. Available: http://www.globalsecurity.org/security/systems/ais.htm.

[3] O. Guenther. (2004, Apr.). Blue Force Tracking. [Online]. Available: http://findarticles.com/p/articles/mi_qa3723/is_200404/ai_n9363252.

[4] W. D. Baumgartner, "Domestic and International Law and Policy Considerations Regarding the Transmission of Encrypted Blue Forces Tracking (BFT) Information Over the Automatic Identification System (AIS): JAG Memo," unpublished.

[5] *Technical Characteristics for USCG Encrypted Automatic Identification System (EAIS) Very High Frequency Data Link (VDL) Standard (v4.0)*, ITU-R M.1371-2, 06 June 2007.

[6] M. B. Lytle, "Operational Requirements for SBU Tactical Information Exchange System Memo," unpublished.

[7] U.S. Coast Guard Navigation Center (2007, Sep. 28). AIS Overview [Online]. Available: http://www.navcen.uscg.gov/enav/ais/default.htm.

[8] Telecommunications Bureau of the Ministry of Internal Affairs and Communications (2007, Dec 10). Development of Technical Examination Services Concerning Frequency Crowding [Online]. Available: http://www.tele.soumu.go.jp/e/fees/purpose/tectest.htm.

[9] J. Pike (2004, Dec. 07). Homeland Security: Automatic Identification System [Online]. Available: http://www.globalsecurity.org/security/systems/ais.htm.

Bibliography

J. Dunlop, "Performance Assessment of the Advance Time Division Multiple Access System by Simulation," *IEEE Colloquium on Advanced TDMA Techniques and Applications*, no. 234, Oct., pp. 3/1 – 3/6, 1996.

"The Complete Guide to Automatic Identification Systems," [Online Document], 2001, Available: http://www.concordelectronics.com/pdf/AIS_Booklet.pdf (accessed September 30, 2007)

E. Wandeler and L. Thiele, "Optimal TDMA Time Slot and Cycle Length Allocation for Hard Real-Time Systems," Design Automation, 2006. *Asia and South Pacific Conference*, 30 Sep 2007.

Edwards, Michael and David J. Pietraszewski. "Automatic Identification System User Requirements." USCG Research and Development Center. 2000.

Tetreault, BJ. "Use of the Automatic Identification System for Maritime Domain Awareness (MDA)." *Proceedings of MTS/IEEE*. 2005.

Balci, M and R. Pegg. Towards Global Maritime Awareness – A technical perspective.

Military Communications Conference. 2006.

Chevli, K.R. "Blue Force Tracking Network Modeling and Simulation." *Military Communications Conference.* 2006.

General Dynamics. Blue Force Tracking. http://www.gdc4s.com.

Hawkeye Technology and the Sensor Manager. http://www.piersystem.com/go/doc/586/92955/.

Fisher, Kim. "Supplementing Marine Radar displays with information from AIS." *IEEE Colloquium.* 2000.

Appendices

Appendix A: Business Case

Appendix B: Functional Requirements

Appendix C: Design Specification

Appendix D: Project Management Plan

Appendix E: Support Plan

Appendix F: Slot Availability Plots