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USACE AIS Transmit Technical Support Summary Report

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James E. Fletcher
E&W Branch Chief
United States Coast Guard
Research & Development Center
1 Chelsea Street
New London, CT 06320



USACE AIS Transmit Technical Support Summary Report

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16. Abstract (MAXIMUM 200 WORDS) The United States Army Corps of Engineers (USACE) operate the Lock Operations Management Application (LOMA) to provide navigation and safety information to lock operators and other users of the U.S. inland waterways. The system uses the Automatic Identification System (AIS) to collect and transmit information. The USACE plans to transmit additional information such as current velocity and direction, weather, river stages, hazards, notices to mariners and gate setting using the AIS Application Specific Messages (ASMs). The United States Coast Guard Research and Development Center (RDC) has developed processes to manage the ASMs. RDC has been working with the USACE to provide AIS transmit technical support, specifically, to implement the creation, management, and transmission of the ASMs in the USACE AIS network. As part of the technical support, the RDC has tested the components of the USACE AIS network. A transmit architecture has been implemented and tested in test beds at Louisville, KY and Pittsburgh, PA. This report describes the results of the tests, makes recommendations for ways to improve the USACE AIS network, and recommends future work to continue improving the system.					
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EXECUTIVE SUMMARY

The Automatic Identification System (AIS) is an autonomous broadcast system that exchanges maritime safety/security information between participating vessels and shore stations. In addition to providing a means for maritime administrations to effectively track the movement of vessels in coastal and inland waters, AIS can be a means to transmit other information to ships in port or underway that contributes to safety-of-navigation and protection of the environment. This additional information may include meteorological and hydrographic data, carriage of dangerous cargos, safety and security zones, status of locks and Aids to Navigation (AtoNs), and other port/waterway safety information.

The United States Army Corps of Engineers (USACE) Lock Operations Management Application (LOMA) is a tool to increase the situational awareness of lock operators and other users of the inland waterways. LOMA uses AIS to gather and disseminate navigation data to and from vessels operating in the vicinity of USACE locks. Information such as vessel location, vessel tracks, current velocity and direction, weather, river stages, hazards, notices to mariners and gate settings will be gathered and made available from a central source to the lock operator, vessel operator and navigation community at large.

The United States Coast Guard (USCG) Research and Development Center (RDC) has been developing the capability of AIS to support a limited message broadcasting capability using Application-Specific Messages (ASMs). The purpose of these messages is to provide mariners with useful marine information, such as tide/water levels, current flow, weather, and area notices, to improve both the safety and efficiency of maritime navigation, as well as to ensure the protection of the marine environment. The USCG RDC and the USACE Coastal Hydraulics Laboratory (CHL) Engineer Research and Development Center (ERDC) entered into a Memorandum of Agreement to expand the capabilities of LOMA by building upon the RDC experience with transmission of navigation safety information via AIS/ASMs.

This report summarizes the work the RDC has completed in cooperation with the USACE to test and improve their LOMA AIS network. The report describes the USACE AIS infrastructure, test architecture, and test results. Tests were performed on various components of the architecture, including the L-3 AIS AtoN transceivers and the CNS DataSwitch. A transmit architecture was developed for the USACE to efficiently manage the creation and transmission of ASMs. Testing of transmitted AIS messages was conducted in Louisville, KY and Pittsburgh, PA. The tests demonstrated that ASMs could be created, managed and transmitted effectively. The results of these tests are presented.

Based on the tests and work performed with the USACE, the following recommendations are proposed. (1) The L-3 AIS AtoN transmitters should be updated to include transmission using reserved slots and the ability to send negative acknowledgements. (2) The CNS DataSwitch has several deficiencies that should be corrected, the most critical being the ineffective Transport, Annotate, and Group (TAG) block processing. (3) The network integration issues between the USACE and USCG must be resolved. (4) Establishment of data management policies and procedures is recommended for the effective creation, management, and transmission of the AIS messages. (5) The coverage area of the LOMA AIS AtoN infrastructure is limited and should be increased by implementing improvements such as raising the transmitter antenna height at several locations.



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Future development work is recommended in the following areas. (1) Investigate the integration of ASM Manager functions into the “AIS Router” or transmitter. (2) Investigate use of repeaters and other means to improve AIS transmit coverage. (3) Develop standard means to measure transmit coverage/assurance of receipt. (4) Develop USACE-hosted AIS message creation services. (5) Develop a real-time monitoring system for the USACE to ensure the system is operating reliably and messages are properly transmitted.



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LIST OF ACRONYMS

ABK	Addressed and Binary Broadcast Acknowledgement
ABM	Addressed Binary Message
AIS	Automatic Identification System
ASM	Application Specific Message
ASM MGR	ASM Manager
AtoN	Aid to Navigation
BBM	Broadcast Binary Message
CHL	Coastal Hydraulics Laboratory
CMTS	Committee on the Marine Transportation System
DAC	Designated Area Code
DTED	Digital Terrain Elevation Data
ERDC	Engineer Research and Development Center
FATDMA	Fixed Access Time Division Multiple Access
FI	Function Identifier
IMO	International Maritime Organization
IT	Information Technology
LOMA	Lock Operations Management Application
LPMS	Lock Performance Monitoring System
MMSI	Maritime Mobile Service Identity
MOA	Memorandum of Agreement
MPI	Multi-Protocol Interface
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
ORFC	Ohio River Forecast Center
PORTS	Physical Oceanographic Real-Time System
RATDMA	Random Access Time Division Multiple Access
RDC	Research and Development Center
STK	Systems Tool Kit
TAG	Transport, Annotate, and Group
TCP/IP	Transmission Control Protocol/Internet Protocol
TFR	Transmit Feedback Report
TIREM	Terrain Integrated Rough Earth Model
USACE	U.S. Army Corps of Engineers
USCG	United States Coast Guard
USGS	United States Geological Survey
UTC	Universal Coordinated Time
VDM	VHF Data-link Message
VDO	VHF Data-link Own-vessel
VHF	Very High Frequency



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1 INTRODUCTION

The Automatic Identification System (AIS) is an autonomous and continuous broadcast system that exchanges maritime safety/security information between participating vessels and shore stations. In addition to providing a means for maritime administrations to effectively track the movement of vessels in coastal and inland waters, AIS can be a means to transmit information to ships in port or underway that contributes to safety-of-navigation and protection of the environment. This includes meteorological and hydrographic data, carriage of dangerous cargos, safety and security zones, status of locks and Aids to Navigation (AtoNs), and other port/ waterway safety information.

In the United States, it is intended that this additional information be transmitted from shore-side AIS transmitters in a binary message format as part of an overall e-Navigation strategy. The Committee on the Marine Transportation System (CMTS) e-Navigation Strategic Action Plan [1] quotes the International Maritime Organization (IMO) definition of e-Navigation as:

“e-Navigation is the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment”

AIS capabilities are recognized as critical parts of the US e-Navigation strategy in the CMTS e-Navigation Strategic Action Plan.

The United States Army Corps of Engineers (USACE) Lock Operations Management Application (LOMA) is a tool to increase the situational awareness of lock operators and other users of the U.S. inland waterways. LOMA uses AIS to gather and disseminate navigation data to and from vessels operating in the vicinity of USACE locks. Information such as vessel location, vessel tracks, water current velocity and direction, weather including wind, rain and fog, river stages, hazards to navigation, notices to mariners, and gate settings will be gathered and made available from a central source to the lock operator, vessel operator, and navigation community at large.

The United States Coast Guard (USCG) Research and Development Center (RDC) has been developing the capability of AIS to support a limited message broadcasting capability using Application Specific Messages (ASMs). The intention of this feature is to provide mariners with useful marine information (e.g., tide/water levels, current flow, meteorological information, ice coverage, and location of marine habitats) to improve both the safety and efficiency of maritime navigation, as well as to ensure the protection of the marine environment.

A Memorandum of Agreement (MOA) [2] was established between the USCG RDC and the USACE Coastal Hydraulics Laboratory (CHL) Engineer Research and Development Center (ERDC) to expand the capabilities of LOMA by building upon the RDC experience with transmission of navigation safety information via AIS.

This report discusses the USACE AIS infrastructure and the results of testing various components of that infrastructure. In addition, the transmit architecture that was developed for the USACE is described as well as the results of testing in Louisville, KY and Pittsburgh, PA. Finally, the report provides some recommendations for future development, implementation and integration with the USCG transmit architecture.



2 USACE INFRASTRUCTURE

A high-level diagram of the LOMA system is shown in Figure 1. The LOMA system is managed by ERDC, in Vicksburg, MS. The system uses a data routing and management software application, called DataSwitch, manufactured by CNS Systems. The LOMA system consists of a hierarchical arrangement of CNS DataSwitches with three DataSwitches that are connected to over 110 AIS AtoN transceivers, all feeding traffic to one master DataSwitch. In order to spread out the load, the transceivers are separated into groups with DataSwitch1 managing the Ohio River units, DataSwitch2 managing the Mississippi River units, and DataSwitch3 connected to all others. A map of the LOMA AtoN transceiver installations is shown in Figure 2.

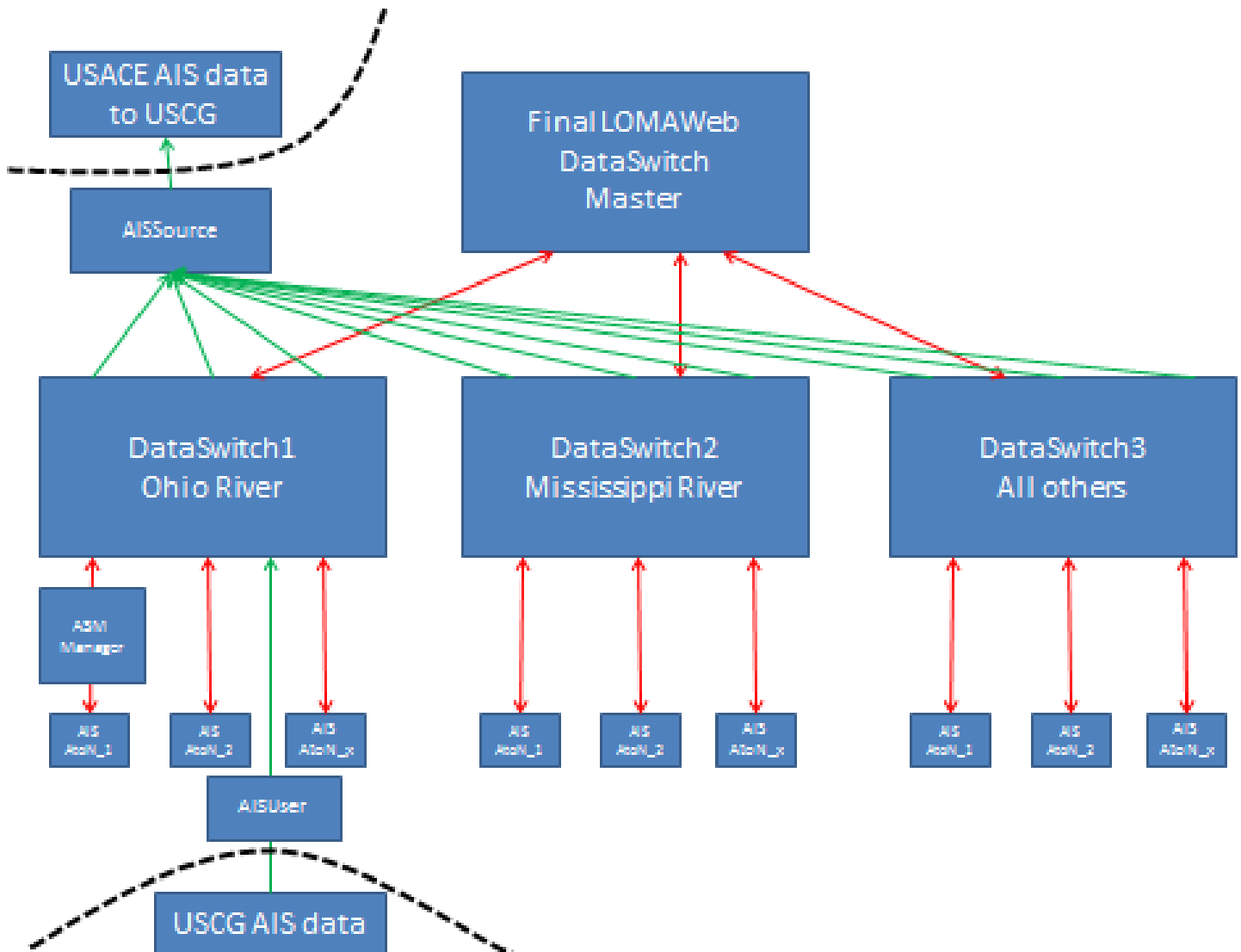


Figure 1. Current LOMA architecture.

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To send all AIS messages received at the LOMA AIS sites to the USCG, top connections from the three geographic DataSwitches (one for each bottom connection) are connected to a software program, AISSOURCE, which sends the messages to RDC. AIS message traffic from the USCG NAIS system is fed into the system via a software program, AISUSER, which is connected to a bottom connection on DataSwitch1. A mock-up system was set up at RDC and the key components (L-3 AIS AtoN transmitter and CNS DataSwitch) were tested. This testing is described in the succeeding sections.

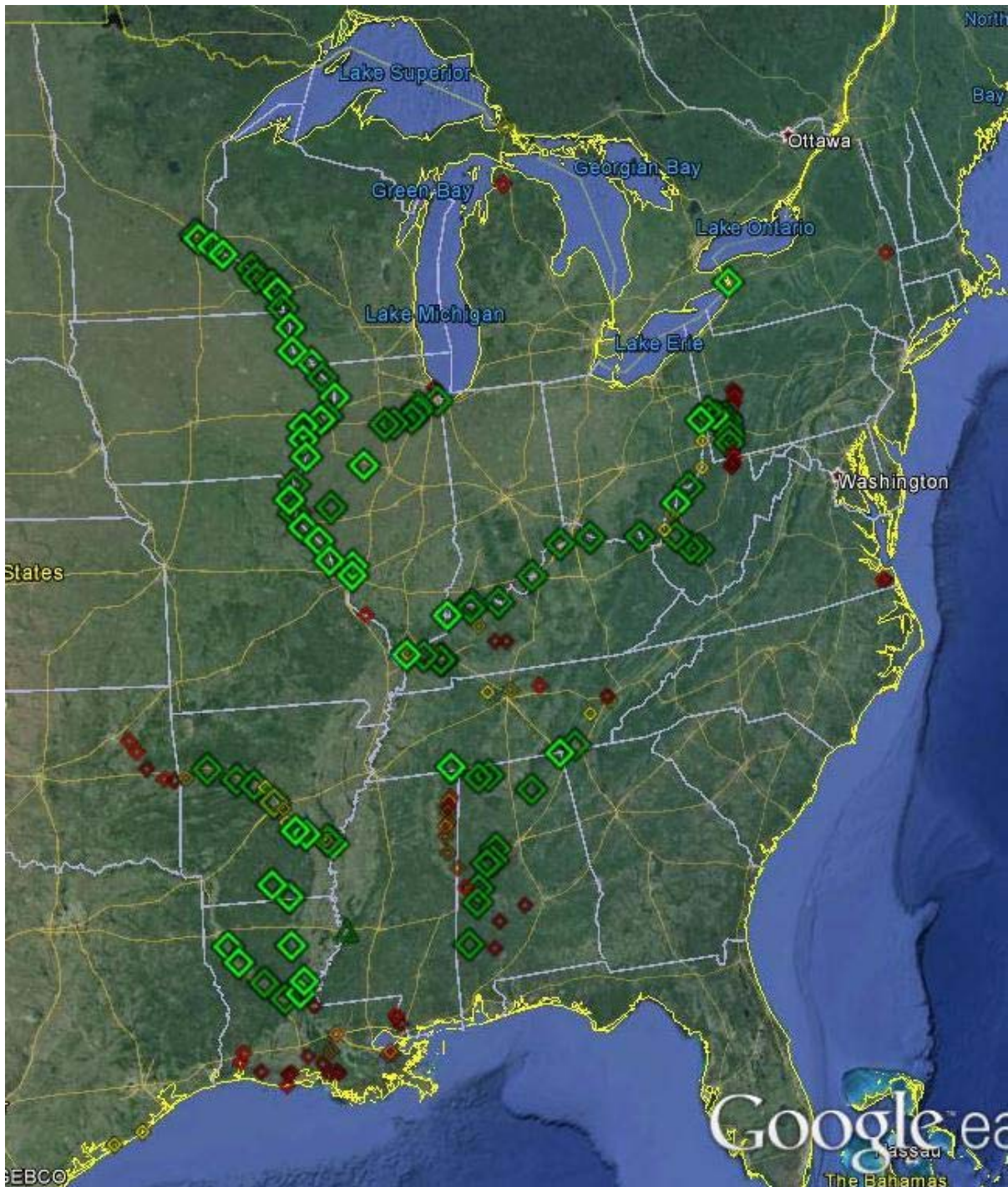


Figure 2. LOMA installation sites (green diamonds).



2.1 L-3 AtoN Testing Results

The L-3 AIS AtoN transmitter was tested for its ability to transmit different types of AIS binary messages encapsulated in National Marine Electronics Association (NMEA) Addressed Binary Message (ABM), Broadcast Binary Message (BBM), and Very High Frequency (VHF) Data-link Message (VDM) sentences. The firmware version on the L3 AtoN that was tested is the same as that used at the USACE AIS sites.

The AIS messages that were tested are listed in Table 1. The table specifies which messages were tested and whether the AtoN transmitted the message. As expected, all messages were transmitted except for the base station messages: Base Station Report (message type 4) and Data Link Management Report (message type 20).

In summary, the L-3 AtoN:

- Will transmit ABM, BBM, and VDM sentences.
 - ABM sentences generate an AIS Addressed and Binary Broadcast Acknowledgement (ABK) sentence either upon receipt of the acknowledgement from the addressed AIS transceiver or after expiration of the timeout period.
 - BBM sentences generate an AIS Addressed and Binary Broadcast Acknowledgement (ABK) sentence upon transmission.
 - VDM sentences generate a Transmit Feedback Report (TFR) sentence; including a negative TFR for the message types 4 and 20 that could not be transmitted.
 - All sentences generate a VHF Data-link Own-vessel (VDO) sentence when the message is transmitted.
- The messages are always sent out using Random Access Time Division Multiple Access (RATDMA) mode within 4 seconds of being presented to the AtoN.
 - Transmit schedule settings of Fixed Access Time Division Multiple Access (FATDMA) and RATDMA have no effect – in fact none of the settings had any impact – and the units transmit without any transmit schedule configured.
 - If there are too many messages to transmit in the 4-second interval, the messages NOT sent do not generate an ABK or TFR sentence (positive acknowledgments only).
- The internally generated AIS Message 21's (Aids-to-navigation report) will NOT transmit without a transmit schedule set.



Table 1. L-3 AtoN message test results.

AIS Message Type	Name	NMEA Sentence Used	Transmitted
1	Position report	VDM	Yes
2	Position report	Not tested	-
3	Position report	VDM	Yes
4	Base station report	VDM	No
5	Static and voyage related data	VDM	Yes
6	Binary addressed message	ABM and VDM	Yes
7	Binary acknowledgement	Not tested	-
8	Binary broadcast message	BBM and VDM	Yes
9	Standard SAR aircraft position report	Not tested	-
10	UTC/date inquiry	VDM	Yes
11	UTC/date response	Not tested	-
12	Addressed safety related message	ABM and VDM	Yes
13	Safety related acknowledgement	Not tested	-
14	Safety related broadcast message	BBM and VDM	Yes
15	Interrogation	VDM	Yes
16	Assignment mode command	VDM	Yes
17	DGNSS broadcast binary message	Not tested	-
18	Standard Class B equipment position report	VDM	Yes
19	Extended Class B equipment position report	Not tested	-
20	Data link management message	VDM	No
21	Aids-to-navigation report	VDM	Yes
22	Channel management	Not tested	-
23	Group assignment command	VDM	Yes
24	Static data report	VDM	Yes
25	Single slot binary message	Not tested	-
26	Multiple slot binary message with Communications State	Not tested	-

2.2 CNS DataSwitch Testing Results

CNS DataSwitch is AIS message routing software that can pass data between multiple clients (called top) and radio (called bottom) connections based on configurable rules and filters. The primary goal of this evaluation was to determine the maximum number of top and bottom connections that DataSwitch can reliably service. Performance tests included varying the number of top and bottom connections, turning on and off DataStore and Target Service, and also testing different data feed rates. In addition to performance testing, there was also a test of the DataSwitch/ Target Service ability to generate AIS binary environmental reports, and an evaluation of how DataSwitch handled passing of ABM, BBM, and VDM sentences and their corresponding acknowledgement sentences. Test details and findings are presented below.

2.2.1 Numbers of Clients

Previous DataSwitch testing, described in [2], focused on maximum throughput and the maximum number of clients possible with a single bottom connection. Maximum throughput with a single top client was found



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to be 3,900 messages per second. With a constant message rate of 600 messages per second into the bottom connection, the maximum number of top clients was found to be 250.

For this testing, DataSwitch was set up on a server provided by the USACE. The server specifications are: Intel Xeon X5550 2.67 GHz (2 processors), 24 GB RAM, 300 GB HDD, Windows Server 2008 R2 Enterprise 64 bit Operating System. Data was sent to DataSwitch bottom connections and recorded from the top connections. Multi-Protocol Interface (MPI) software (developed in-house) was used to send and receive the data. MPI software was set up to play data from a file to DataSwitch bottom connections using a Transmission Control Protocol/Internet Protocol (TCP/IP) server, and to record data received from DataSwitch Top connections using TCP/IP clients. MPI saved the data into log files with a time-received applied to each line. Sent and received data sets were then compared line-by-line using Matlab scripts to determine how much data (if any) was being lost.

2.2.1.1 Multiple Top Connections and Multiple Bottom Connections Testing

The focus for this test was to establish the maximum number of bottom connections that could be supported. A nominal data rate of 15 messages per second (equivalent to 50 Class A AIS units maneuvering on the river at 0-14 kts – a 3.3 sec report rate) was used. Each bottom connection was mapped to a separate top connection using a filter and a rule (one bottom connection per one top connection). A diagram of the test configuration is shown in Figure 3. Testing started with 10 bottom connections and was increased in groups of 10 up to 100. During the testing, the network load, and CPU utilization were monitored. The file sizes were checked at the end to ensure all data was routed.

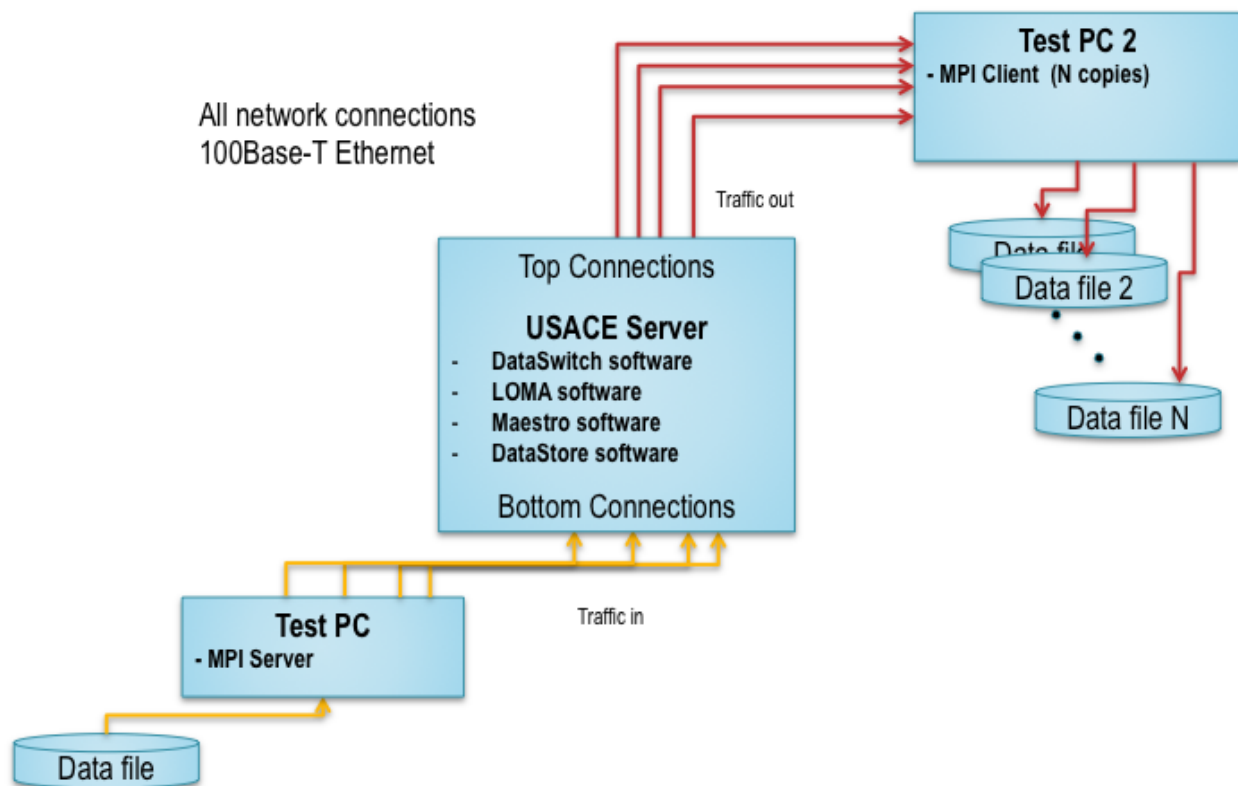


Figure 3. DataSwitch multiple bottom connections, multiple top connections.



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For the test, data was fed to the bottom connections from the MPI server at the nominal rate of 15 lines per second and recorded by MPI clients connected to the top connections. With Target Service and DataStore OFF, DataSwitch could service a maximum of 71 connections before experiencing data loss. DataSwitch was losing data with 72 connections, and as more connections were added, more data was being lost (0.45% data loss at 72 connections, 2.0% at 75, 4.8% at 80). With Target Service and DataStore turned ON, DataSwitch could service 20 connections without data loss. At 30 connections, some of the data was lost, with additional connections data loss was inconsistent (0.68% data loss at 30 connections, 0.20% at 40, 1.2% at 50, 0.43% at 60). All files were identical during the 70 connections test (920 kb). Files were different in sizes during the 72 and 71 client tests. Complete results are listed in Table 2.

DataSwitch also experienced stability issues during the 80 connections test; DataSwitch had TCP/IP read/write errors (as reported by MPI software). Also during the 80 connections test DataSwitch service crashed and had to be restarted.

2.2.1.2 Single Top Connection and Multiple Bottom Connections Tests

For the single top connection and multiple bottom connections tests, rules and filters were set up so that data fed into bottom connections would be aggregated into a single top connection. A diagram of the test configuration is shown in Figure 4.

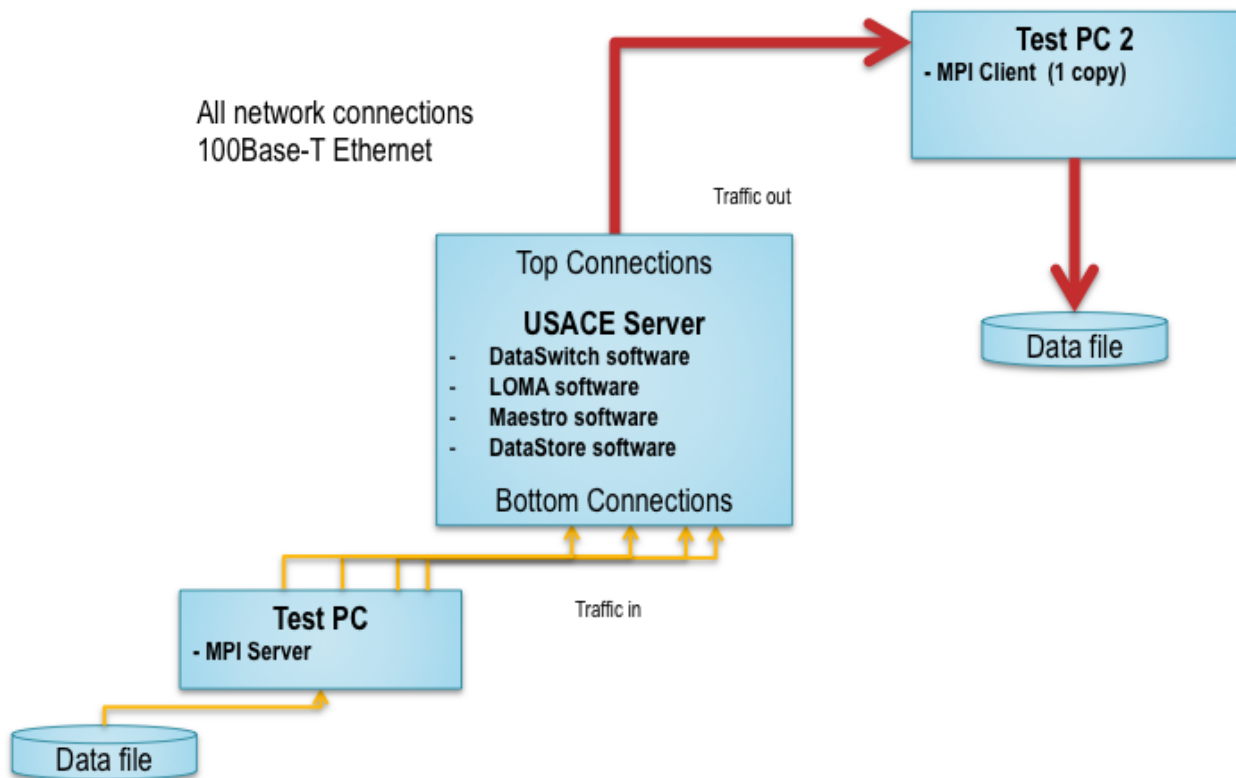


Figure 4. DataSwitch multiple bottom connections, single top connection.



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There were three types of tests carried out. The first test was with Target Service and DataStore OFF, and with data fed to each bottom connection at the rate of 15 lines per second. There was negligible data loss at 60 connections (0.02%), and data loss increased linearly as more connections were being added (1.4% at 71 and 3.5% at 80). The second test was with the same data rate with Target Service and DataStore turned ON. Unlike in the multiple top and bottom connections tests, turning on Target Service and DataStore did not lead to increased data loss. At 70 connections, data loss was 0.06%, and with 80 connections, it was 1.5%. The third test was with DataStore and Target Service turned ON, and data rate doubled compared to the first tests (30 lines per second vs. 15 lines per second for each bottom connection). Doubling the data rate led to increased CPU load (see aggregated test results table for details), but did not lead to increased data loss (0.09% at 60, 0.10% at 70, and 0.20% at 80 connections). Again, complete results are listed in Table 2.

Table 2. DataSwitch client testing results.

Sentences per second	Target Service and DataStore	Top Connections	Bottom Connections	Lines per bottom connection	Server CPU Load	Network Utilization	Received Lines	Lines Missing	% of lines missing	Files incomplete
15	off	1	60	7004	1%	1.70%	420138	101	0.02%	1
15	off	1	71	7004	1%	2.00%	490225	6863	1.40%	1
15	off	1	80	7004	2%	2.20%	540599	18921	3.50%	1
15	on	1	70	7004	1% -10%	1.90%	490008	294	0.06%	1
15	on	1	80	7004	2% -14%	2.20%	551978	8224	1.49%	1
30	on	1	60	7004	7% -20%	3.00%	419861	378	0.09%	1
30	on	1	70	7004	8% -21%	3.30%	489766	490	0.10%	1
30	on	1	80	7004	10% -21%	3.70%	559172	1118	0.20%	1
15	off	70	70	7004			490280	0	0%	0
15	off	71	71	7004			497284	0	0%	0
15	off	72	72	7004			502006	2282	0.45%	14
15	off	75	75	7004			515024	10276	2.00%	24
15	off	80	80	7004			534699	25621	4.79%	48
15	on	20	20	7004			140080	0	0%	0
15	on	30	30	7004			208700	1420	0.68%	14
15	on	40	40	7004			279602	558	0.20%	2
15	on	50	50	7004			346007	4193	1.21%	18
15	on	60	60	7004			418446	1794	0.43%	10



2.2.2 Integration with L-3 AIS AtoN

The integration of the CNS DataSwitch with the L-3 AtoN transmitter was also tested in order to verify transmission of various messages and correct routing. A diagram of the test configuration is shown in Figure 5.

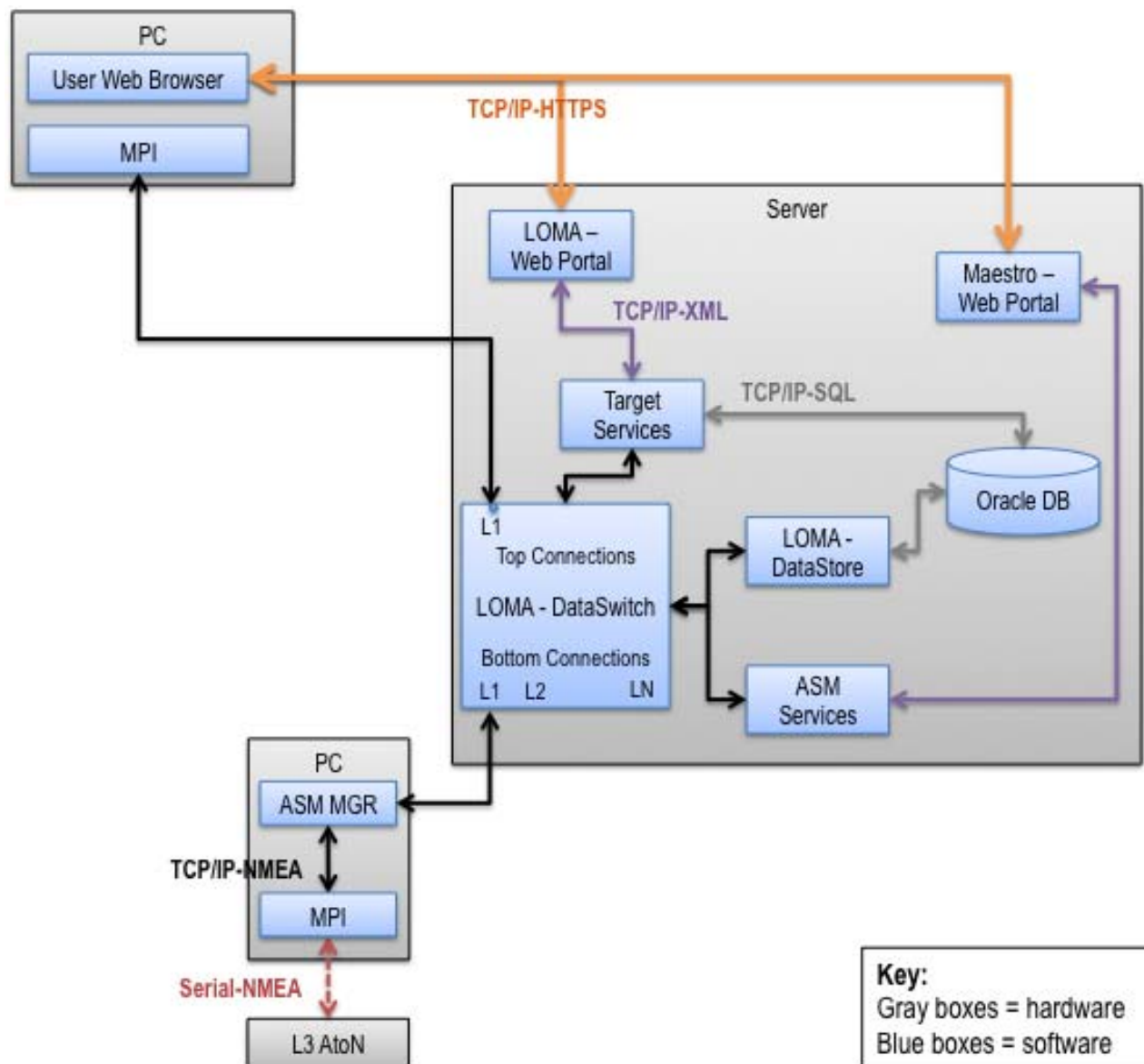


Figure 5. DataSwitch integration with L-3 AtoN test architecture.

2.2.2.1 External Client Generated (ABM/BBM/VDM)

For this test, MPI software on a PC was used to connect to a top connection (L1). ABM, BBM, and VDM sentences were sent into the DataSwitch. MPI software running on the same computer as the ASM Manager was used to “tap into” the ASM Manager (ASM MGR) to AtoN connection in order to record the traffic flow. The data was checked on the ASM MGR and then on MPI to see if the sentences flowed correctly through the system. They were also checked to see if traffic from the AtoN made it back to the PC at the top connection.

In this evaluation, DataSwitch handling of ABM, BBM, and VDM sentences was tested along with the handling of the corresponding ABK and TFR acknowledgements. ABM, BBM and VDM sentences were going from the top connection to the bottom connection, while their ABK and TFR acknowledgements were going from the bottom connection to the top. DataSwitch passed VDM sentences and TFR replies without modification. For BBM sentences, DataSwitch generated its own sentence sequence numbers and generated its own acknowledgement back to the top connection. For ABM sentences, DataSwitch also generated its own sentence sequence numbers. Additionally, DataSwitch needed to have the ABM sentence's destination Maritime Mobile Service Identity (MMSI) already in its internal tracking table (generated by DataSwitch from received messages), otherwise it would not accept the sentence. For ABM and BBM sentences, DataSwitch generated its own ABK acknowledgements without waiting for acknowledgements from the bottom connection. In addition, DataSwitch filtered out acknowledgements coming in from the bottom connection.

2.2.2.2 LOMA Generated Messages

In this evaluation, Target Service's ability to generate AIS binary environmental messages was tested. The Butte City (Sacramento) gauge (random selection) environmental data feed was turned on and configured for transmission through Aberdeen Lock (again, random selection) by specifying the Aberdeen Lock destination Transport, Annotate, and Group (TAG). The DataSwitch bottom connection was set up to receive Aberdeen Lock environmental messages from LOMA and forward to the AtoN. The DataSwitch bottom connection output was monitored with MPI software that recorded data to a file. After a few minutes, Target Service generated the following report and transmitted it on the DataSwitch bottom connection:

```
\s:LOCK_1,d:LOCK_1*3B\!UPBBM,2,1,0,A,8,Fr47lJLoASVVFTrW9u8P01OAaj4`67R000000000=u6W<89udww50P0<00,0*42
```

```
\s:LOCK_1,d:LOCK_1*3B\!UPBBM,2,2,0,A,8,0,2*2F
```

Partial decoding of the sentence binary contents showed that it had 366/33 for Designated Area Code (DAC)/Function Identifier (FI) (current environmental messages use DAC of 367; 366 is the previous version). Notably, when attempting to transmit this sentence with the L3 AIS AtoN, it was ignored. Checking the sentence against NMEA specifications showed that the sentence did not conform to the specification because the channel field contained the letter 'A', while the only allowed values by the specification are 0, 1, 2 and 3. The sentence was accepted and successfully scheduled for transmit after the channel was manually changed to a value conforming to specifications.

Another test was carried out with DataSwitch set up to convert BBMs to VDMs. In that test, DataSwitch produced a NMEA compliant VDM sentence from the Target Service BBM message:

```
!UPVDM,1,1,0,A,803;?lAK`@7?MkM6>JIJCbLWlR004Luo8BPHN8000000000ikoLhPVnkwA200h000,4*64
```

This sentence was accepted by L3 AtoN and successfully scheduled for transmit. An anomaly was noted however, in that the DataSwitch does not correctly convert multi-line NMEA sentences from BBMs to VDMs.

2.2.3 Transport, Annotate, and Group Blocks

DataSwitch version 2.7.60 (currently used by USACE) has some limited support for TAG block processing. DataSwitch can add TAG blocks and set the source parameter for messages that are being received from a



DataSwitch bottom connection (such as AIS AtoN); these are carried through to the top connection output. In addition, DataSwitch can route messages coming from top connections to specific bottom connections based on the TAG block destination parameter. The current implementation is rudimentary; however, CNS indicated that upcoming versions of DataSwitch would have better support for TAG blocks. It will also allow the use of custom values for bottom connection source/destination parameters (current values are system-generated). DataSwitch does not add TAG blocks to messages going from the top to the bottom connection. Also, DataSwitch can't route messages from a bottom connection to specific top connections using TAG blocks. Destination TAG blocks are required to properly route acknowledgement messages from the AToN radios through the bottom DataSwitch connection to the appropriate top connection so this is a limitation on usage of the system for now.

DataSwitch adds TAG block with the source parameter to messages going from the bottom connection to the top if the following conditions are met:

```
DataSwitch->Administration->AIS->Add Tag Blocks - is enabled
DataSwitch->Setup->Filters->[ConnectionFilterName]->TagBlock - is enabled
DataSwitch->Connections->Bottom Connections->[BottomConnectionName]->Tag Block
Id:[Select Tag Block ID] - is specified
```

It was also observed that TAG block source/destination parameters are based on lock name (their alphabetic sequence number). For example, Aberdeen Lock is the first lock when the list is sorted alphabetically and correspondingly its Lock ID is 0FG2. For Aberdeen Lock, the resulting NMEA TAG block ID is LOCK_1. Amory Lock A is the tenth lock on the list, its Lock ID is 0JJH, and it's NMEA tag-block ID is LOCK_10. If locks are added or deleted, it was unclear if the lock numbers change or if they are static. If the numbers change, this would be problematic, so this should be tested.

3 TRANSMIT DATA

3.1 Data Sources Available Now

Table 3 lists the data sources that were used in the test bed, along with the information available from each data source. Data sources include National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), United States Geological Survey (USGS), Ohio River Forecast Center (ORFC), USACE Lock Performance Monitoring System (LPMS), and Davis weather stations. The table also lists how often the data sources are updated and what ASMs are generated. The ASM FI for environmental messages is 33, for waterways management messages it is 35, and linked text messages are 29. The environmental message report types used are 0 – site location, 1 – station identification, 2 – wind, 3 - water level, 4 – vertical current profile, and 9 – weather.

Table 3. AIS data sources and message types.

Source	Information Available	Data Update Rate	Message Types
NOAA/NWS	- Aviation Routine Weather Report weather data	Hourly	FI 33, Report types 0,1,2,9
NOAA/USGS	- Water level	Hourly	FI 33 Report types 0,1,3
ORFC	- River currents (predicted)	Daily	FI 33 Report types 0,1,4
USACE LPMS	- Vessels awaiting lockage	As Lock Masters enter data	FI 35, 29
Davis Weather Stations	- Weather data	Once a minute	FI 33 Report types 0,1,2,9

3.2 Hydrodynamic Models

The USACE has developed the capability to model the water currents in the vicinity of a lock and dam. The inputs to the model are the bathymetry of the area, the structures (lock, dam, pilings, etc.), the pool depths (water levels), and the dam gate openings. The output of the model is a field of current vectors; an example is shown in Figure 6. To date, the modeling program has not been developed to the point where it can be used to model conditions other than full-and-open. “Hydraulic Modeling of Lock Approaches (Draft Report)” [3] describes the work that has been done to date. This report presents the initial phase of the research in which computational models were developed for open river conditions.

The goal is to select a limited number of points (around 10) from the field of current points to transmit using AIS. These points could be key points along the approach to the lock. They could be selected by using historical AIS data to examine the typical approach path. Once the model is run for various gate opening conditions, the current values (direction and speed) for the pre-selected points could be stored for each of the conditions. A process would be written to check the current gate settings and pool depths, then retrieve the correct set of current values based upon the settings, and finally transmit the data for the limited number of points. This type of message generation will be developed by the USACE Mobile District, along with other database and web services.

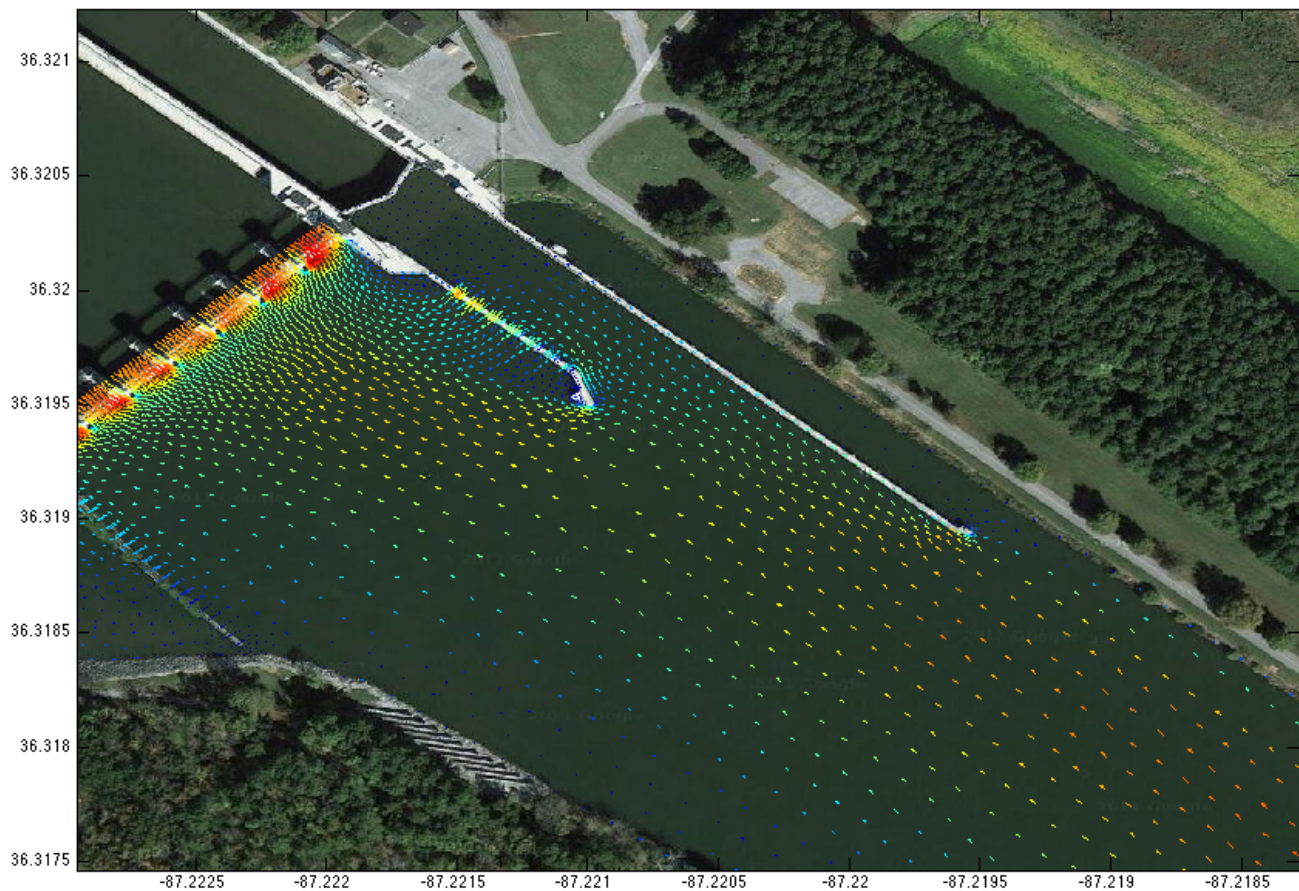


Figure 6. Sample current field data. Red is the highest flow rates, blue is the lowest.

4 TRANSMIT ARCHITECTURE

4.1 Description

In order to facilitate AIS transmit operations, RDC has worked with USACE to modify their architecture to incorporate the ASM Manager. The ASM Manager Service resides logically between the DataSwitch and the AIS AtoN transmitters. The ASM Manager Service creates separate transmit queues for each transmitter and manages the message flow for each transmitter individually. Figure 7 shows the ASM Manager inserted into the architecture, for a single AtoN only, just for clarity. During the transition period, the ASM Manager will manage some of the AIS AtoNs, not all.

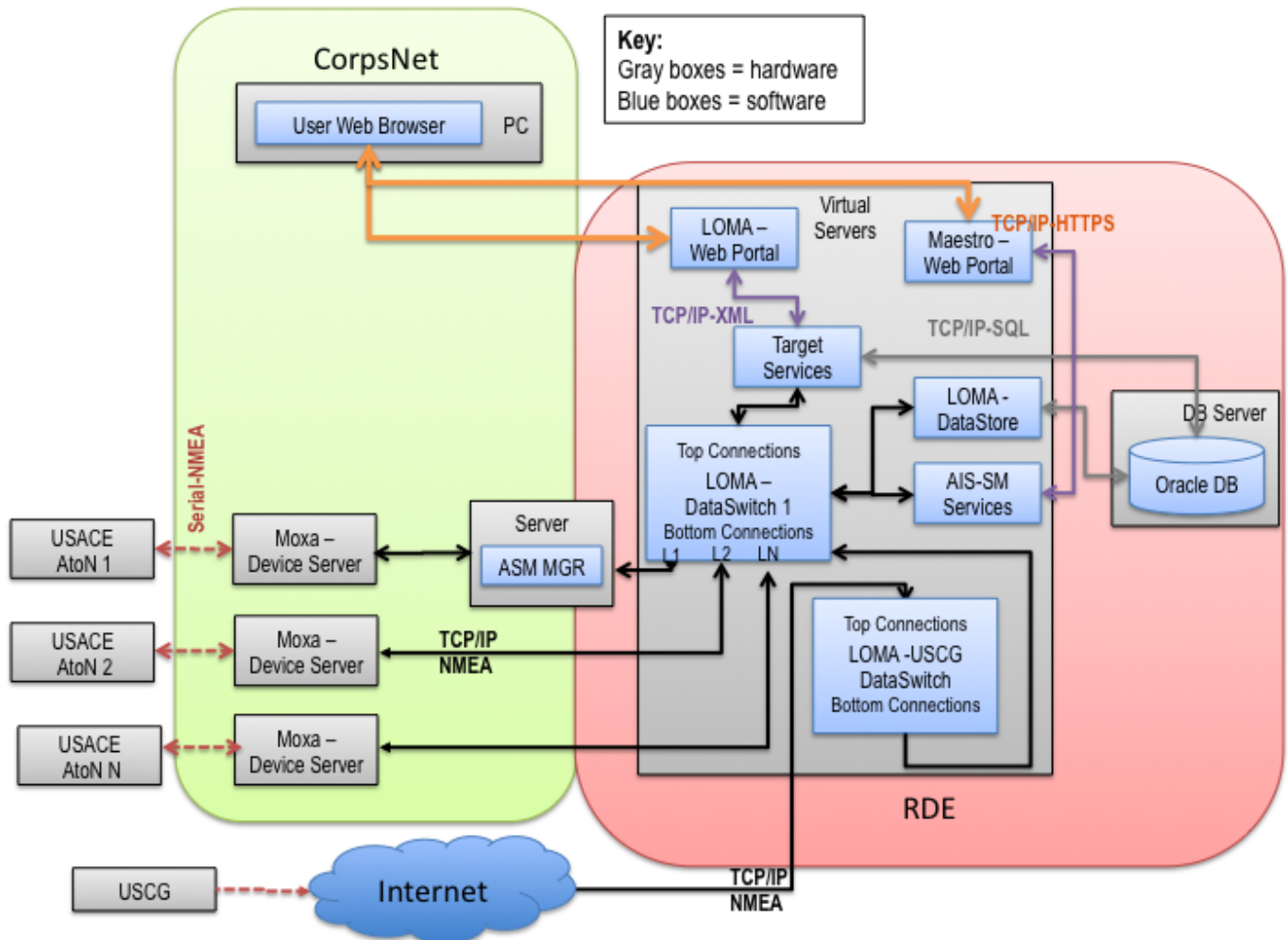


Figure 7. USACE AIS transmit test architecture.

Figure 8 shows the data flow in the new transmit architecture. The ASM Manager Service is shown managing transmit queues for three AIS AtoNs: McAlpine Lock in Louisville and Emsworth and Braddock Locks in the Pittsburgh area. The operations occurring at each labeled point in the figure (A thru F) are described below.

- A. DataSwitch maps top connections to bottom connections. Currently this only works using TAG blocks to route data from the top connection to the correct transmitter(s). To route the same data to

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multiple transmitters, separate copies of the data are needed with different destination TAGs corresponding to the different transmitters (only one destination tag per sentence is supported). The DataSwitch filter/rule only works to isolate data from a bottom connection going to a top connection.

- B. ASM Manager is inserted between DataSwitch and the AIS AtoNs off of bottom connection(s). An individual transmit queue is created for each AtoN unit; each queue has it's own TCP/IP port to receive data. Each transmit queue is configured for a maximum of 10 slots/min because the L-3 AtoN works in RATDMA mode and will transmit all messages at once (within 4 sec). If more slots are needed, then the transmit queue can be configured for 10 slots every 30 seconds. ASM Manager should also have the transmit buffer synchronized to Universal Coordinated Time (UTC) to allow for better control of the timing.

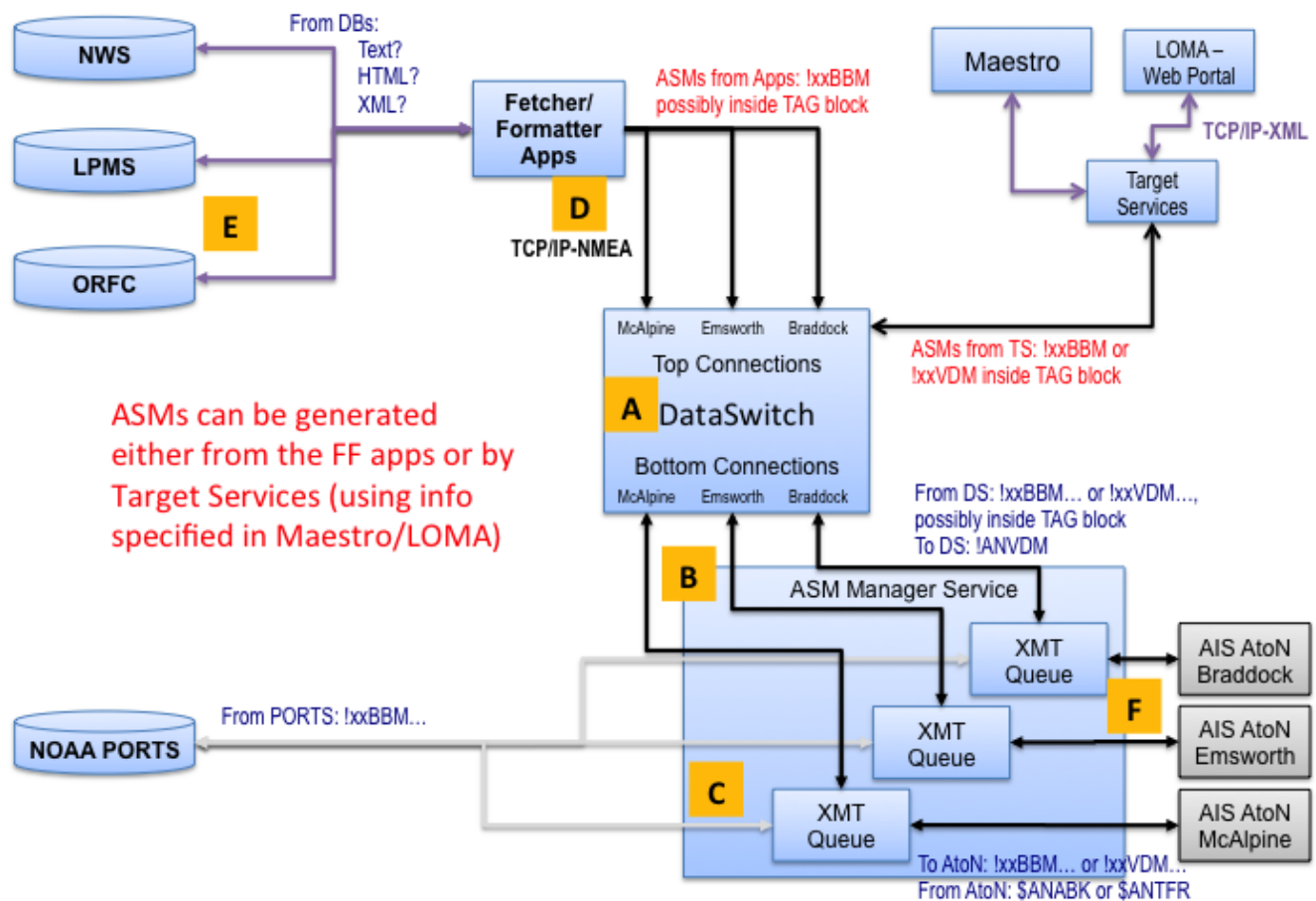


Figure 8. USACE AIS transmit test data flow.

- C. Each transmit queue can be configured to get data from NOAA Physical Oceanographic Real-Time System (PORTS) (up to 3 different PORTS sites) via the Internet. This is not being used currently, as there is no PORTS data available for the test locations.
- D. A number of fetcher/formatter apps are used depending upon what data are required/desired – these can get data, format the data into the ASM, embed it in a BBM sentence, apply the destination TAG(s) for the desired transmitter(s) and feed into a top connection.



- E. The fetcher/formatter apps get data from the specified database over the Internet; LPMS for lock queue and water levels, NWS for weather, ORFC for forecast currents.
- F. The ASM Manager transmit queues connect to the L3 AtoN units. Configuration is RATDMA enabled (FATDMA mode is not supported by the L-3 AtoNs). The AtoNs should be configured with the information and transmit assignment for the message 21 (3 minute interval, alternating channels, start minute 0, slot 600 for example).

4.2 McAlpine Lock Test

4.2.1 ASM – DataSwitch Configuration

The ASM Manager Service is inserted (logically) between the DataSwitch and the AIS AtoN radio. A separate configuration file is required for each AtoN radio to be managed (each AtoN transceiver has its own transmit queue and settings). A device server, manufactured by Moxa, provides the TCP/IP connection to the serial AIS AtoN radio. The IP address and port of this device needs to be known and accessible to ASM Manager: For example the McAlpine AtoN radio is assigned IP address 155.80.95.129, port 4001.

To configure the ASM Manager to connect to the AtoN radio at IP A.A.A.A port aaaa, the following changes are required in the ASM Manager initialization file.

```
# AIS Radio IP Address and Port
RADIO_TCPIP_IP = A.A.A.A
RADIO_TCPIP_PORT = aaaa
```

The server for Louisville is assigned IP address 134.164.48.151. The McAlpine bottom connection is port 9102. To configure the ASM Manager to listen on port bbbb, the following changes are required in the ASM Manager initialization file.

```
# Run server to accept BBM messages on the specified port
INCOMING_MSG_SERVER_PORT = bbbb
```

Other ASM Manager settings should be configured as desired. For example, the recommended values of maximum sensor reports is 4, and 10 messages every 30 seconds. The DataSwitch bottom connection must be configure for the desired AtoN to connect to the ASM Manager at IP B.B.B.B port bbbb.

4.2.2 Fetcher/Formatter Applications

One copy of each Fetcher/Formatter application is needed for each AtoN radio that is selected to transmit the data. For the McAlpine test, only one copy of the Waterways Management ASM generator program and one copy of the Environmental ASM generator program were used to send messages to the McAlpine AtoN radio. Since the USACE Information Technology (IT) policies required that the applications be installed as services, the programs were converted to services and then installed.

Each application has an initialization file to configure various parameters. Included in the parameters are the IP address and port to which the messages are sent. For example, the DataSwitch has an IP: 134.164.48.151 and the Top Server for McAlpine is configured for port 8102. The parameters in the initialization file must be set to these values. Also, the DataSwitch Top Servers must be set to NOT require login.



4.2.3 Test Results

During the McAlpine test, one waterways management ASM generator program and one environmental ASM generator program were configured to send ASMs to the McAlpine top connection of the DataSwitch. The waterways management generator software was set up to send two reports every three minutes, or 960 reports in 24 hours. The environmental generator software was set up to send report types 0 (Site Location), 1 (Site Identification), 2 (Wind), 3 (Current), and 9 (Weather). The type 0 and type 1 reports were sent at a rate of three reports every six minutes, or 720 reports in 24 hours. The type 2 and 9 reports were sent at a rate of one report every two minutes or 720 reports in 24 hours. The type 3 reports were sent at a rate of two reports every two minutes, or 1440 reports in 24 hours. Most days during the test, the messages failed to transmit several hours during the day due to DataSwitch or network problems. However, when there were no disruptions, most of the generated messages were transmitted. Table 4 shows the number of messages generated and received on May 27, 2014.

The message drops may be due to failure to get data from the external data source or message transmission while another radio was transmitting (all transmissions are RATDMA).

Table 4. Messages generated and received on May 27, 2014.

ASM Type	Report Type	Messages Generated	Messages Received	Throughput
Waterways Management	N/A	960	960	100%
Environmental	0 (Site Location)	720	720	100%
Environmental	1 (Site ID)	720	720	100%
Environmental	2 (Wind)	720	717	99.58%
Environmental	3 (Current)	1440	1348	93.61%
Environmental	9 (Weather)	720	715	99.31%

4.3 USCG Integration Options and Issues

Based upon the testing of the CNS DataSwitch, an architecture to allow integration of USCG and USACE AIS transmit operations has been developed, as shown in Figure 9. Currently, there is no easy way to directly connect the two DataSwitches and allow routing of messages between the two using the TAG blocks. Since the DataSwitch only supports a single destination TAG for a bottom connection, there would have to be separate bottom connections created on the USCG DataSwitch for every USACE transmitter. These bottom connections would be configured to connect to the USACE DataSwitch top connection. This does not seem to be feasible with the limitations on the number of connections on the DataSwitch.

An alternative method to send AIS messages, generated by USCG Message Generators, to both USCG and USACE AIS networks would be to send separate messages to each system. This would be performed by the following steps (paragraph letters correspond to the letters annotated in the gold boxes on Figure 9).

- A. USCG Message Generators create the ASMs (could be user-created or auto-created from a database), embed in a BBM sentence, apply the TAG block for the correct transmitters, and then send to the USACE AIS network.
- B. Outbound openings in the USCG firewall for the USCG Message Generators source IP are given authority to connect to the USACE DataSwitch IP and port for the inbound client connection.

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- C. Inbound openings in the USACE firewall for the USCG Message Generators source IP are given authority to connect to the USACE DataSwitch IP and port for the inbound client connection.
- D. Messages are received at the USACE DataSwitch top connection and routed to the correct bottom connection(s) based upon the TAG block.
- E. USCG Message Generators also send messages to the USCG transmit system with the TAG blocks for the appropriate USCG transmitter(s).

This concept was tested in Pittsburgh during the Wireless Waterways Demonstration in June 2014.

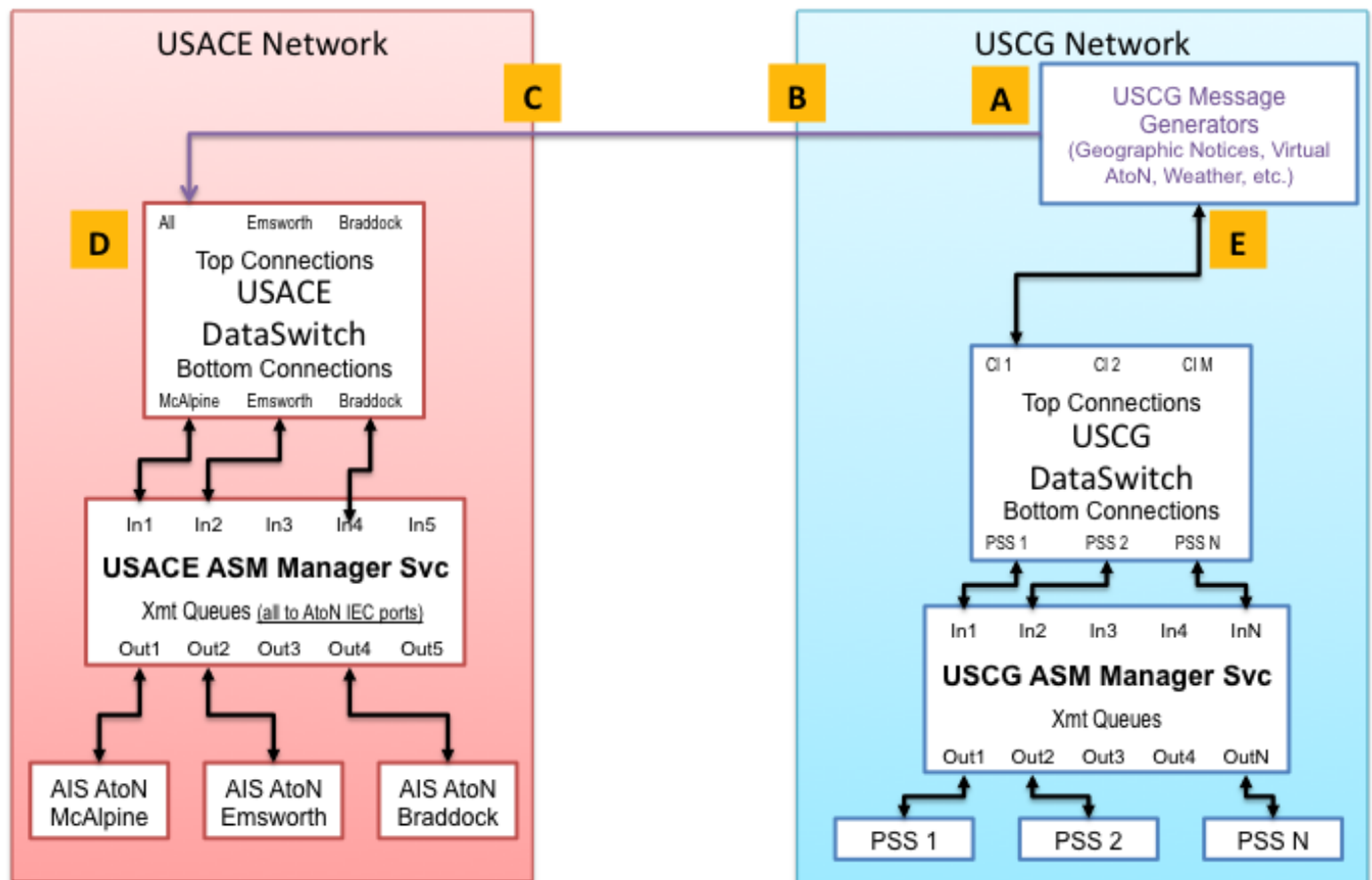


Figure 9. Initial USCG - USACE integration architecture.

4.3.1 DataSwitch Configuration

The CNS DataSwitch was programmed to map each top connection to a bottom connection. An ASM Manager is connected between each bottom connection and an AtoN transmitter. Figure 10 shows the DataSwitch configuration for the Pittsburgh test.



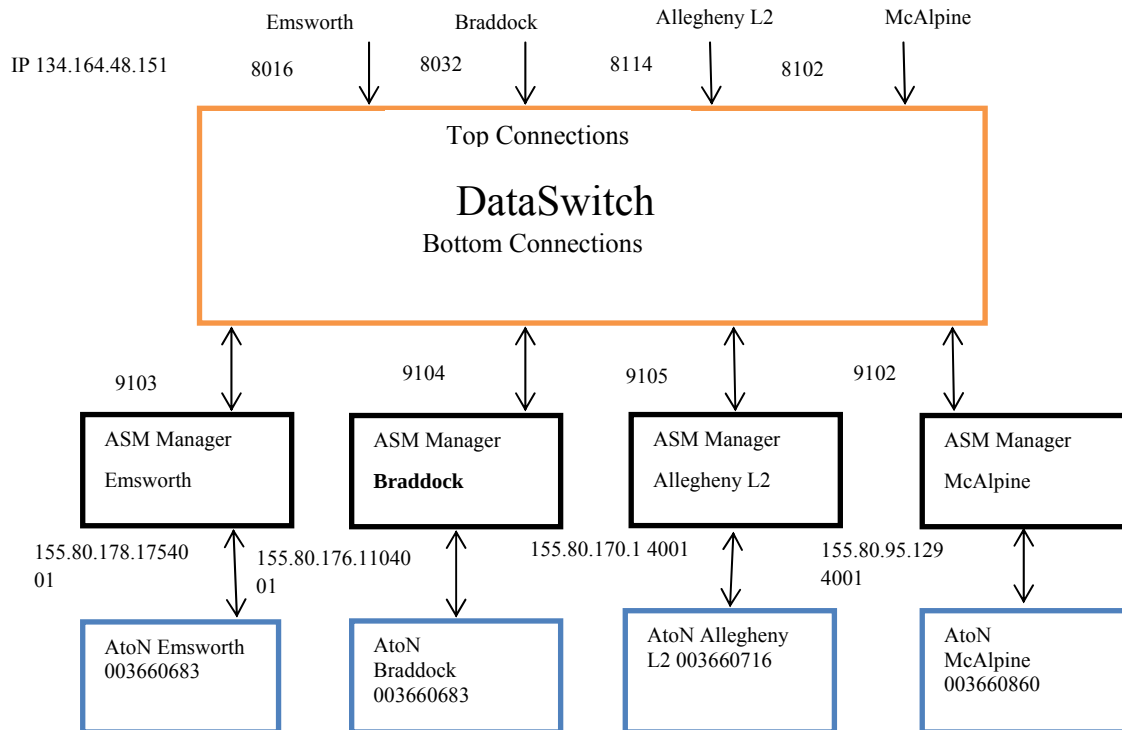


Figure 10. Pittsburgh demonstration configuration.

4.3.2 Software Configuration

For the Pittsburgh test, four types of fetcher/formatter programs were used – (1) the Waterways Management ASM generator, (2) the Environmental ASM generator, (3) the Water Current ASM generator, and (4) the Water Level ASM generator. Three copies of the Waterways Management ASM generator were used to produce the messages from Emsworth Lock, Braddock Lock, and Allegheny Lock 2. The Waterways Management ASM generator can send messages to multiple IP ports, so each generator was programmed to send the messages to the three AtoN radios at Emsworth, Braddock, and Allegheny Lock 2. The Environmental ASM generator was programmed to generate water depth messages from Emsworth and weather and wind messages from a Davis weather station near Emsworth. The Environmental ASM generator can only send messages to one IP port, so three copies of the program were used to send the messages to the three AtoN radios. The Water Current ASM generator produced ASM current reports for four sensor sites. The Water Current ASM generator can send messages to multiple IP ports, so it was programmed to send the messages to the three AtoN radios. The Water Level ASM generator produces a water level report for one sensor site and can send the messages to only one port. Only one copy of the Water Level ASM generator was used to send the messages to Emsworth. Figure 11 summarizes the message generation and routes to the AtoN radios.

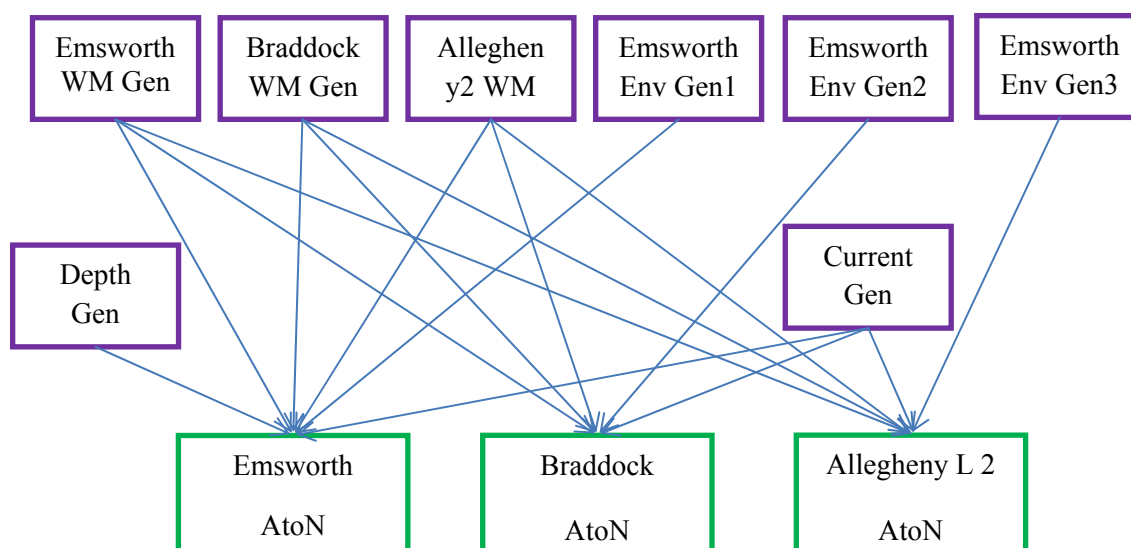


Figure 11. Pittsburgh demonstration message routes.

The fetcher/formatter programs ran on a computer at the RDC. This allowed personnel to easily monitor the software. If it had run on the USACE server, only USACE personnel would have access.

Originally, the fetcher/formatter apps were configured to send the messages to the three top connections of the CNS DataSwitch corresponding to the Emsworth, Braddock, and Allegheny Lock 2 connections (ports 8016, 8034, and 8114). By setting the filter parameters of the DataSwitch, messages sent to a top connection were only supposed to be routed to one bottom connection, which passes the messages through the ASM Manager and on to the AtoN radio. Also, any messages received from the radio were sent through the ASM Manager and into a DataSwitch bottom connection and routed to just one top connection. Unfortunately, this did not work as expected. Any messages sent to a top connection were routed to **all** of the bottom connections. It turns out, the DataSwitch filtering only works from the bottom to top connections. Any messages received at a bottom connection were properly routed to just one top connection. The correct routing could be accomplished by using destination TAGS, as discussed above. This was tested and originally worked, but then the DataSwitch stopped routing the messages; this problem is still under investigation by CNS. To resolve this problem, instead of sending the ASM messages to the top connections, the ASM messages were sent directly to the ASM Managers (Emsworth at port 9003, Braddock at port 9004, and Allegheny Lock 2 at port 9005).

In all cases, since the messages were being generated by a computer on the RDC network and sent to the DataSwitch or ASM Manager Service on the USACE network, IT permissions were required on both the USCG RDC network and USACE network. Firewalls on both networks were adjusted to allow connections through the appropriate IP addresses and port numbers.



4.3.3 Test Results

The Pittsburgh test ran from 17 to 20 June, 2014. Message generation was monitored during the day and performed reliably. Some messages were lost when the fetcher/formatter software was unable to connect to the DataSwitch IP ports. The Waterways Management ASM generator software logged the number of attempts and failures to make the IP connection. Table 5 summarizes the connection statistics for 19 June 2014. Normally the fetcher/formatter will run on the same computer as the DataSwitch and there should be no IP connection failures.

Table 5. IP connection statistics.

ASM Generator	Connections Attempted	Failed Connections	Connection Rate
Emsworth WM	480	32	93.3%
Braddock WM	480	33	93.5%
Allegheny Lock 2	480	21	95.6%

During the Pittsburgh tests, AIS messages transmitted from the various USACE AIS AToN transmitters were recorded on several test vessels traveling on the Ohio River. Both AIS message 21 (AtoN report) and message 8 (broadcast binary, ASM message) were recorded. Figure 12 shows the positions of the vessel (blue) when the vessel could receive messages from the AIS AtoN transmitters (cyan). The figure indicates the transmission coverage of the USACE AIS AtoN transmitters on June 18 to June 21, 2014. Table 6 shows the maximum transmission range calculated for each Lock transmitter as the vessel traversed the river. Emsworth's range of only 0.04 miles was due to a poor antenna connection (which has since been corrected). It appears that topography has a major effect on the AIS AtoN transmission range. Dashields and Pike Island, with transmission greater than 10 miles, are located where the river is fairly straight. Other locks, such as Monongahela Lock 3 and Braddock, located near river bends and hills, have limited range.

Table 6. Lock AIS AToN maximum transmission range.

Lock	Maximum Transmission Range (miles)
Monongahela River Lock 3	3.60
Braddock	2.52
Emsworth	0.04
Dashields	10.25
Montgomery	6.80
Pike Island	13.62
New Cumberland	5.83
Hannibal	4.84
Willow Island	4.61
Belleville	2.40
Racine	2.28



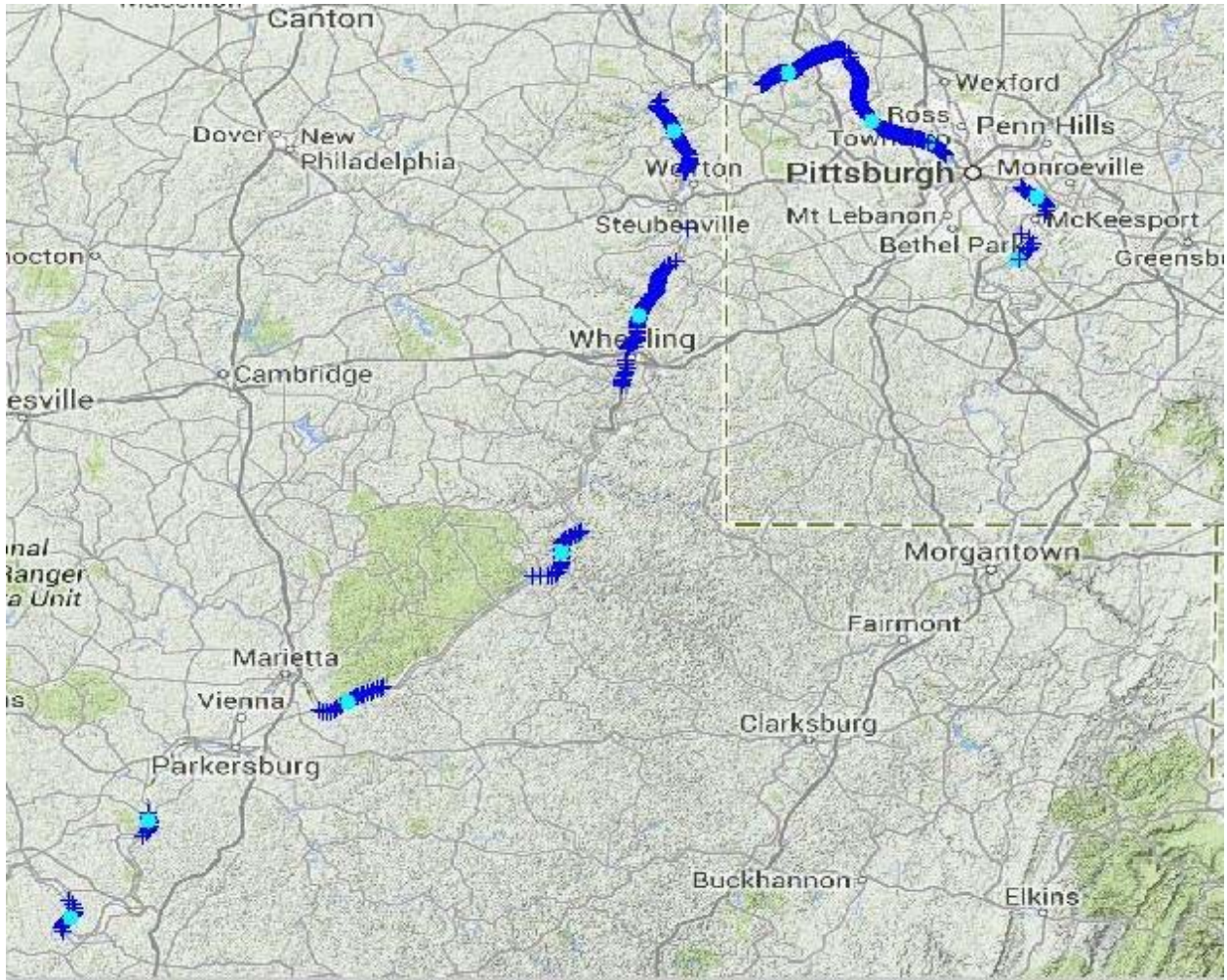


Figure 12. Vessel positions of received AIS AtoN transmissions.

A rough calculation of the USACE Lock AIS AtoN's transmission coverage on the Ohio River can be extracted from Table 6. Assuming that the coverage for each lock is twice the maximum range, the total coverage (Emsworth to Racine) from Table 6 is about 101 miles. The length of the Ohio River from Emsworth to Racine is about 237 miles. Although there is some overlap in coverage at Dashields, the rough estimate of transmission coverage is a little less than 50% of the river.

5 COVERAGE PREDICTIONS

Transmitter coverage predictions have been made for an initial set of USACE transmitters using Systems Tool Kit (STK) software from AGI, Inc. The set of USACE transmitters included the locks and dams on the Ohio River between and including Markland and Olmsted. The STK software includes the Terrain Integrated Rough Earth Model (TIREM) module to estimate propagation paths and signal strengths along the path taking into account the terrain. For the predictions, the location of each transmitter and the height of the antennas were supplied by the USACE. The predictions are done in a 50 km circle around each transmitter (100 km for the sites with higher antennas). Digital Terrain Elevation Data (DTED) level 1 terrain data is used for the topography. The AIS specifications [4] call for data to be received at a signal level of -107 dBm and for a receiver to reject anything below -117 dBm. Data received from the McAlpine



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Lock was plotted against the predicted coverage signal strengths, and reports were received reliably down to a predicted level of -115dBm, so this has been used as the cutoff for the coverage predictions. Figure 14 shows the expected coverage from each site (green and magenta shading) using the -115 dBm cutoff value.

Figure 13 shows the predicted coverage for Dashields Lock and the vessel positions where the vessels received AIS messages from the lock. The colored blocks on the map show the predicted signal strength (only blocks > -115 dBm, the minimum for reception are shown). The black dots are the positions of the received signal. The received signals correlate well with the predicted coverage.

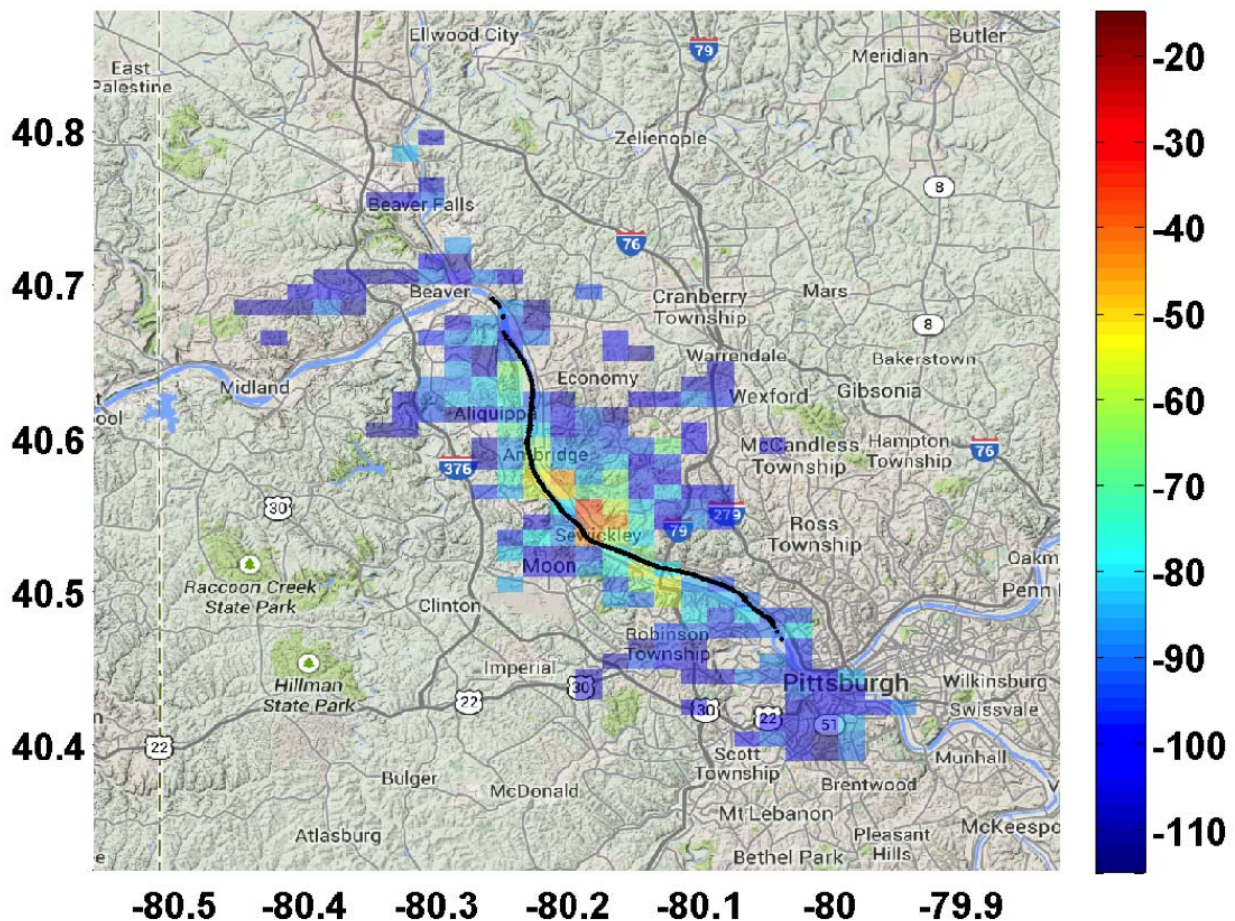


Figure 13. Predicted AIS coverage (dBμV) and positions of received transmissions (black dots) for Dashields Lock.



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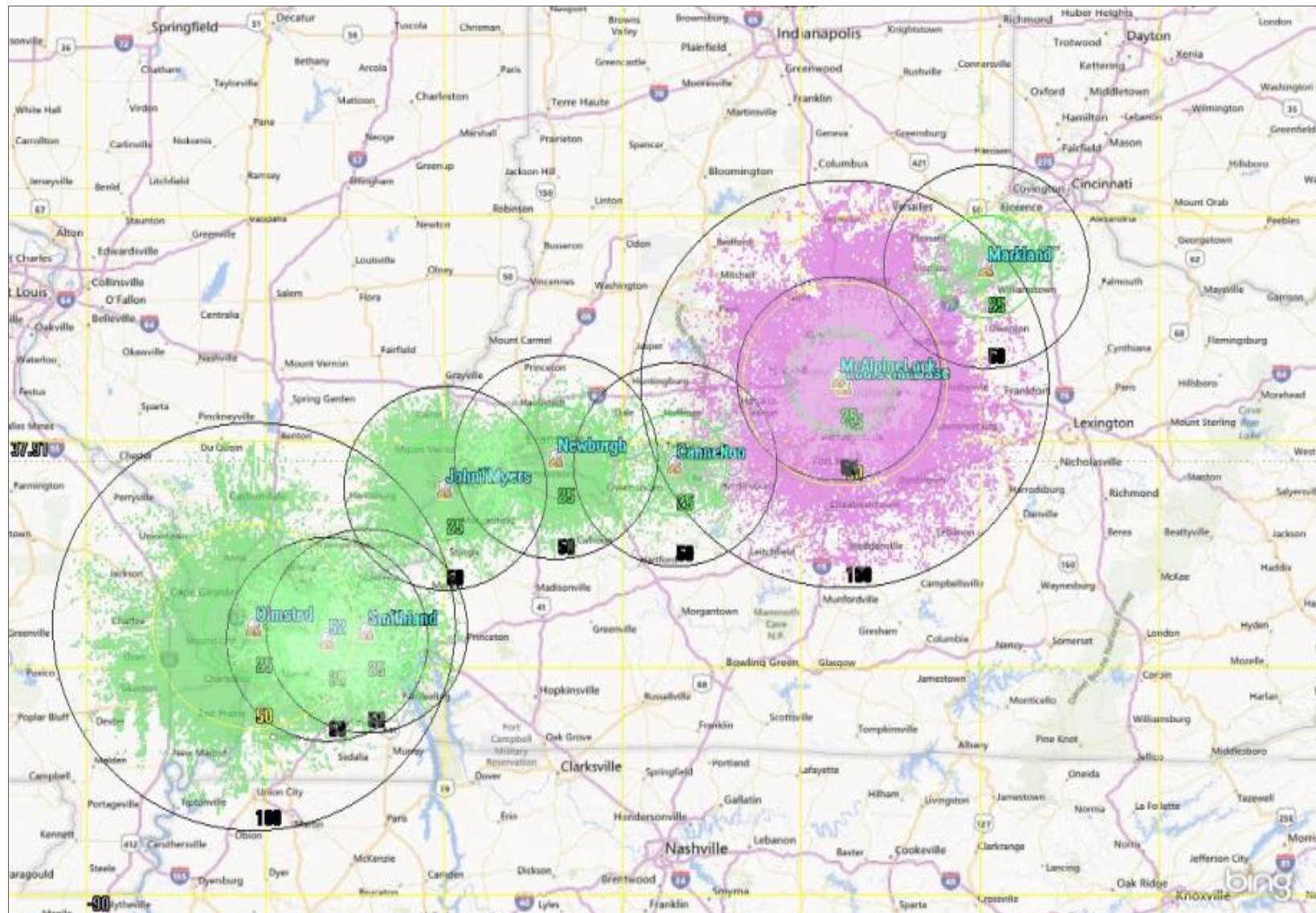


Figure 14. Predicted coverage from USACE sites (in green) and the USCG base station (in magenta). Range circles are shown in black at 50 or 100 km range from the transmitters.



6 FUTURE RECOMMENDATIONS

Based upon the results of the testing of the various system components, the following recommendations for the future are offered.

6.1 L-3 AIS AtoN Transmitters

The L-3 AIS AtoN transmitters that are used in the USACE LOMA system have limited capabilities. One major limitation is that the L-3 AtoN transmitters can only operate in RATDMA mode. While this is currently adequate in areas with very little load in the VDL, in order to ensure that the messages sent from the transceiver can be received by vessels in areas with more AIS traffic (such as New Orleans), reserved slots (FATDMA mode) need to be used. This will also be a requirement as more information is sent via the VDL, even in low-VDL load areas. Another limitation of the L-3 AIS AtoN transmitter is that it only generates acknowledgement messages when messages are properly transmitted. It does not generate a negative acknowledgement if there are too many messages to be sent in the 4-second RATDMA window. The L-3 should be upgraded to correct these limitations. Other options would be beneficial, such as adding TAG blocks at the radio and other site controller functions. Another option would be to use a different AIS AtoN transmitter, such as from Vesper Marine, or SRT Marine Technology.

6.2 CNS DataSwitch

The primary source of difficulty in the USACE LOMA system is the CNS DataSwitch. The system has implementation errors that include:

- **BBM to VDM translation.** This translation doesn't work for multi-line messages. Translation is also limited to a single global MMSI. A better implementation would be for a virtual MMSI that is based upon the client.
- **Bottom Connections/Rules.** There are limitations to the connections and rules. For example, the filters are not bi-directional.
- **BBM sentence creation.** The BBM messages created by LOMA are incorrectly created.
- **TAG blocks.** The current implementation is very rudimentary and needs to be totally revised. The user should be able to assign source/destination TAG blocks to bottom connections and the system should be able to route messages based upon the source/destination tags (similar to what is done by MMSI for addressed messages).
- **Addressed messages.** The current implementation is to send the addressed message to ALL base stations if the MMSI is unknown. If the location of the MMSI is unknown, it would be better for the DataSwitch to do nothing and return a failed transmission notification.

In addition, the software does not seem to be very reliable; there have been numerous crashes and reboots and system hang-ups just during the test period. There are alternative AIS router products; however switching to one of them would be difficult for USACE because of the way LOMA has been implemented. Continued work with CNS is recommended to attempt to correct the DataSwitch problems.

Any creation of ASMs within LOMA software or the DataSwitch should be removed and performed externally. The ASM formats change and this would require constant revisions to the LOMA and DataSwitch software. Also, the more that is embedded into the "AIS Router," the more difficult it is to change vendors.



6.3 USCG USACE Network Integration

Further work is required to resolve the integration problems between the USACE and USCG AIS networks. There are two difficulties with transmitter sharing (USCG sending data to USACE transmitters and vice versa).

- 1) IT policy restrictions: appropriate firewall permissions and policies have to be enabled.
- 2) Data routing: the current TAG block implementation on the DataSwitch makes it difficult to route messages exactly as desired; it is possible, but requires some work-arounds.

6.4 Policies

Establishment of data management policies and procedures is recommended. Much work has to be done to examine existing policies and procedures regarding handling data intended for AIS transmission. For example, how to determine what data is appropriate for transmission, changes to existing applications and databases that handle navigation information, or creation of new ones (e.g., USACE Notice to Navigation Interest (NTNI), and hydrodynamic model services). This can be approached by a “pave over cow paths” method – e.g., keep existing procedures and systems essentially the same and just “add AIS” to them. Or the entire data flow can be analyzed and a new, hopefully more efficient process can be developed. There are pros and cons for each of these methods, including the time involved, cost of creating or modifying existing systems, bureaucratic inertia and other factors associated with changes to existing methods.

6.5 AIS Coverage

The coverage using the USACE AIS AtoN transmitters is limited. Most transmitter antennas are installed at close to water level near the lock. Coverage would be substantially increased if the antennas were mounted at a higher location, such as the roof of the lock master tower, as has been done at Olmsted Lock. It is recommended that the antennas be moved to optimize transmission and reception range except in high-traffic areas.

6.6 Future Development

Future development work is recommended in the following areas.

- Investigate the feasibility of integration of some of the ASM Manager queuing functions into the “AIS Router” or transmitter.
- Investigate use of repeaters and other means to improve AIS transmit coverage.
- Develop standard means to measure transmit coverage/assurance of receipt.
- Develop USACE-hosted AIS message creation services (e.g., hydrodynamic models, LPMS and LOMA-generated data, etc.) similar to NOAA PORTS services and compatible with LOMA, NAIS and ASM Manager.
- Develop a real-time monitoring system for the USACE to ensure the system is operating reliably and messages are properly transmitted.



7 REFERENCES

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- [2] G. Johnson and I. Gonin, "Initial Test and Evaluation of AIS Network Controllers," USCG Research & Development Center, New London, CT, Internal Report Deliverable 3 under Contract No. HSCG32-10-D-R00021 Task Order HSCG32-12-J-300035, 11 March 2013.
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