U.S. Department of Transportation

Federal Transit Administration

Washington State Ferries Wireless Connection High-Speed Data Project

July 2009

Report FTA-WA-26-7006-2009.01

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The Washington State Ferries High Speed Data Project is a Research & Development project to study the feasibility of providing technologies capable of very high data transmission rates for wireless networks in a mobile marine environment. WSF is installing a high speed network infrastructure onboard vessel in an effort to improve ferry security and system monitoring. WSF wishes to explore ways of increasing transmission rates, facilitate a larger number of real-time camera views and improve overall performance. Intellicheck Mobilisa has established the viability of that system. The initial project test location selection resulted in using the Fauntleroy/Vashon Island/Southworth Ferry route. A demonstration of promising technologies was performed in June 2007 at the Fauntleroy terminal, utilizing the MV Klahowya. Technological concepts resulted in the decision being made to perform the final evaluation at the same terminal utilizing the same ferry. During final evaluation testing, several issues developed, including interference from a WSF WI-FI installation, power issues on the MV Klahowya, and power issues at the terminal resulting from a generator installation. The decision was made to move the final evaluation to the Port Townsend/Keystone ferry route, where it was successfully conducted in March 2008.</td></tr>
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WASHINGTON STATE FERRIES WIRELESS CONNECTION HIGH-SPEED DATA PROJECT

July 2009

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FINAL REPORT

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FOREWORD

Washington State Ferries (WSF) operates the largest ferry system in the United States, comprising 22 vessels serving 20 terminals and the surrounding community. Each of the vessels in the system is staffed by some two dozen WSF employees. Many people are surprised to learn that these ferry boats have office and security needs like any other workplace. It is a challenge to provide these floating offices with network access to company resources, and to offer computer-based services like email, helpdesk, and shared document management in such remote and mobile environments.

Since 2001, security has become an even greater concern of the ferry system than previously. With assistance from the U.S. Department of Homeland Security, a sophisticated system of electronic door locks, video cameras, and surveillance software has been installed on the vessels and in the terminals. Live video from these locations is streamed back to a terrestrial security center, where officers and cadets of the Washington State Patrol monitor the fleet and terminal facilities.

As video technology has improved, high-resolution cameras have been installed at some locations. Demand for ever-greater networking bandwidth, for security just like any business application, has led WSF to investigate new technologies that can be employed in the unique over-water environment of the ferry system.

Wireless-Over-Water (WOW) environments present a challenge defined by two vectors. The problem combines significant distance (a typical WSF journey covers seven miles) with the inability to create an orderly array of antennas in the open water. The option of deploying a system of buoys has been discarded as a potential hazard to navigation in the very busy waterways of Puget Sound. In the specific case of WSF, the problem is compounded by the electrolytic character of salt water, which further degrades the radio signal.

To explore these issues in more depth and look for new solutions, Washington State Ferries received funding under FTA grant WA-76-7006 for the demonstration project that is the subject of this report.

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Executive Summary

The Washington State Ferries (WSF) High Speed Data Project (HSD) is a Research and Development project funded via the Federal Transit Administration (FTA) under a cooperative agreement to study the feasibility of providing technologies capable of very high data transmission rates for wireless networks in a mobile marine environment. The objective was to specifically enable off ship (ferry) transmission of video (security cameras), file services, and administrative data from a moving ferry, thereby; enabling off ship recording of video and improved efficiencies in administration. WSF wished to explore ways of increasing transmissions rates, facilitate a larger number of real-time camera views and overall, improve system performance to suit the needs of WSDOT, WSF and other supporting agencies.

The purpose of this project was to research technology feasibility of providing very high data transmission rates for wireless networks in a mobile marine environment, formulate a Proof of Concept, develop, test and roll out a prototype system to a single WSF vessel. The initial project was located at the Fauntleroy/Vashon Island/Southworth Ferry route. Research and Development was conducted along that route, as well as the Port Townsend/Keystone ferry route. A demonstration of promising technologies was successfully performed in June 2007.

Project results include: Achieved a consistent data throughput rate of over 25MBps and up to 200 MBps with 99% connectivity in a line of sight/non-blocking environment. The system architecture was validated by demonstrating 10 video cameras streaming video, while simultaneously transferring a 50mb file and streaming a video movie from the moving ferry to shore.

Due to mechanical issues with ferries and WSF infrastructure along both the Southworth and Port Townsend route, a fully installed system evaluation was not performed. A temporary installation onboard a leased ferry (MV Steilacoom II) along the Port Townsend/Keystone route was successfully performed in March, 2008.

The contract term ended March 31, 2008.

1. Introduction

1.1 Background

The Washington State Ferries (WSF), in cooperation with the Washington State Department of Transportation (WSDOT), is installing high speed network infrastructure (known as Super LAN) onboard WSF systems in an effort to improve ferry security and system monitoring. This system provides the backbone for video and security monitoring that feeds live video in real-time to the WSF monitoring center located onshore, in addition to ships' business data, Voice over IP, Fax server, etc. In its current configuration, live video feeds have limited bandwidth capacity and often become overwhelmed when increasing frame rates or when viewing multiple camera instances. WSF wishes to explore ways of increasing transmissions rates, facilitate a larger number of real-time camera views and improve overall system performance to suit the needs of WSDOT, WSF and other supporting agencies.

1.2 Goals and Objectives

Intellicheck Mobilisa™ (Contractor, formerly Mobilisa, Inc.) was tasked to research feasible technologies capable of providing very high data transmission rates for wireless networks in a mobile marine environment; formulate a Proof of Concept (POC) system and to develop, test and roll out a prototype system to a single WSF vessel, as per the WSF Wireless Connection High Speed Data project contract # DP01165. Implementation of this system into the current infrastructure would enable WSF to rapidly transmit digital video from moving passenger ferries to shore-based security facilities to be viewed, analyzed and archived. These objectives were accomplished by a combination of instrument development and testing, field measurements, data analysis, modeling, and prototype evaluation. Intellicheck Mobilisa has researched, tested and evaluated current technologies to provide the required throughput in a consistent manner.

The system scope is based on communications with WSF and the Implementation Plan/Statement of Work (IP/SOW) for the WSF Wireless Connection Project – High Speed Data. The prototype system was successful and met the following requirements:

1.3 Requirements

Project requirements are categorized into two sections:

- General Requirements
- Functional Requirements

1.3.1 General Requirements

1.3.1.1 Proof of Concept

Intellicheck Mobilisa, Inc. utilized standard scientific research and development methodologies in support of the Proof of Concept (POC). The contractor provided the conduit for transitioning the POC into a working model capable of supporting a wireless high speed data network. The model demonstrated feasibility, functionality and scalability.

1.3.1.2 Build Prototype System

Based on the model, the contractor constructed and configured a prototype system by combining the designed architecture and individual technologies proven in the POC. The prototype system was successful in supporting functional requirements. The prototype was installed on multiple WSF ferries. Furthermore, the prototype was evaluated by a third party to ensure it met the requirements as prescribed by WSF.

1.3.1.3 Integration

The prototype is capable of integration into the existing WSF infrastructure. The requirement of: *"Specifically from the vessel, it must process data for the Super Local Area Network (SuperLAN) Vigilos video camera system via a server-side interface. For the shore side, the system must be capable of secure communications through the WSF wired backbone for outside connectivity (off the vessel) and onto the WSF network"* was waived by WSF IT director due to WSF operational requirements.

1.3.1.4 Homeland Security/Emergency Response

The prototype system does support high transmission rates in support of the installed video surveillance system. The system is robust enough to handle maximum data transmission rates from at least two vessels in case of simultaneous emergencies on multiple vessels and the bandwidth available to assist in monitoring and carrying out emergency response operations. In the event of a vessel emergency or act of terrorism, the system would be the only source of real-time video.

1.3.1.5 WSDOT Business

In addition to video monitoring, the system is constructed with consideration of other WSF applications. These other WSF applications will likely share bandwidth during non-peak and non-emergency periods and may include the WSF Maintenance Productivity Enhancement Tool (MPET), fax services and telephony and potentially Voice over Internet Protocol (VoIP).

1.3.2 Functional Requirements

Functional requirements capture the intended behavior and expected architecture of the system. This is expressed in terms of services, tasks or functions of system performance. The functional requirements section identifies the key objectives to the project that drove design and ultimately validated the final architecture.

1.3.2.1 Network and Hardware Performance

The system provides continuous and reliable performance in delivering data throughput at very high rates of speed. To achieve this goal, the system required superior computing components, network infrastructure and support equipment, products and tools necessary to achieve the highest magnitude of availability, the least amount of downtime and the maximum level of system performance.

The system hosts a variety of support systems in addition to providing real-time video data to shore-based systems for dissemination. The WLAN services within existing network and architectures provide fail-over, redundancy and load balancing for greater redundancy and network performance.

The hardware chosen for the system was configured for optimal performance of the prototype. The design utilizes a client/server approach for model development, model execution, security, configuration, and system management.

1.3.2.2 High Data Capacity

Careful research and significant engineering efforts were required to identify suitable technologies platforms and to develop and integrate a complete solution capable of meeting the design criteria.

Upload bandwidth from vessel to a simulated WSF Network Operations Center (NOC) did not drop below 25 Megabits per second (Mbps) during unobstructed operation; e.g., there is a physical vessel blocking line-of-site as the vessel traverses the route.

Connectivity proved to be virtually continuous; meaning greater than 99% of data is received from vessel to WSF NOC as the vessel traversed the route unobstructed.

1.3.2.3 Off-board Transmission of Data

The system was able to transfer video data off the vessel for the purposes of archiving and duplication, subject to the 25 Mbps limitations. The objective was to reduce storage requirements onboard the vessel while improving shore-based data collection capabilities.

1.3.2.4 Throughput Optimization of Live Video

A minimum of 10 video viewing sessions was supported. This was initially defined as one camera view for each session as the vessel traverses the route. In addition, normal ships business, in particular to the vessel, was not impacted.

1.3.2.5 Security

The system was designed with security considerations in mind to protect against viruses, worms, packet floods, data interception and unauthorized system access. Security measures occur at various points within the system.

The Contractor provided evidence that the information presented was the actual data being transmitted from the cameras on the ship.

1.3.2.6 Mutual Authentication

Both the shore side radios and the ship borne radios authenticated with each other before establishing a network link. This prevented the introduction of "rogue" devices either representing a ship or a shore side radio, into the network. Rogue devices are the primary means of conducting a Man-In-The-Middle (MITM) attack in a wireless network.

1.3.2.7 Layer 2 (Ethernet) Encryption

The Advanced Encryption Standard (AES) was used and is capable of large key input including 128 and 256-bit, with minimal system overhead.

1.3.2.8 Non-interference with Existing WSF Systems

The prototype system was constructed and installed on a not-to-interfere basis with other unrelated WSF networking systems.

2. Work Plan

Five (5) major phases to the project:

1. Research – Bandwidth Analysis & Wireless Technologies
2. Design
3. Demonstration of promising Technologies
4. Build Prototype & Test
5. Third Party Evaluation

2.1 Research

The Contractor completed a technology review that captured the functional requirements of the project. The technology investigation included top-level trade studies that evaluated technology versus cost versus effectiveness.

2.1.1 Radio/Frequency R&D Requirements

- Identify the most effective band that use available commercial high speed solutions (2.4 GHz, 4.9 GHz [safety –licensed] 5.8 GHz)
- Focus on Commercial-Off-The-Shelf (COTS) wireless technologies w/high speed capability (significantly greater than 25 Mbps)
- Understand the effect of these technologies in the mobile, maritime environment
- Identify Fresnel zones, RF coverage
- Consider tidal changes
- Identify optimal antenna configurations & placement in the field
- Adjust for RF Line of Sight (LOS)
- Resolve the Point-To-Point vs. Point-To-Multi-Point (PTMP) issue (roaming) for High Speed
- Optimize solution and configuration

2.1.1.1 RF Bands Analyzed for a High Speed Solution

2.1.1.1.1 2.4 GHz Unlicensed Band

-Large selection commercial hardware.
-Saturated commercial usage and co-channel interference likely.
-Limited high speed solution (54 Mbps theoretical maximum).
-Not effective over long ranges w/PTP connections, especially over water.

2.1.1.1.2 4.9 GHz FCC licensed Safety Band

-Very little usage, good!

-Small frequency range (intended for voice communications).
-Only two non-overlapping channels, limits high speed techniques.
-High Speed commercial solutions non-existent.

2.1.1.1.3 5.8 GHz Unlicensed Band

-Decent selection in commercial hardware.
-Low usage & Interference.
-Multiple non-overlapping channels allowing multi-signal techniques to achieve high speed solutions.
-Long range PTP connections very good.

2.1.1.2 Results of Radio Frequency Research:

A desire to utilize Commercial-Off-the-Shelf (COTS) solutions on the project, linked with the data gathered in the above frequency ranges, resulted in the decision to focus on COTS wireless technologies w/high speed capability in the 5.8 GHz range. The 5.8GHz spectrum, while becoming heavily used, provided the vehicle to achieve the required range, required throughput and cost efficiencies. Future development may require a shift into a different frequency band, possibly the licensed public safety band of 4.9GHz or WIMAX 6.0Ghz band.

2.1.2 Radio Research:

Several radios were tested and evaluated for use in the Wireless Over Water configuration. While these radios are designed for fixed applications, Intellicheck Mobilisa. Inc. has developed techniques which enable radios to be used in waterborne mobile applications.

A Mobile equipment package (MATS Box) and antenna system were set up on a fixed shore location and onboard a moving ferry. Each radio was tested against three specified requirements.

Characteristics:

Frequency spectrum and tunability, Data Rate, Jitter, Latency, Receiver Sensitivity, encryption capability.

Management:

Management capability, SNMP, Firmware Support, Spectrum Analyzer, Diagnostics.

Operation:

Network Interface, PoE, Antenna Connector, Alignment aid.

		Radio Products Evaluated																	
Features		**Alvarion BreezeNET B100**		**Axxcelera AB-Full Access**		**Eion Wireless LIBRA 5800**		**Motorola PTP-400**		**Motorola PTP-600**		**Proxim TeraBridge**		**Proxim Tsunami MP.11a**		**Redline RedCONNEX**		**Solectek Skyway 7500**	
Characteristics	**Weight**	**AV**	**TOT**	**AV**	**TOT**	**AV**	**TOT**	**AV**	**TOT**	**AV**	**TOT**	**AV**	**TOT**	**AV**	**TOT**	**AV**	**TOT**	**AV**	**TOT**
RF Band	**10**	3	30	3	30	3	30	3	30	3	30	3	30	3	30	3	30	3	30
Data Rate Marketed	**10**	2	20	3	30	1	10	2	20	5	50	2	20	2	20	2	20	2	20
Channel Bandwidth	**8**	1	8	1	8	3	24	3	24	4	32	3	24	1	8	1	8	1	8
Modulation Type	**8**	3	24	3	24	1	8	3	24	5	40	2	16	3	24	3	24	3	24
Transmit Power	**7.5**	4	30	4	30	3	22.5	5	37.5	5	37.5	3	22.5	3	22.5	4	30	5	37.5
Receive Sensitivity	**5**	4	20	4	20	4	20	4	20	4	20	3	15	4	20	4	20	4	20
Latency	**5**	4	20	1	5	3	15	4	20	5	25	4	20	4	20	4	20	5	25
Encryption	**4**	5	20	2	8	2	8	4	16	5	20	0	0	3	12	0	0	4	16
OFDM	**4**	4	16	1	4	3	12	3	12	3	12	4	16	4	16	4	16	4	16
Bridge Mode	**4**	3	12	3	12	5	20	3	12	3	12	3	12	4	16	3	12	3	12
Turbo Mode	**3**	2	6	2	6	4	12	4	12	4	12	4	12	2	6	2	6	2	6
Section Subtotal		**35**	**206**	**27**	**177**	**32**	**182**	**38**	**228**	**46**	**291**	**31**	**188**	**33**	**195**	**30**	**186**	**36**	**215**
Management																			
Management	**8**	3	24	4	32	3	24	4	32	4	32	4	32	4	32	5	40	4	32
SNMP	**7**	3	21	3	21	3	21	3	21	3	21	3	21	3	21	3	21	3	21
Firmware Support	**7**	3	21	1	7	3	21	3	21	3	21	1	7	3	21	3	21	3	21
Spectrum Analyzer	**5**	3	15	1	5	1	5	3	15	3	15	1	5	0	0	3	15	3	15
Diagnostics	**5**	1	5	1	5	1	5	3	15	3	15	1	5	1	5	3	15	3	15
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Operation																			
Network Interface	**10**	3	30	3	30	3	30	3	30	4	40	3	30	3	30	3	30	3	30
PoE	**10**	3	30	0	0	3	30	3	30	3	30	0	0	5	50	5	50	3	30
Antenna Connector	**9**	3	27	3	27	3	27	4	36	4	36	3	27	3	27	3	27	2	18
Alignment Aid	**5**	3	15	1	5	1	5	3	15	3	15	2	10	2	10	3	15	3	15
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Table 1 - Results of radio research

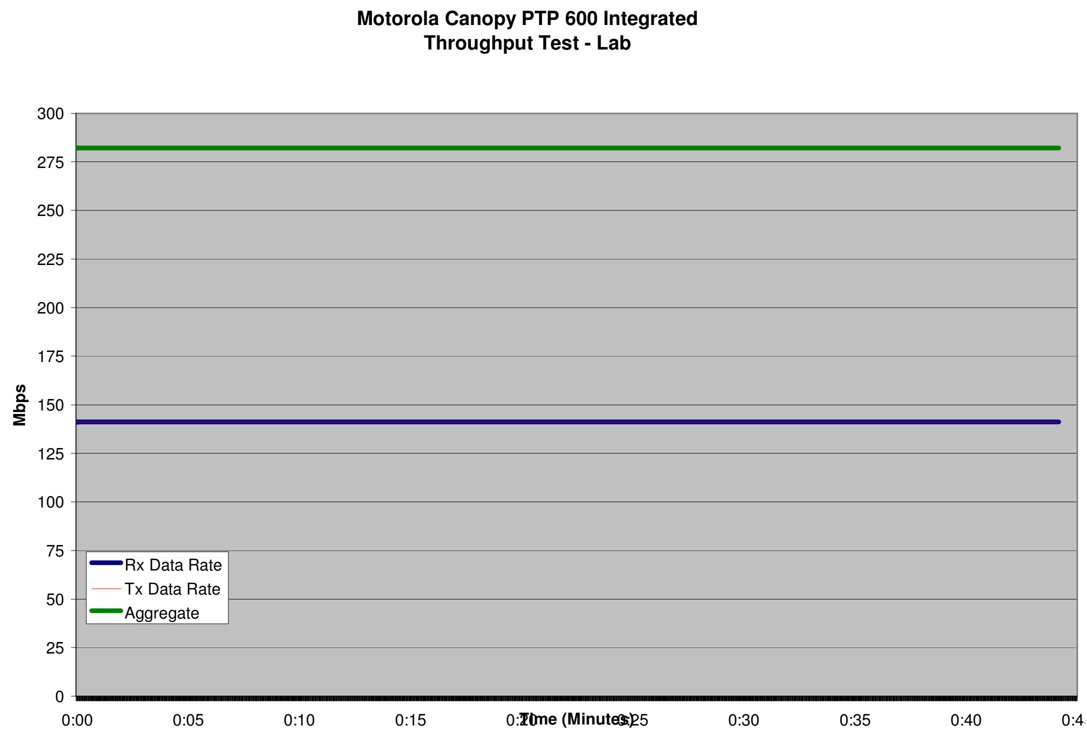


Figure 1 Lab throughput graph testing results of Motorola PTP-600 radio

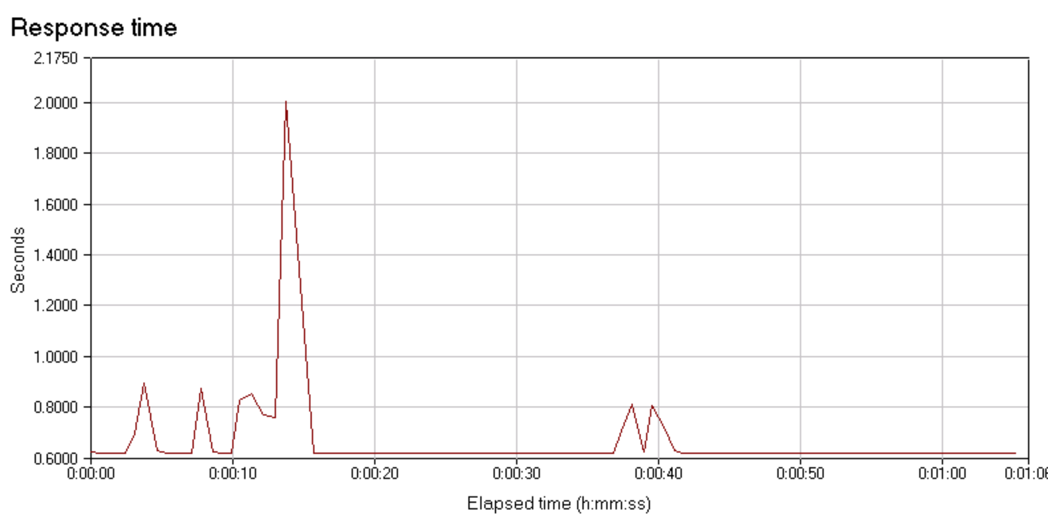


Figure 2 Response time graph of Motorola PTP-600 radio

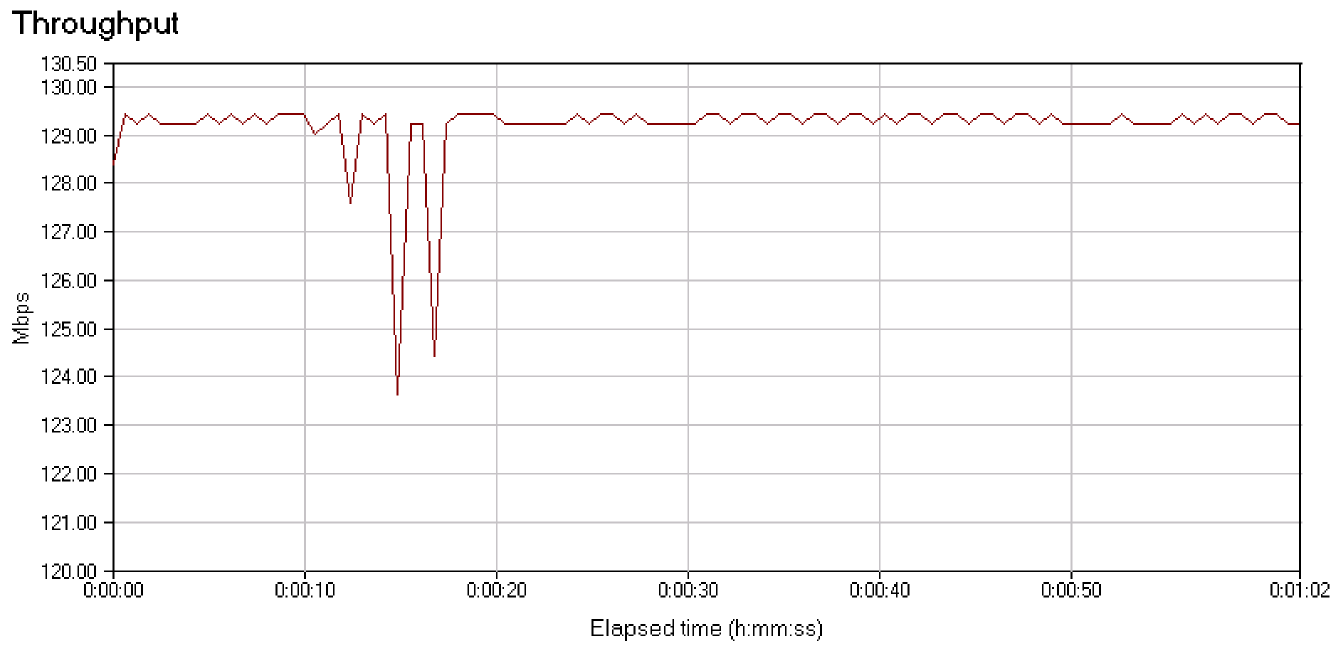


Figure 3 Throughput graph of Motorola PTP-600 radio

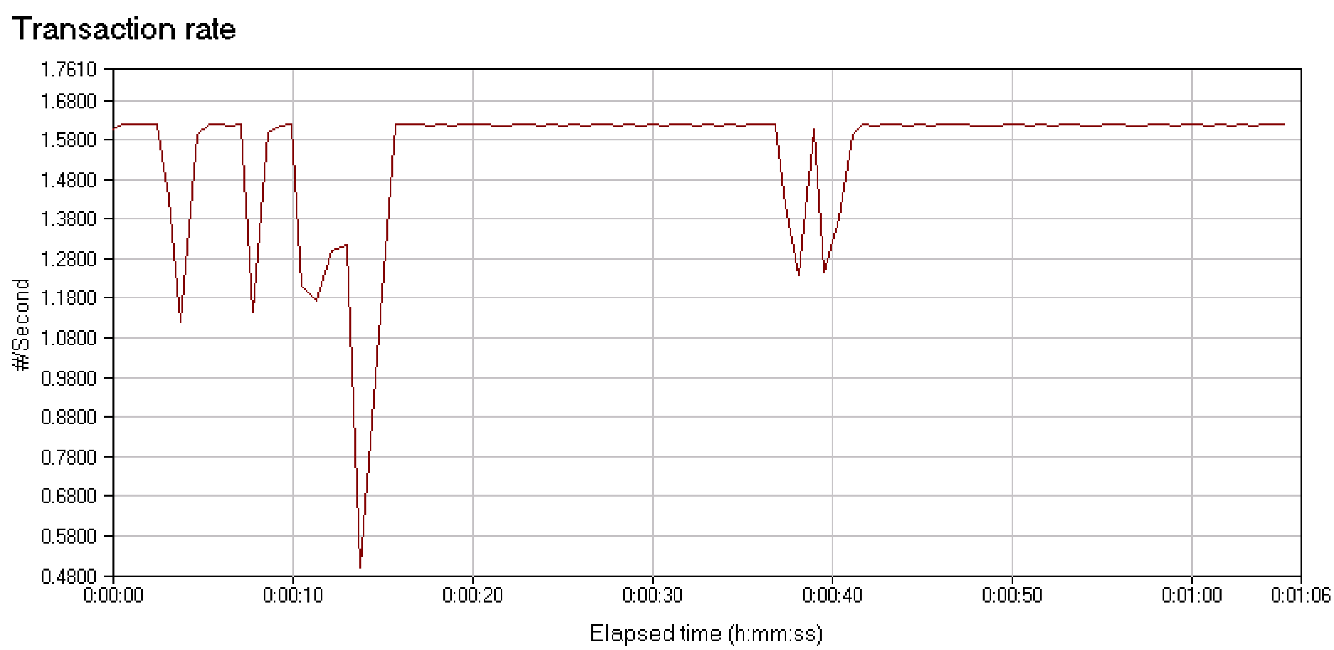


Figure 4 Transaction rate graph of Motorola PTP-600 radio

Figure 5 MATS radio and antenna testing

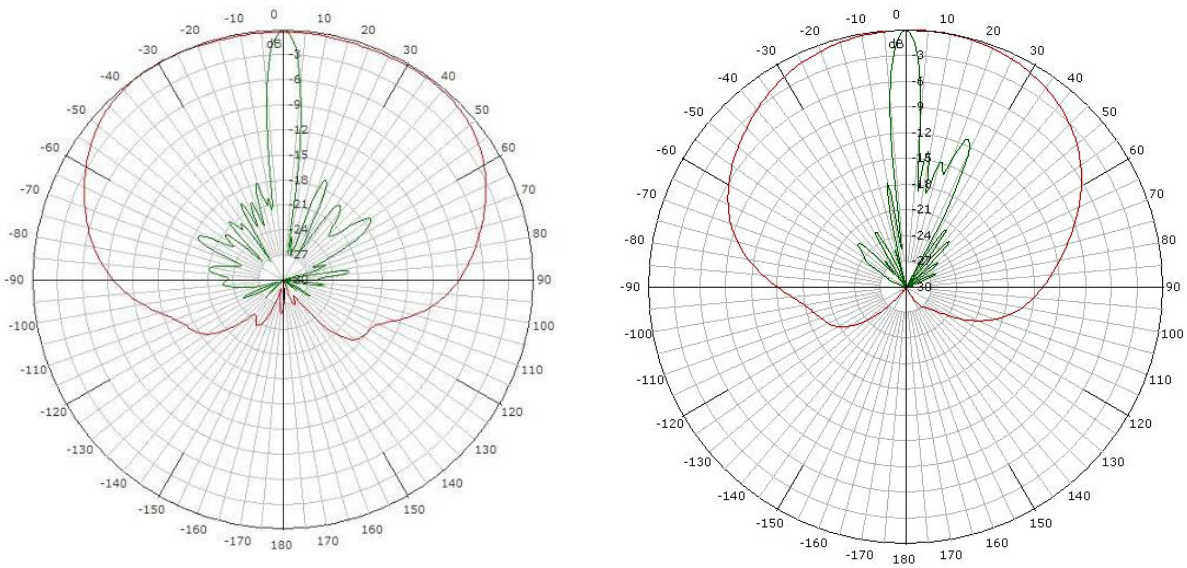
2.1.2.1 Results of Radio Research:

Utilizing known scientific weighting methods, combined with thorough analysis of published radio characteristics and cost/benefit analysis, research indicated the use of Motorola PTP-600 radios due to their performance, usability, scalability and availability.

2.1.3 Antennas:

Several antennas in varying configurations were evaluated, including Proxim Panel sectorized (10, 60, 90 & 120deg), Maxrad Omni, Andrew sectorized (90deg), Pacific Wireless vertical and Horizontal polarized (60, 90 and 120 deg) and Orthogon sectorized (90 deg). The tables below show the specifications of the selected antennas.

Vertically Polarized Sector Antennas
5725 to 5850 MHz Operation
Features
- Hi Gain 16dBi or 17dBi in a small form factor
- Vertically Polarized
- Type N Female Integrated Connector
- Completely Weatherproof
- Easy to use tilt bracket



Specifications

Frequency Range 5725 5850 MHz
Impedance 50 OHM
Pole Diameter (OD) 1.5" (38) 3" (76) Inch (mm)
Gain 17dBi 16 dBi
Vertical Beam Width 7 deg 7 deg
Front to Back >25 dB >21 dB
Weight 2.6 lb (1.2kg) 2.6 lb (1.2kg)
VSWR 1.5:1
Input Power 100 W
Operating Temperature -40 +70 Deg C
Horizontal Beam Width 90 deg 120 deg
Polarization Vertical
Mechanical Downtilt 15 deg 15 deg
Dimensions *(LxWxH)* 21.5" x 5" x 2.8" (545 x 125 x 71mm)

Figure 6 Antenna patterns

2.1.3.1 Results of /Antenna Research

Testing of antennas in various configurations provided detailed capabilities of each antenna. The data established that the antenna gain, pattern, and size of the Pacific Wireless vertical antenna gave the superior capabilities needed for the project. By using these antennas in a horizontal and vertical polarized configuration simultaneously with spatial separation, a high throughput was achieved.

2.1.4 Initial Radio/Antenna Testing:

Testing was conducted on the Port Townsend to Keystone Ferry run over a four day period from February 5-8 2007. The intent of the test was to evaluate link connection and throughput as the vessel traversed the route from Keystone to Port Townsend. The shore-side connection was located at Fort Flagler with the other node located on the M/V Klickitat. The antennae were located on the forward port quarter oriented at roughly forty-five degrees off the bow.

During the test, a connection was held for nearly the entire route. A Non-Line-Of-Sight (NLOS) connection was maintained at the Keystone terminal and side-lobe / rear-lobe connections at the Port Townsend Terminal. The radios performed extremely well and maintained between 52 and 160 Mbps while inside each others' beams. Performance suffered slightly on 6 February and was corrected after the antennae were discovered to be out of alignment.

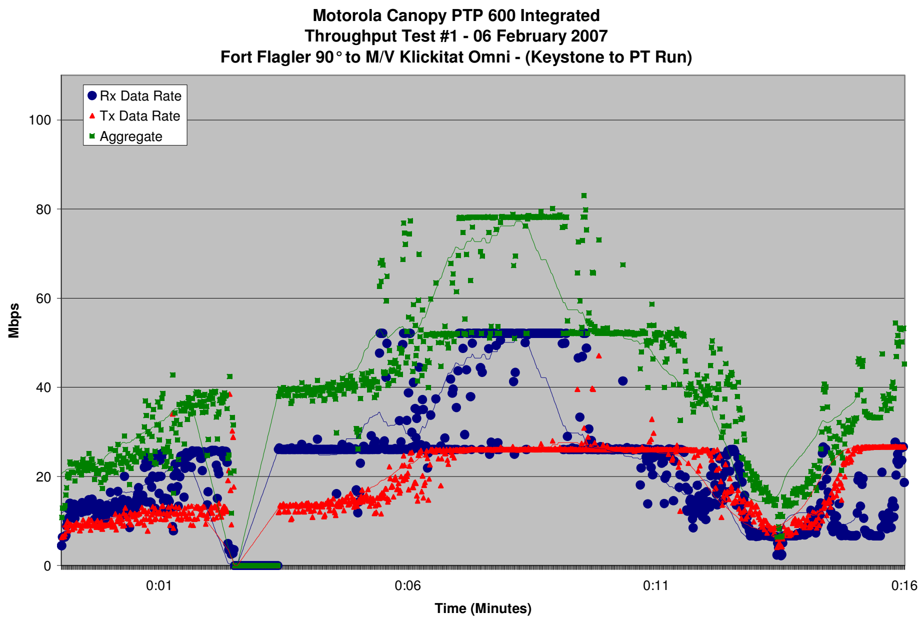


Figure 7 Graph depicting throughput test #1

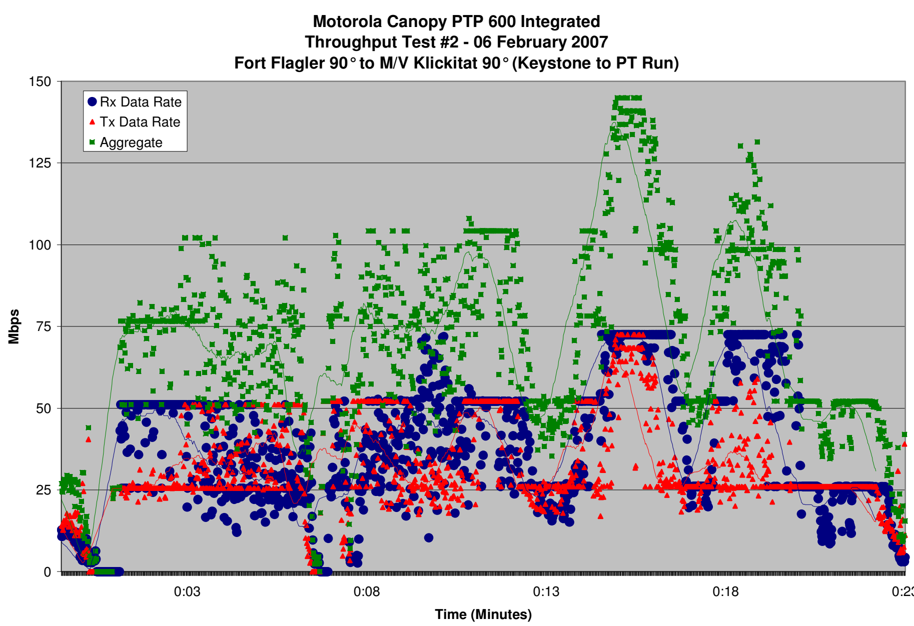


Figure 8 Graph depicting throughput test #2

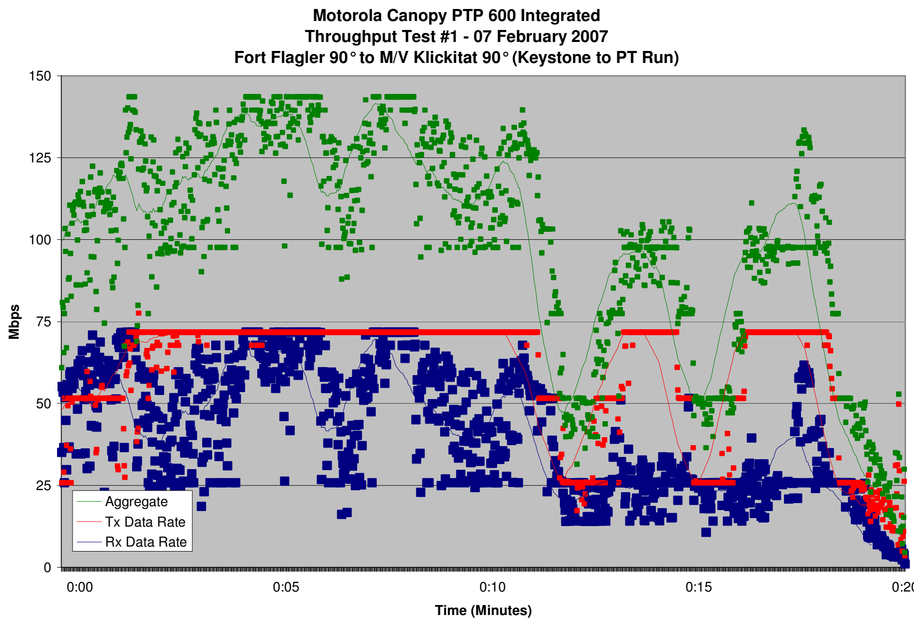


Figure 9 Graph depicting throughput test #3

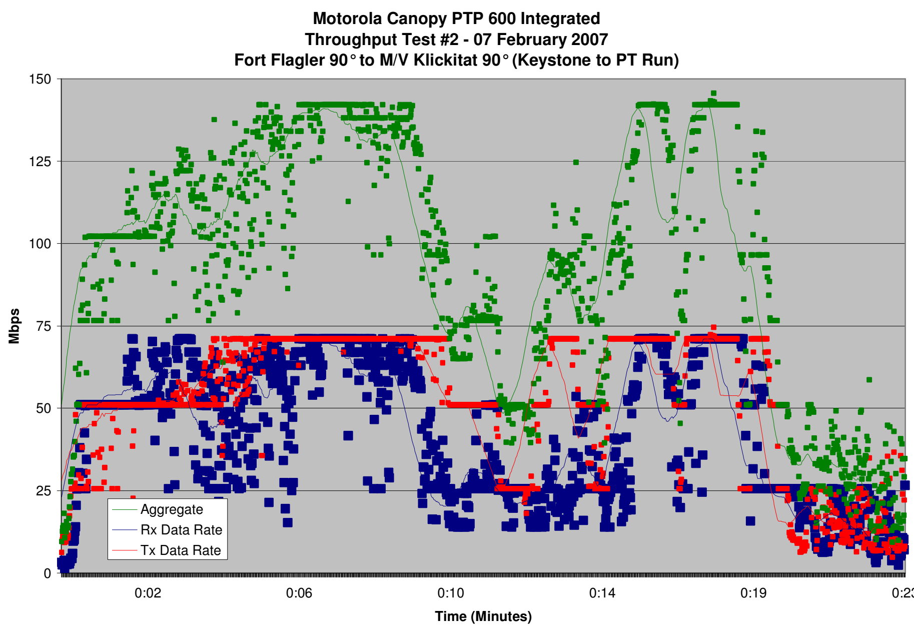


Figure 10 Graph depicting throughput test #4

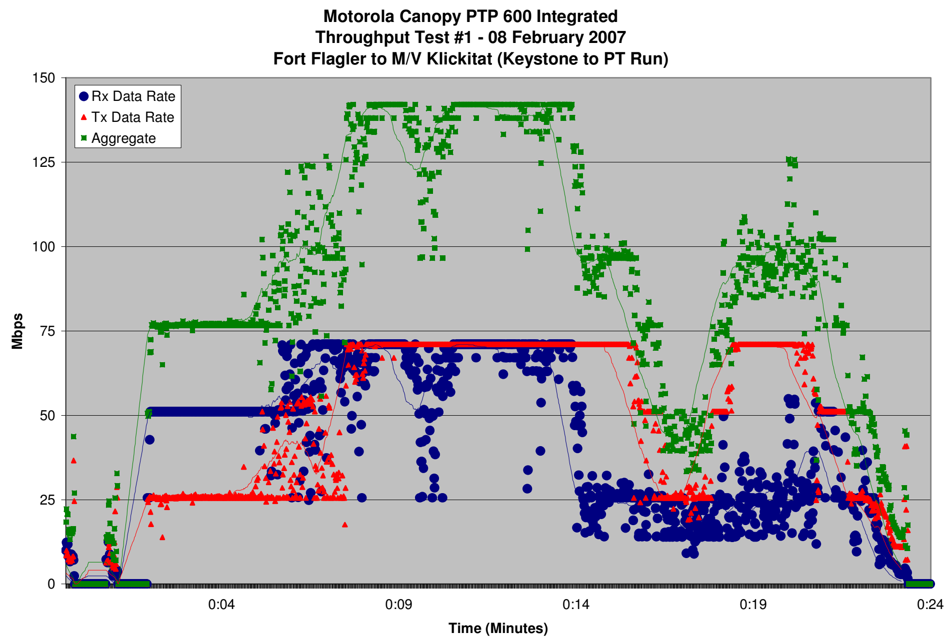


Figure 11 Graph depicting throughput test #5

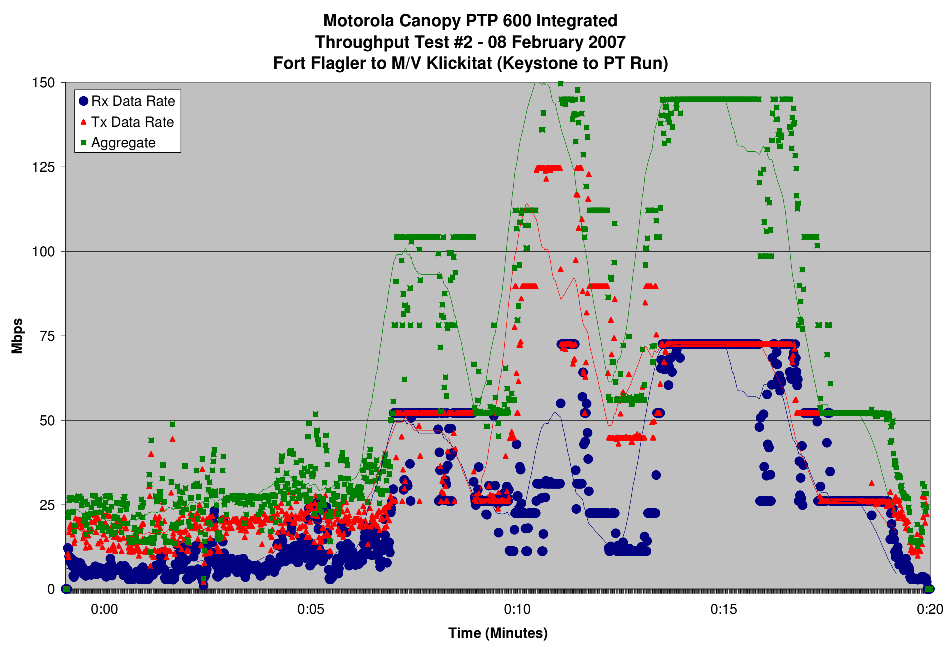


Figure 12 Graph depicting throughput test #6

The above graphs show that the aggregate data rate varied between 17 and 150 Mbps. Figure 7 shows that the performance of an Omni antenna is extremely poor for throughput, maintaining below 25MBps over 80% of testing time. Figures 8-12 uses a 90 degree antenna in different configurations and alignments, and the performance is well above that of Omni directional antennas. Figure 12 provided evidence of Line-Of-Sight blockage/antenna alignment issues during the first 7 minutes of the test, when a ship was loitering directly between the test vessel and shore site. Further testing proved that by performing an alignment adjustment, the data rate was maintained above 25 Mbps continuously. The radios performed extremely well in a mobile marine environment and further testing concentrated on antenna configuration, tuning and alignment.

2.2 Design:

The design focus is for Commercial-Off-The Shelf (COTS) Solutions which are:
-Cost effective
-Readily available, scalable solutions
-Adaptable for mobile, maritime environment

2.2.1 Commercial-Off-the-Shelf (COTS) Objectives:

•Identify technologies that meet or exceed WSF data requirements as identified in the Implementation Plan (IP).
•Operate technologies operate in the currently approved IEEE 802.11 standard band (compatible).
•Identify and research high speed radio solutions that meet requirements.

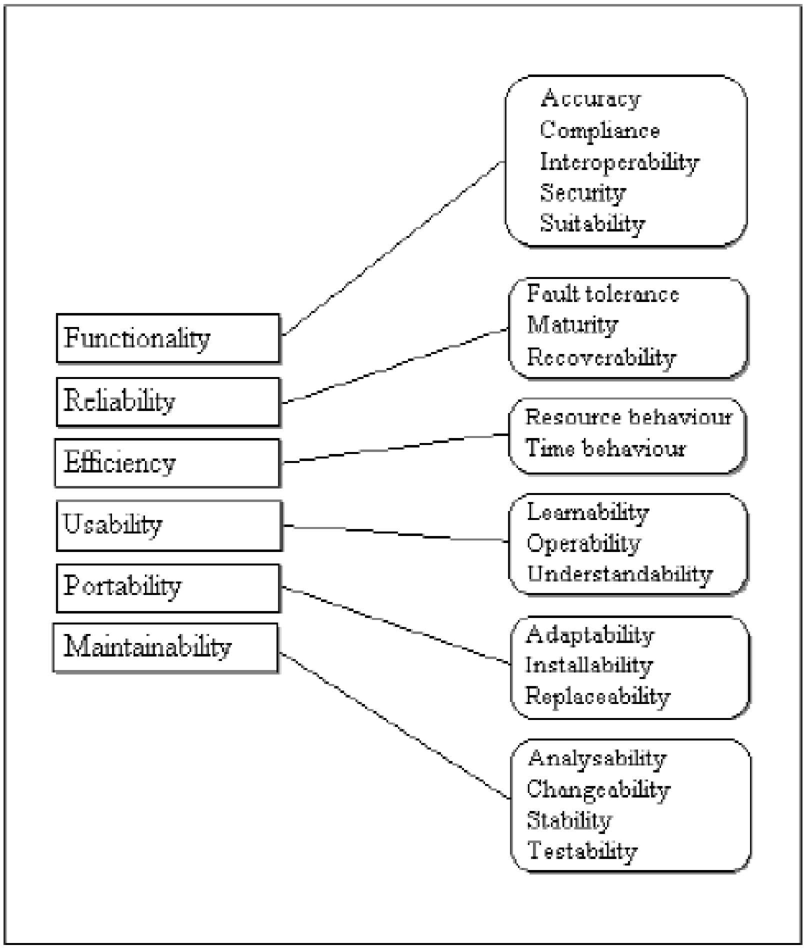


Table 2 Graphic of COTS solution requirements

2.2.2 Initial Design

Original design and testing were conducted at the Port Townsend lab of Intellicheck Mobilisa, Inc. Testing was conducted both land based and over water using the Ferry MV Klickitat. Once the equipment was selected, evaluated and configured, it was then moved to the Southworth, Fauntleroy, Vashon Island route and the MV Klahowya. This route was selected as the test route by the WSF IT Director.

The Backhaul was installed on the terminals at Fauntleroy and Southworth. The WSF IT director approved the non-connection into the WSF Ferry SuperLAN and Vigilos system, due to WSF operational requirements. A Modem was also installed at the Fauntleroy terminal for remote system monitoring. The diagrams below show the installation and testing of this ferry route. Figure 13 depicts the Southworth/Vashon/Fauntleroy ferry route. This route proved challenging when during peak transit times the ferry MV Klahowya would turn 180 degrees while offloading vehicles at the Vashon terminal, which disconnected the PTP radio connection. This issue can be alleviated with an Omni antenna and separate shore backhaul equipment set-up. This set-up was not used due to financial considerations, and it was decided by the WSF IT Director to negate the performance issue as a known configuration change.

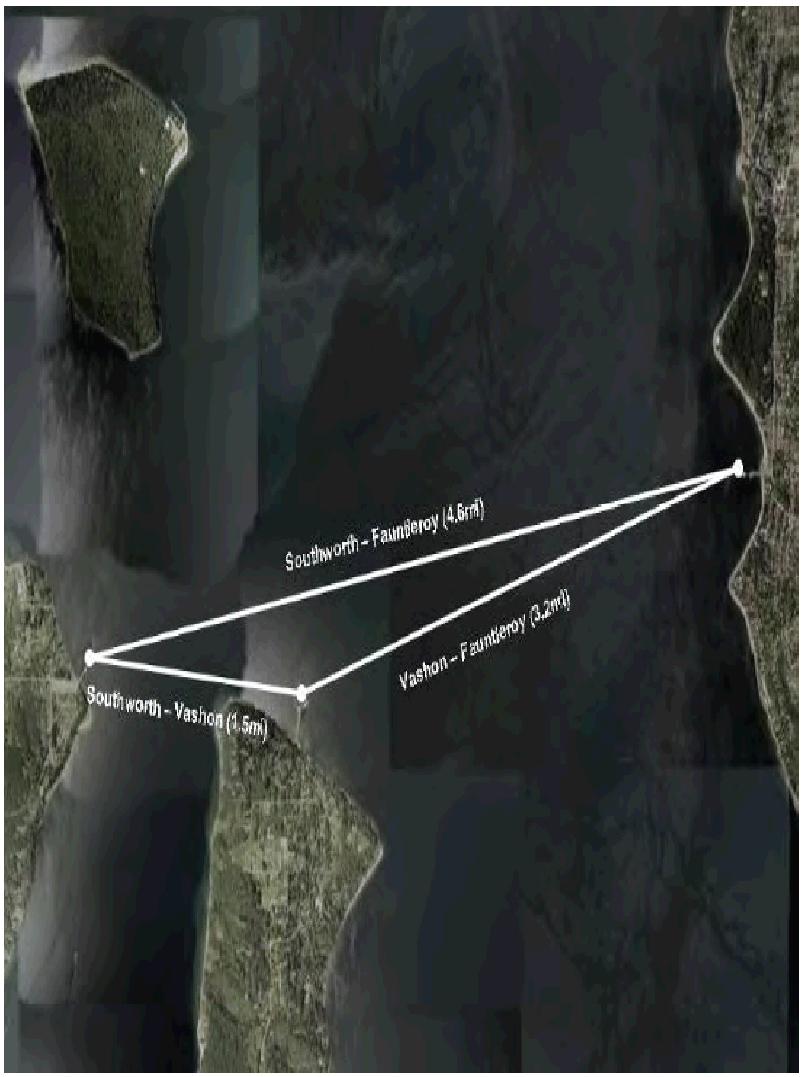


Figure 13 **Planned location for prototype**

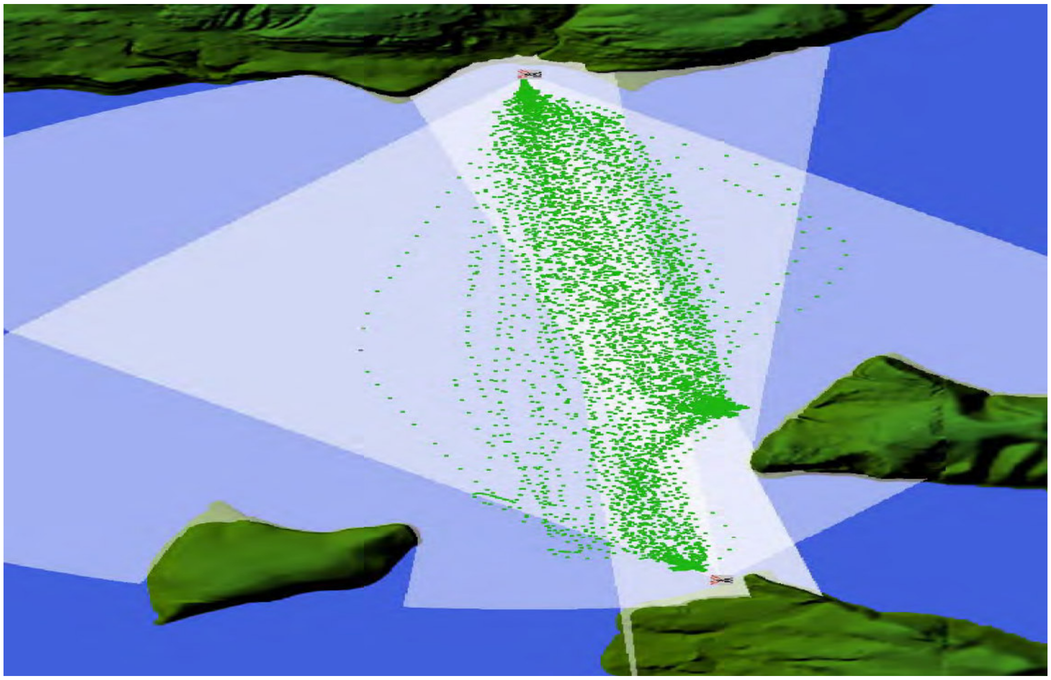


Figure 14 RF coverage/shed analysis–triangle route (Southworth/Fauntleroy)

Figure 14 shows the GPS/shed analysis of a 24 hour period of the Southworth/Fauntleroy/Vashon ferry route. This GPS data dictated the antenna coverage required to meet all objectives.

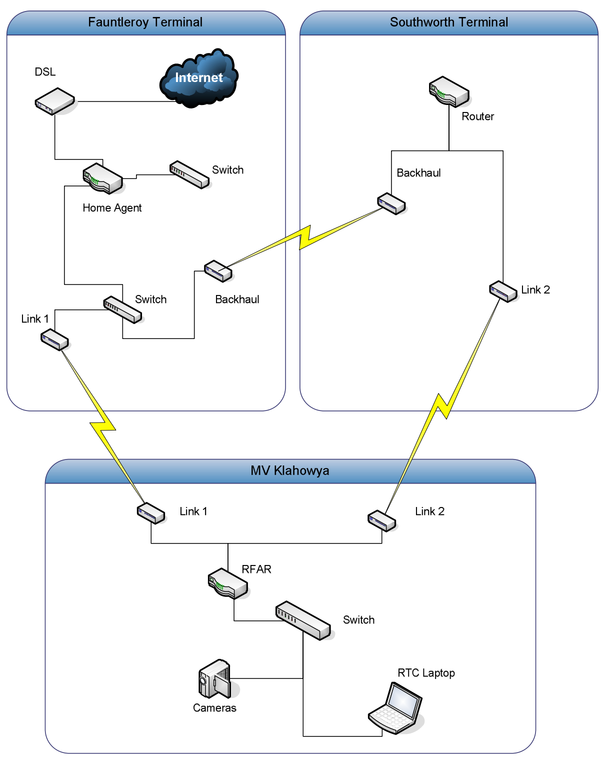


Figure 15 Diagram of network configuration of Southworth/Fauntleroy route

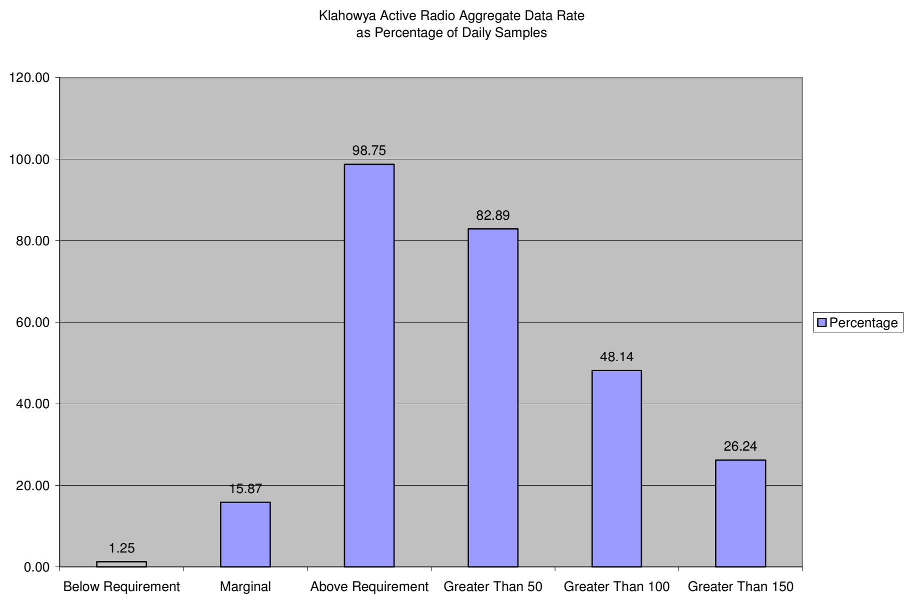


Figure 15 24 hour bar graph of achieved throughput of Southworth/Fauntleroy route

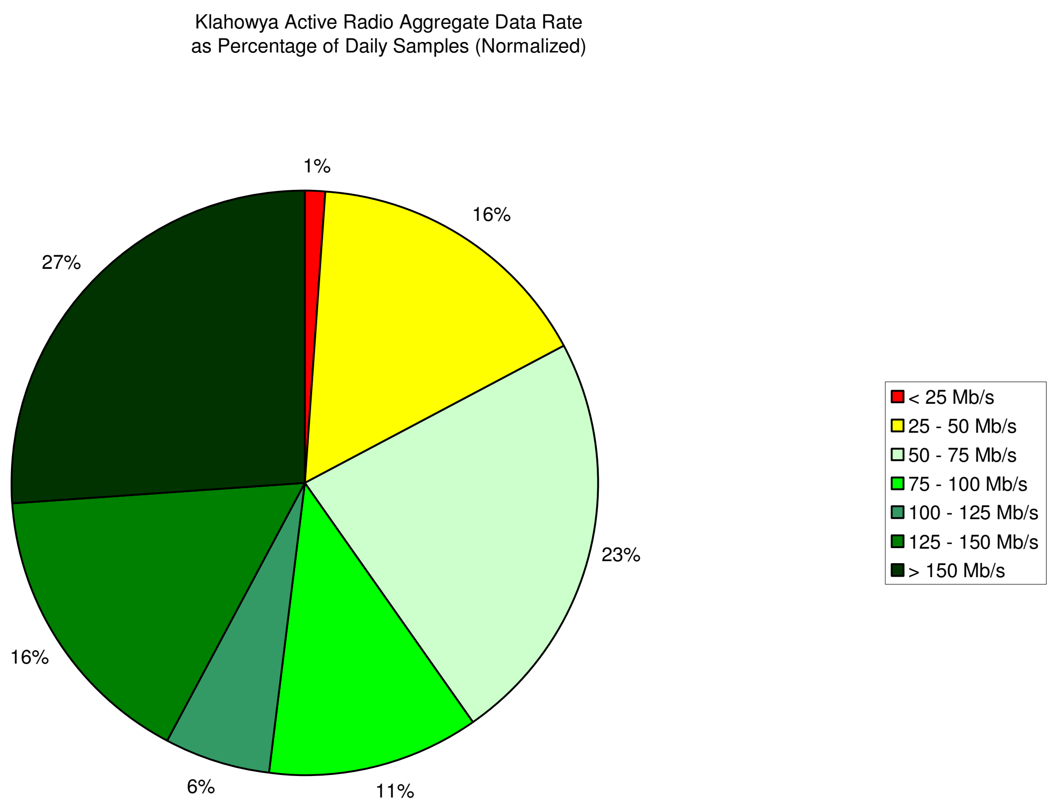


Figure 16 Pie chart of achieved throughput- normalized

The preliminary network design required a change of venue when during the initial Third Party evaluation, the week of October 8, 2007; there were several network degrading issues. When the MV Klahowya switched to their Auxiliary Sea Water pump (every evening), the ship's electrical system would spike and shut down both Intellicheck Mobilisa's and the evaluators' systems, requiring Intellicheck Mobilisa technicians to return to the ferry and re-start both systems. This was not normally an issue and was caused by a defect in the pump, scheduled for repair. A scheduled power outage at the Fauntleroy terminal to install an emergency generator shut down the network for four hours a day for two days during the evaluation. A commercial installation of WIFI was being installed and tested on the route which directly interfered with the evaluation and could not be rescheduled or secured.

After discussion with the WSF IT Director, due to the intermittent power/system outages and the inability of the third party evaluator to achieve four days of uninterrupted data collection, the decision was made to move all equipment and testing to the Port Townsend/Keystone Ferry route and to re-schedule the evaluation for March 7-17, 2008.

2.2.3 Final Evaluation Design:

The change of venue required technicians to install the system onboard the MV Klickitat at the Port Townsend Keystone ferry route and to conduct the third party evaluation at that location. The Port Townsend/Keystone route was chosen due to its proven low RF interference environment and known installation requirements. This route did provide challenges, as there is a high volume of freighter traffic that crosses the line of sight between terminals; thereby, blocking the Line of Sight temporarily. Also, the weather and sea state are much more severe than the previous location, and lease hold sights must be maintained to provide the required RF coverage.

The system was fully installed on board the MV Klickitat and back-haul sites, tested and prepared for the evaluation. Due to unforeseen ferry maintenance issues, the MV Klickitat was removed from service the week prior to the scheduled evaluation and was not placed back in service. A second ferry (Passenger Only) was placed in temporary service. After evaluating the capabilities of the ferry, it was found that the ferry was unable to support the HSD system without an added infrastructure cost. A third ferry was placed in service (Vehicle Ferry) which could house a temporary installation vice a full installation. This ferry (MV Steilacoom II) was much smaller, and weather affected it significantly compared to the initial designed to ferry, causing route changes and cancellations.

Establishing a capability of a mobile installation, which could also be utilized as a contingency installation during crisis evolutions, engineers developed a temporary system that was fully capable of meeting all WSF requirements. Antennas were temporarily mounted on the hand rails of the upper deck of the MV Steilacoom II, and the Router and switches which normally would have been installed inside an equipment cabinet, were installed in a MATS box and strapped topside of the ferry.

Figure 17 Intellicheck Mobilisa engineer configuring HSD system onboard MV Steilacoom II

Figure 18 #2 end antennas onboard MV Steilacoom II

Figure 19 MV Steilacoom II center antenna array

Utilizing leased Intellicheck Mobilisa properties, and 90/120 degree antennas, the back-Haul radios were installed on a rooftop of the Admirals Cove Beach Club (ACBC), on Whidbey Island. This provided a 27 degree offset for RF coverage. The Port Townsend back-haul site was located on the ferry trestle at the Port Townsend Ferry terminal, where the link was transferred via land-line to the Intellicheck Mobilisa HQ for monitoring and evaluation. This off-site capability simulated the WSF NOC in that the data was available 24/7 for recording and monitoring. Also the communication link was monitored continuously for link quality, stability, and connectivity.

Figure 20 Admirals Cove Beach Club (ACBC) backhaul location

Figure 21 Port Townsend trestle shore infrastructure

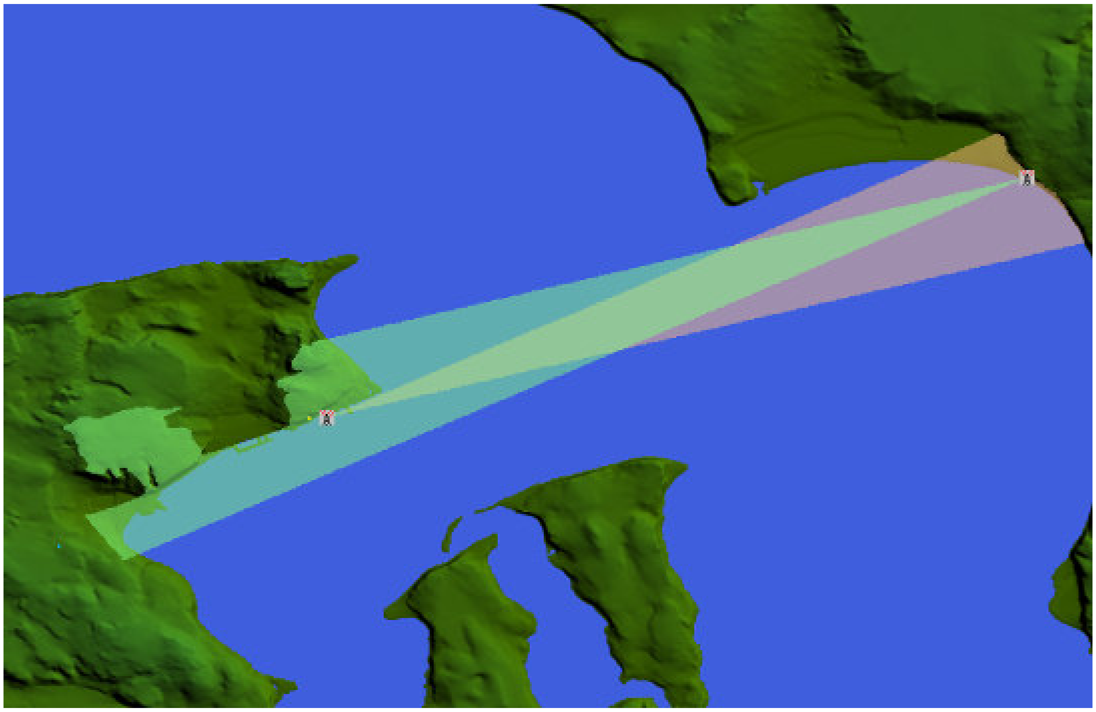


Figure 22 Backhaul radio RF coverage

The RF coverage on the Port Townsend-Keystone route was excellent. Challenges to the installation included the ferry being much smaller than the system was designed for, and the ferry's varying route due to weather and sea state. The route was extremely susceptible to severe weather, causing route changes and route cancellations. However, in spite of these challenges, the installed system performed excellently with continuous connectivity during Line of Sight operations, and provided the system capabilities of the WSF requirements.

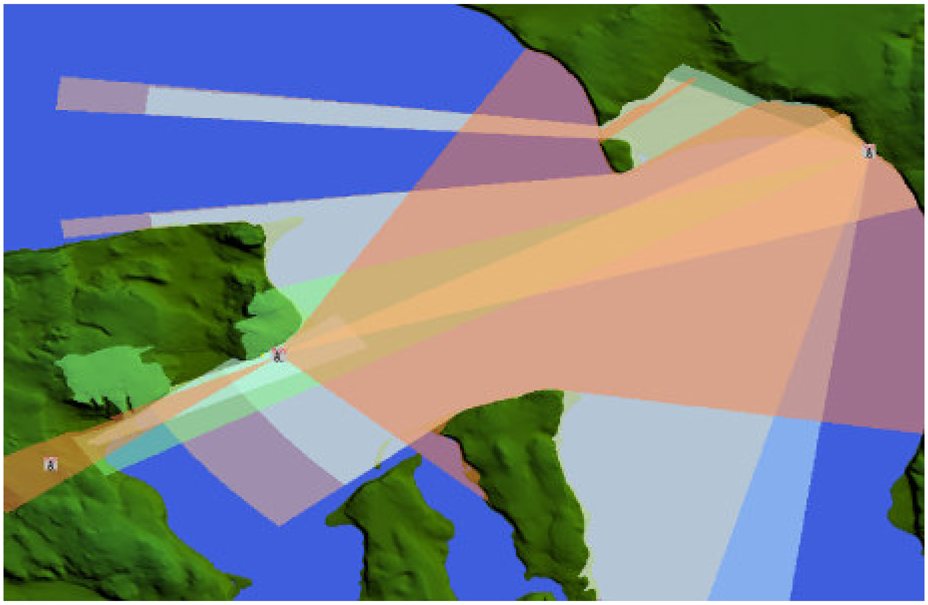


Figure 23 Complete Port Townsend- Keystone route RF coverage

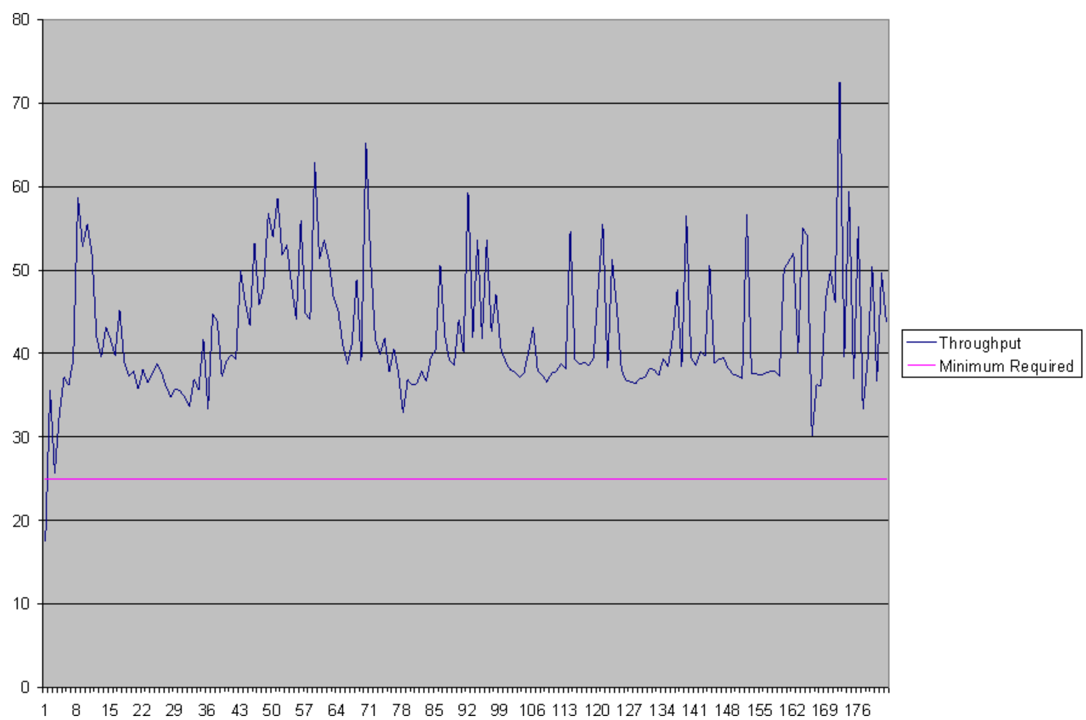


Figure 24 Throughput plot for 24 hour period

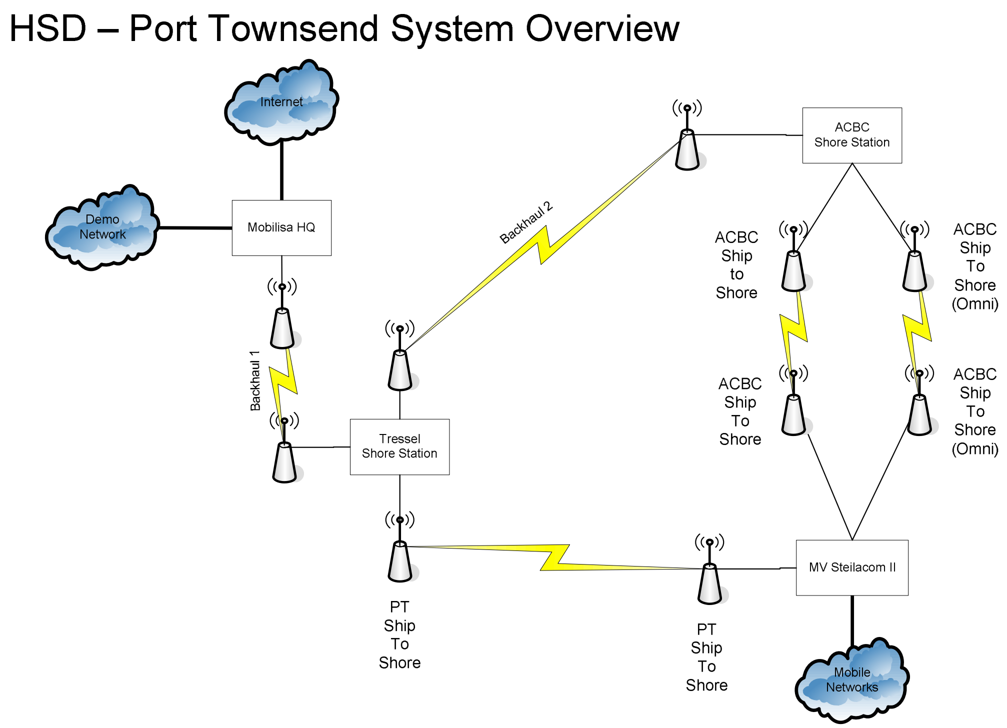


Figure 25 Port Townsend/Keystone ferry route network diagram

2.3 Demonstration of Promising Technologies:

2.3.1 Meeting events:

A briefing of the project was performed at the WSF headquarters in Seattle, WA on 19 June 2007. Present for the briefing were:

Intellicheck Mobilisa	WSF	WSDOT	CASE
Craig Bleile	Sam Kuntz	Tom Akehurst	Brandon Smyth
Curtis Sneddon	Steve Vandor	Randy Baker	Irving Petrowsky
Jim Rabb	John Daane	Todd Turner	
	Francis Daane		
	Ned Kiley		
	Trudi Tyler		

Curtis Sneddon and Craig Bleile of Intellicheck Mobilisa conducted an overview on the current status of the High Speed Data Project. This included an overview of the tasks required and challenges, project schedule, and a detailed briefing on the technologies evaluated/selected. The briefing concluded with the way ahead discussion and the schedule of events for the demonstration at the Fauntleroy ferry terminal.

During the briefing, Curtis Sneddon and Craig Bleile led an open dialogue with WSF, WSDOT-OIT and CASE to discuss such items as data storage requirements of the ferry system, current storage and retrieval methods, frequency bands used and contingency plans for when they are polluted, issues in moving boats to other routes and maintenance periods, roaming capabilities of RFAR (RF Aware Router), switching connectivity and latency requirements.

The options of using MATS cases for the system, which will enable flexibility for vessel switching and maintenance periods were discussed, as well as the financial savings of such a plan. This discussion proved to be extremely valuable as the discussed architecture was developed and used during the final third party evaluation.

The LOS (Line Of Sight) issues were discussed but will be resolved at a later date when the options and requirements are fully understood by all parties.

Discussions about incident issues were brought up. For example, if there is an incident on a ferry, the ferry would probably be directed out of the LOS of the antennas, and what would be the plan then? The evaluation of a portable MATS solution that can be utilized in a contingency event will then be performed.

The group then departed for the ferry terminal for the demonstration. The demonstration occurred at approximately 12:00 noon and lasted approximately 1-1/4 hours.

2.3.2 Demonstration Events

At the Fauntleroy Terminal several displays were shown depicting the overall WSF/HSD project and technologies involved within the project.

Figure 26 Demonstration of promising technologies displays (Fauntleroy terminal)

During the demonstration, data throughput speeds achieved a minimum of 56 and maximum of 235 Megabits per second (Mbps); about 200 times a standard Digital Subscriber Line (DSL)/cable Internet connection and twice as fast as a standard wired network (100 Mbps). A video movie transmitted simultaneously with 10 video cameras and a 50MB data file with minimal jitter and no packet loss, from the ferry to simulated shore NOC was achieved. The solution exhibited was the framework for the prototype (beta) system.

Figure 27 Network engineer Jay Radtke providing demonstration

2.3.3 Demonstration Environment

The ferry MV Klahowya was used as the test and demonstration platform, utilizing one horizontally and one vertically polarized 90 degree directional antenna with a three foot vertical separation. The radios used operated at a frequency of 5.8 GHZ. On shore, the same antenna arrays were used and were placed on the roof of the Fauntleroy and Southworth terminal buildings. The antennas and radios are connected using LMR600 cable, and the radios are connected to the display via CAT5E Ethernet cable via the terminal equipment room.

Figure 28 Map depicting Southworth/Fauntleroy ferry route

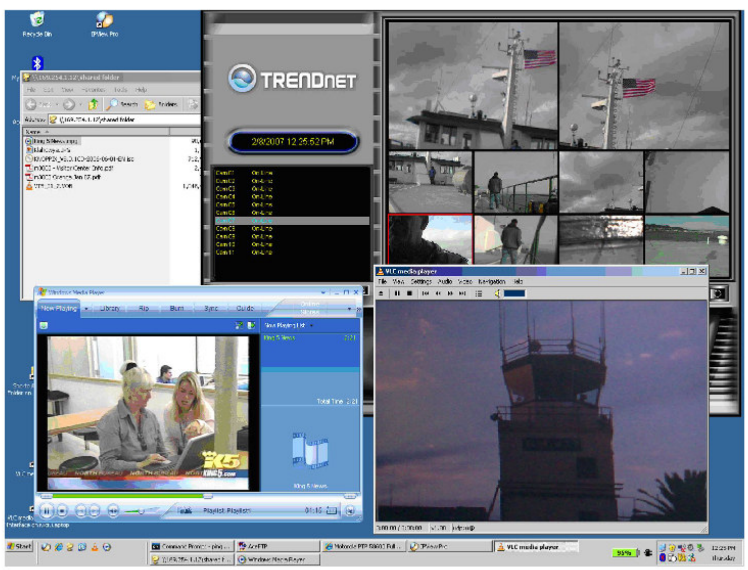


Figure 29 Live video feed from the ferry to terminal

2.3.4 Demonstration Results

Although connectivity was over 90% during non obstructed operations, there remain challenges in achieving a complete solution. Line Of Sight (LOS) blockages still plague the areas around the ferry dock, due to the antenna and ferry height. With this blockage, the signal is severely degraded or completely occluded. Intellicheck Mobilisa continued to develop and assess technology with the goal to alleviate the blockage caused by LOS issue and improve throughput.

There appeared to be a possibility of mitigation of the LOS/Blockage issues with one of two options. Option 1: Achieve an antenna height above the terminal trestle with an added 15-20 foot extension to get above a ferry at high tide, coupled with antenna placement on the pilot house vice the existing railing. Option 2: Obtain horizontal offset with agreements with private property owners on each side of the ferry run which have a direct LOS between terminals. Research and testing were conducted, and the LOS issues were resolved using height at the terminals and on the ferry superstructure.

2.3.5 Summary

The demonstration was a success in that the throughput achieved a minimum of 56 Mbps and a maximum of 235 Mbps with no disruption; whereas, the minimum requirement was 25 Mbps. In accordance with the Statement of work, the combination of video and data flow showed acceptable latency with no data loss or video jitter.

2.4 Build Prototype and Test:

A Prototype system was developed, Installed and tested onboard the MV Klahowya at the Southworth/Fauntleroy ferry route IAW paragraph 2.2.2 Design. Utilizing an equipment cabinet at the Fauntleroy and Southworth terminal buildings, technicians installed the switch, router, and supporting equipment. Onboard the MV Klahowya antennas and supporting equipment were installed utilizing the IT equipment space topside.

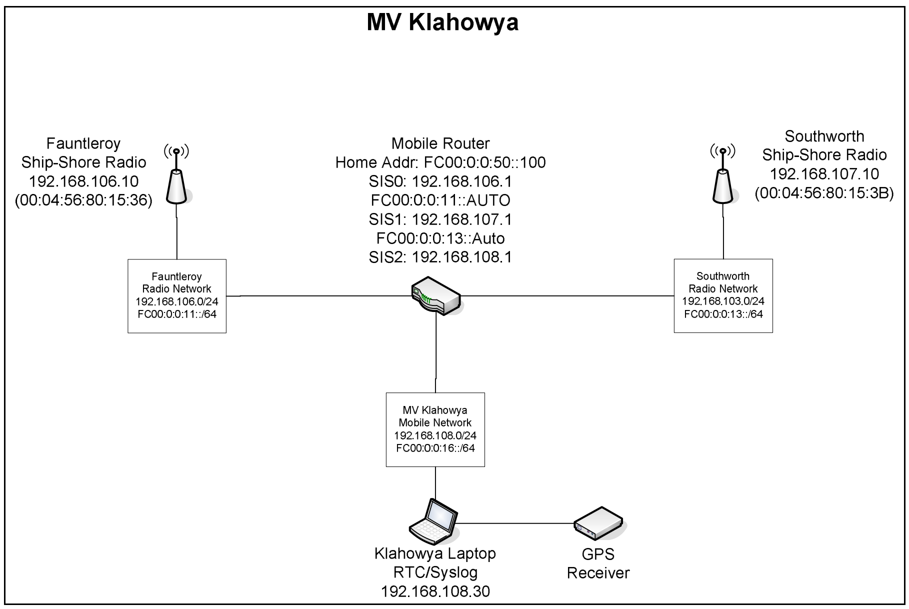


Figure 30 Final network diagram of Southworth/Klahowya ferry route

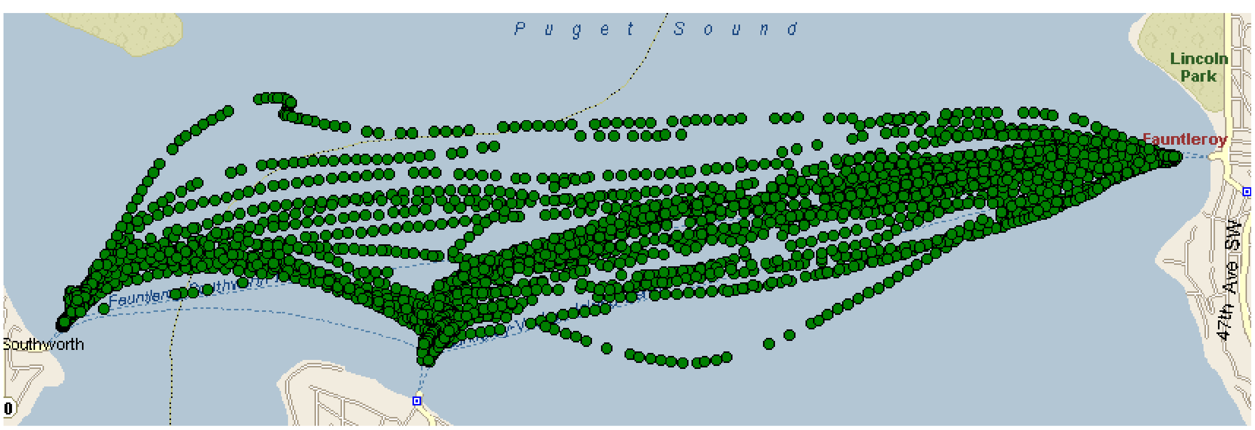


Figure 31 GPS data plot of the Southworth ferry route

Figure 32 Southworth terminal radio and antenna installation

Figure 33 MV Klahowya IT equipment rack

Figure 34 MV Klahowya forward antenna installation

2.5 Third Party Evaluation:

During the initial Third Party evaluation of the system, the week of October 8, 2007, there were several network degrading issues which were out of the control of both Intellicheck Mobilisa and the evaluation team. When the MV Klahowya switched to their Auxiliary Sea Water pump (every evening), the ship's electrical system would spike and shut down both Intellicheck Mobilisa's and the evaluator's systems, requiring Intellicheck Mobilisa technicians to return to the ferry and re-start both systems. This was scheduled to be repaired during the ship's upcoming shipyard period. There was a scheduled emergency generator installation at the Fauntleroy terminal which required the system to be secured for four hours a day for two days during the evaluation, as well. Also there was a commercial installation of WIFI being installed which directly interfered with the evaluation and could not be rescheduled.

After discussion with the WSF IT Director, the decision was made to move all equipment and testing to the Port Townsend/Keystone Ferry route and to re-schedule the evaluation from March 7 to March 17, 2008, in order to have an uninterrupted evaluation.

The final evaluation was rescheduled for March 7 to March 17, 2008 and was to be held on the Port Townsend/Keystone route. The equipment was installed in accordance with the final design described in paragraph 2.2.3.

3. Conclusion/Summary/Recommendations:

The developed HSD system results showed that Intellicheck Mobilisa's WOW technology could sustain over the required 25MBps when LOS is maintained. LOS, as per the contract requirements, took into consideration that when a ship moves across the network's line of sight, connectivity will be lost for the length of time it takes the ship to pass. The rapid reconnection of the Intellicheck Mobilisa network when this occurred minimized the loss of connectivity.

The system as delivered did take into consideration that when a ferry turns 180 degrees, connectivity would be lost due to the point-to-point radio configuration used in the prototype. This can be alleviated in the final design by either using Omni directional antennas, which will significantly reduce throughput due to lower gain of the antennas, or to develop a smart router that will select and mesh the nodes without losing connectivity. This capability is currently being developed by Intellicheck Mobilisa and will be available within the year.

The contract recommended Quality of Service (QOS) use, and it is believed that this can be obtained through some development and integration of additional equipment. The existing budget and timeframe did not allow for this to be developed into the prototype. The main goal of the prototype was to validate the concept by showing capabilities of the Wireless Over Water techniques, utilizing COTS equipment, and to bring the project in on-time and under budget.

Due to its unlicensed nature, the ease of obtaining COTS equipment, coupled with the ability of the frequency band to carry large amounts of data with minimal external interference, made 5.8 GHz the frequency of choice for this project. As this band is becoming more crowded, future projects could move into the public safety band or into the licensed band.

The prototype system has proven its ability to transmit large amounts of data successfully from a moving ferry to a shore NOC. With further development, it will be able to offer increased functionality by improving the security posture of the DOT/WSF ferry system before enabling live video monitoring of traffic and passengers on the ferry. This increased security posture will be achieved with the ability to provide real-time monitoring and shore based video recording, resulting in the capability of playback during a casualty or for after action analysis. The existing architecture can be used for further development of a final solution.

In today's dynamic homeland security environment, there is a requirement for added security to be provided to the public transportation sector. This system can provide this added security by providing the proven 25+ MBps throughput between the moving ferry and shore station. It is believed that this number is severely understated, and much higher throughput can be achieved. In addition, this technology can also be utilized for daily administrative requirements, thereby providing cost efficiencies to the WSF system, as well.

The achieved results, coupled with research to further develop the Wireless Over Water configuration, will provide the necessary network to enhance the security of the public ferry passengers.

Appendix A. Glossary/Definition of Terms

Abbreviations used in this document:

100base-T	Fast Ethernet
AES	Advanced Encryption Standard
AP	Access Point
CFR	Code of Federal Regulations
COTS	Commercial Off-the-Shelf
dB	Decibel
dBm	Decibel MilliWatt
FCC	Federal Communications Commission
FIPS	Federal Information Processing Standard
GHz	Gigahertz – 1 billion cycles per second
HSD	High Speed Data
IDU	Indoor Unit
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
LOS	Line Of Sight
MATS	Mobile Application Test Suite
MIMO	Multiple Input Multiple Output
mW	milliWatt
OFDM	Orthogonal Frequency Division Multiplexing
PDA	Personal Digital Assistant
PMP	Point-to-MultiPoint
POC	Proof of Concept
PoE	Power over Ethernet
PtP	Point-to-Point
QoS	Quality of Service
RF	Radio Frequency
SSID	Service Set Identifier which uniquely identifies the WLAN
TCP/IP	Transmission Control Protocol/Internet Protocol
TDM	Time Division Multiplexing
UDP	User Datagram Protocol
UNII	Unlicensed National Information Infrastructure
UNII	Unlicensed National Information Infrastructure
VLAN	Virtual LAN
VPN	Virtual Private Network
WAN	Wide Area Network
WEP	Wired Equivalent Privacy
Wi-Fi	Wireless Fidelity
WISP	Wireless Internet Service Provider
WLAN	Wireless Local Area Network
WSDOT	Washington State Department of Transportation
WSF	Washington State Ferries

802.11 - A family of specifications developed by the Institute of Electrical and Electronics Engineers, Inc. (IEEE) for wireless LAN technology. 802.11 specifies an over-the-air interface between a wireless client and a base station or between two wireless clients. The IEEE accepted the specification in 1997.

Advanced Encryption Standard (AES) - A symmetric 128-bit block data encryption technique developed by Belgian cryptographers Joan Daemen and Vincent Rijmen. The U.S government adopted the algorithm as its encryption technique in October 2000, replacing the DES encryption.

Contractor – Assigned vendor to carry out the Statement of Work as defined in the Implementation Plan. Intellicheck Mobilisa, Inc. was assigned as the primary contractor authorized in the Letter Of No Prejudice (LONP) from Federal Transit Administration (FTA) to Washington State Department of Transportation (WSDOT), Washington State Ferries (WSF) dated February 15, 2006.

Direct-Sequence Spread Spectrum (DSSS) – A transmission technology used in Wireless network transmissions, where a data signal at the sending station is combined with a higher data rate bit sequence, or chipping code, that divides the user data according to a spreading ratio. The chipping code is a redundant bit pattern for each bit that is transmitted, which increases the signal's resistance to interference. If one or more bits in the pattern are damaged during transmission, the original data can be recovered due to the redundancy of the transmission.

Discrete Fourier Transform (DFT) - A Fourier transform widely employed in signal processing and related fields to analyze the frequencies contained in a sampled signal.

Encapsulating Security Payload (ESP) – Header data designed to provide a mix of security services in Internet Protocol Version 4 (IPv4) and Internet Protocol Version 4 (IPv6).

Fast Ethernet – Also annotated as 100Base-T, an Ethernet standard that supports data transfer rates of 100 Megabits/second (Mbps). The Ethernet specification serves as the basis for the Institute of Electrical and Electronic Engineers (IEEE) 802.3 standards, which specifies the physical and lower software layers. A new version, Gigabit Ethernet, supports data rates of 1 gigabit (1,000 megabits) per second.

Fast Fourier Transform (FFT) - An efficient algorithm to compute the discrete Fourier transform (DFT) and its inverse. FFTs are of great importance to a wide variety of applications, from digital signal processing to solving partial differential equations, to algorithms for quickly multiplying large integers.

File Transfer Protocol (FTP) - The protocol for exchanging files over the Internet

Frequency-Hopping Spread Spectrum (FHSS) - A transmission technology where the data signal is modulated with a narrowband carrier signal that "hops" in a random, but predictable sequence, from frequency to frequency, as a function of time over a wide band of frequencies.

The signal energy is spread in time domain, rather than chopping each bit into small pieces in the frequency domain. This technique reduces interference, because a signal from a narrowband system will only affect the spread spectrum signal if both are transmitting at the same frequency at the same time. If synchronized properly, a single logical channel is maintained.

Fresnel Zone – A theoretically infinite number of concentric ellipsoids of revolution which define volumes in the radiation pattern of a (usually) circular aperture. Fresnel zones result from diffraction by the circular aperture.

Gigabits per second (Gbps) – A measure of data transfer speed equal to 1,000 megabits per second.

H.264 – Also known as MPEG-4 Part 10, or Advanced Video Coding (AVC), a digital video codec standard which is noted for achieving very high data compression.

Internet Protocol Security (IPSEC) - A set of protocols that support secure exchange of packets at the Internet Protocol (IP) layer. IPSEC has been deployed widely in implementing Virtual Private Networks (VPNs).

Jitter – The distortion of a signal or image caused by poor synchronization.

Latency - In general, the period of time that one component in a system is waiting for another component. In networking, this is the amount of time it takes a packet to travel from source to destination. Together, latency and bandwidth define the speed and capacity of a network.

Line of Sight (LOS) - An unobstructed path between the location of the signal transmitter and the location of the signal receiver. Obstacles that can cause an obstruction in the line of sight include trees, buildings, mountains, hills and other natural or manmade structures or objects.

Man-in-the-Middle (MITM) - In the context of a computer network, an attack in which an attacker is able to read, insert and modify at will, messages between two parties without either party knowing that the link between them has been compromised. The attacker must be able to observe and intercept messages going between the two victims.

Megabits per second (Mbps) - A measure of data transfer speed (a megabit is equal to one million bits). Network transmissions are generally measured in Mbps.

Multiple-Input Multiple-Output (MIMO) - Uses multiple transmitter and receiver antennas to allow for increased data throughput through spatial multiplexing and increased range by exploiting spatial diversity.

Network – Two or more interconnected computers.

Non-Line-of-Sight (NLOS) - A term used to describe radio transmission across a path that is partially obstructed, usually by a physical object in the Fresnel zone.

Orthogonal Frequency-Division Multiplexing (OFDM) - A digital multi-carrier modulation scheme which uses a large number of closely-spaced orthogonal *sub-carriers*. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation) at a low symbol rate, maintaining data rates similar to conventional *single-carrier* modulation schemes in the same bandwidth. In practice, OFDM signals are generated using the Fast Fourier transform algorithm

Ping – A utility to determine whether a specific IP address is accessible. It works by sending a packet to the specified address and waiting for a reply. PING is used primarily to troubleshoot and test network connections.

Point-to-Point (PTP) - A traditional point-to-point data link is a communications medium with exactly two endpoints and no data or packet formatting. The host computers at either end had to take full responsibility for formatting the data transmitted between them.

Proof of Concept (POC) – Demonstrated evidence that that a model or idea is feasible.

Quadrature Amplitude Modulation (QAM) - A modulation scheme which conveys data by changing the amplitude of two carrier waves. These two waves, usually sinusoids, are out of phase with each other by 90° and are thus called quadrature carriers

Quality of Service (QoS) - A networking term that specifies a guaranteed throughput level.

Secure Sockets Layer (SSL) – An internet-based protocol used for transmitting data via the internet. SSL uses a cryptographic system that uses two keys to encrypt data – a public key known to all and a private or secret key known only to the recipient of the message.

Switch – In a network, a device that filters and forwards packets between network segments

Shall – Indicates a mandatory requirement in order to comply.

Statement of Work (SOW) – The statement for contractual assignment of work and deliverables.

SuperLAN – A proprietary WSF network installed onboard some ferries. Currently used as the networking infrastructure for the video monitoring system. SuperLAN installations are part of an ongoing homeland security project via Washington State Department of Transportation (WSDOT).

Virtual Private Network (VPN) - A remotely connected network that is constructed by using public wires (such as the internet) to connect nodes. Typical VPNs systems use encryption and other security mechanisms to ensure that only authorized users can access the network and that the data cannot be intercepted.

Voice over Internet Protocol (VoIP) - A category of hardware and software that enables use of the Internet as the transmission medium for telephone calls by sending voice data in packets using IP rather than by traditional circuit transmissions.

Wireless Fidelity (Wi-Fi) - A generic term used generically when referring of any type of IEEE 802.11 standard wireless network, whether 802.11b, 802.11a, dual-band, etc. The term is promulgated by the Wi-Fi Alliance.

Wireless Over Water® (WOW) – A trademarked technology by Intellicheck Mobilisa. Wireless Over Water technology, successfully implemented for the Washington State Ferry (WSF) Wireless Connection Project, is a blend of terrestrial-based unlicensed RF band radio and antenna hardware in conjunction with software-based algorithms and configurations to provide optimal coverage of Wi-Fi in a mobile marine environment.

Federal Transit Administration

Office of Research, Demonstration and Innovation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

www.fta.dot.gov/research

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