16th ICCRTS

"Collective C2 in Multinational Civil-Military Operations"

Title of Paper

Information Sharing Between Platforms in DRDC's Networked Underwater Warfare Demonstration Trial

Topic(s)

Topic 9: Networks and Networking

Name of Author(s)

Marcel Lefrançois
Defence R&D Canada – Atlantic
9 Grove Street
Dartmouth, NS
Canada, B2Y 3Z7

Point of Contact

Marcel Lefrançois

Defence R&D Canada – Atlantic
9 Grove Street, Dartmouth, NS
Canada, B2Y 3Z7
902.426.3100 x349
marcel.lefrancois@drdc-rddc.gc.ca

Abstract:

The final demonstration trial of Defence R&D Canada's (DRDC) Networked Underwater Warfare (NUW) Technology Demonstration Project (TDP) brought together 4 vessels and a reach-back centre to develop, maintain and share a single operating picture while performing anti-submarine warfare. Sensor information was shared by operators across platforms using network tools and chat applications in web pages and applications embedded within a DRDC developed Network Enabled Combat System (NECS). In all, 22 work stations were linked through a wireless UHF network using SubNet Relay (SNR) and via CFAV QUEST over satellite to a reach-back centre hosted at Canadian Forces Maritime Warfare Centre in Halifax. Aboard QUEST, 2 sets of NECS systems were installed; one set allowed the operators to exchange information with the other platforms and users and the other set using only the information available aboard QUEST from its sensors. This paper will begin by describing the network and the information sharing capabilities that were created. Noted differences between the set sharing information and isolated systems aboard QUEST will be highlighted. In addition, the importance and utility of a web service publishing information from the NECS will be described in detail.

Introduction

The Networked Underwater Warfare (NUW) Technology Demonstration Project (TDP) was a undertaken by Defence R&D Canada (DRDC) to demonstrate future naval capabilities to carry out single and multiplatform UnderWater Warfare (UWW). The project began in 2001 with the demonstration sea trial occurring in May 2007 involving 4 naval platforms and a shore based reachback centre.

The project was initiated recognizing the potential benefits of Net-Centric Warfare (NCW). The objectives were broadly defined to demonstrate:

1. net-centric warfare constructs [1],
2. that the effectiveness of a naval force is increased by sharing information, and
3. situational awareness is increased by passing both sensor and track level information.

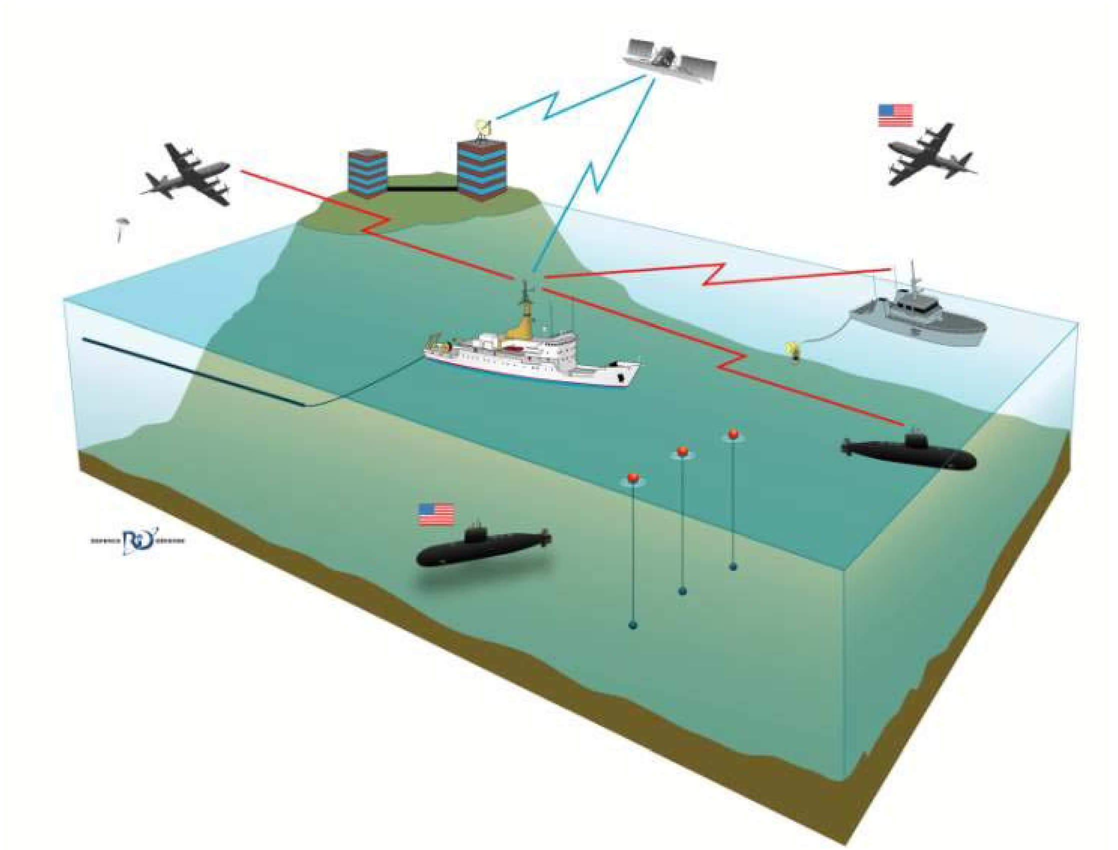

Figure 1 NUW Demonstration Trial

The demonstration concept was defined early in the project as an Anti-Submarine Warfare (ASW) exercise [2]. This choice gave the demonstration a real operational context and built on previous sonar system developments from DRDC's Towed Integrated Active Passive Sonar (TIAPS) TDP [3]. In this context, the demonstration conceived was a small task force as shown in Figure 1. The force consisted of a surface ship towing a line array, a Maritime Patrol Aircraft

(MPA) deploying sonobuoys, a submarine, and a Maritime Coastal Defence Vessel (MCDV) towing an active source. All platforms would share sensor information in real-time using SubNet Relay (SNR) [*] over UHF radios [4][5]. The force was connected by satellite communications to a shore-based reachback centre. Sonar operators on each platform and at reachback were permitted to share sensor information and collaborate through chat and other tools in order to demonstrate that by sharing information the Common Operating Picture (COP) could be formed more rapidly and accurately than the case where no information is shared.

In this paper, the information types and exchange requirements will be discussed followed by a description of the demonstration and the Network Enabled Combat System (NECS) that was created with web services. The paper will conclude with a discussion of some of the major results.

Information Exchange Requirements

Early in the project a team of knowledgeable ASW experts were assembled comprising DRDC scientists and engineers and sonar operators from the Canadian forces. The group was asked to identify what information could potentially be useful to sonar operators trying to detect, classify, localize and track underwater targets (submarines). This was a bottom up process in that the team set out to define what was required without reference to a data model. The findings of the group were the 12 types of data identified [6][7] for ASW operations as summarized in Table 1.

Table 1 NUW Data Types for ASW

	Data Type	**Notes**
1	Environmental Data	both measured and predicted acoustic properties
2	Receiver Information	includes acoustic sensor type, characteristics, and locations
3	Source Information	acoustic emitter or source characteristics and location
4	Echo Repeater Information	characteristics of device during testing and trials
5	Ping Information	waveform descriptions, ping schedules, ping status such as successful or missed transmission
6	Main Blast Data	information such as time and strength of received acoustic signal which traveled by direct path from the source
7	Feature Data[†]	received acoustic information such as tones or active sonar returns
8	Contact Data[†]	features that are likely related to a real platform
9	Track Data[†]	a set of features or contacts describing the path or course of a platform
10	Sonograms	raw acoustic data or images from raw acoustic data
11	Email and Chat Messages	to facilitate discussions between users for problem solving and to improve COP accuracy
12	Tactical Information	such as movements, sonobuoys drop areas, and other

[*] The SNR units were obtained from IP Unwired Inc. which is now a part of Rockwell Collins Government Services Canada Inc.
[†] Since the definitions vary in the literature causing confusion a consistent set of definitions for feature, contact and track [8] were adopted early in the project.

		command messages

Having identified the pertinent data types the next issue was to solve the problem of information delivery and expected quantities of data. Both LINK 11/16 and LC2IEDM were examined [6] and were found, at the time, lacking the breadth and fidelity required. In the end, a binary messaging format was created containing all of the expected data types which could be exchanged over IP based networks [9].

In addition to the data model, communication rates had to be considered. The data link chosen for the demonstration was SubNet Relay (SNR) using existing tactical radios (WSC-3 (surface ship) and ARC-210 (air)). SNR supports Internet Protocol (IP) based networking and has the advantage of managing the data links. Transparent to the operator, SNR automatically handles disconnects and reconnections and will dynamically allocate bandwidth based on data load from each networked node. The UHF radios used in the demonstration are line of sight units and are therefore susceptible to generating network disconnects resulting from manoeuvring. The SNR network management feature mitigated the impact of these disconnects by automatically reconnecting and recovering communications when the link was restored.

Yet another issue is the heavy demand on the network for communication flow in a tactical environment. Even though SNR buffers data for transmission and reallocates bandwidth, it does not mean that important information will be transmitted in a timely manner. The total bandwidth available in NUW was 64 kilobytes per second – divided over the SNR nodes. In addition, SNR does not have sufficient privilege capability in its buffer to reorganize the outgoing tactical data. There is a priority layer in SNR but it handles network configuration and allocation issues, not the IP data being passed through the unit[‡]. This means data has to be compact and that new information management and priority policies had to be implemented. Further, the priority handler and data buffering had to happen on the classified side, before transmission through the KG-84 encryption unit into the SNR unit. It was recognized that the prioritization scheme and mechanism had to be flexible since each platform had its own interests and that those interests, and thus priority, may change with operational phase and with the unit's role, objectives, and capabilities. An example priority matrix is given in Table 2. Note that the priority or value within an operational phase decreases to the right and the timeliness or urgency of the data increases going downward. Through examination one can see that the combined priority increases diagonally downward to the left in the table. Such a combined priority set makes sense since, for instance, a platform may be tracking a target while staying vigilant to the possibility of a second target thus performing in two operational phases at once; tracking and detection.

Priority settings for each platform was configured through a simple web interface as shown for the MPA subscriptions to the MCDV data in Figure 2. This interface allows each platform to set up data subscriptions with the data sources, setting both the period for updates the assigned priority.

[‡] Even if SNR could handle a priority scheme there exists technical and policy hurdles of moving that information between classified and open domains through encryption equipment.

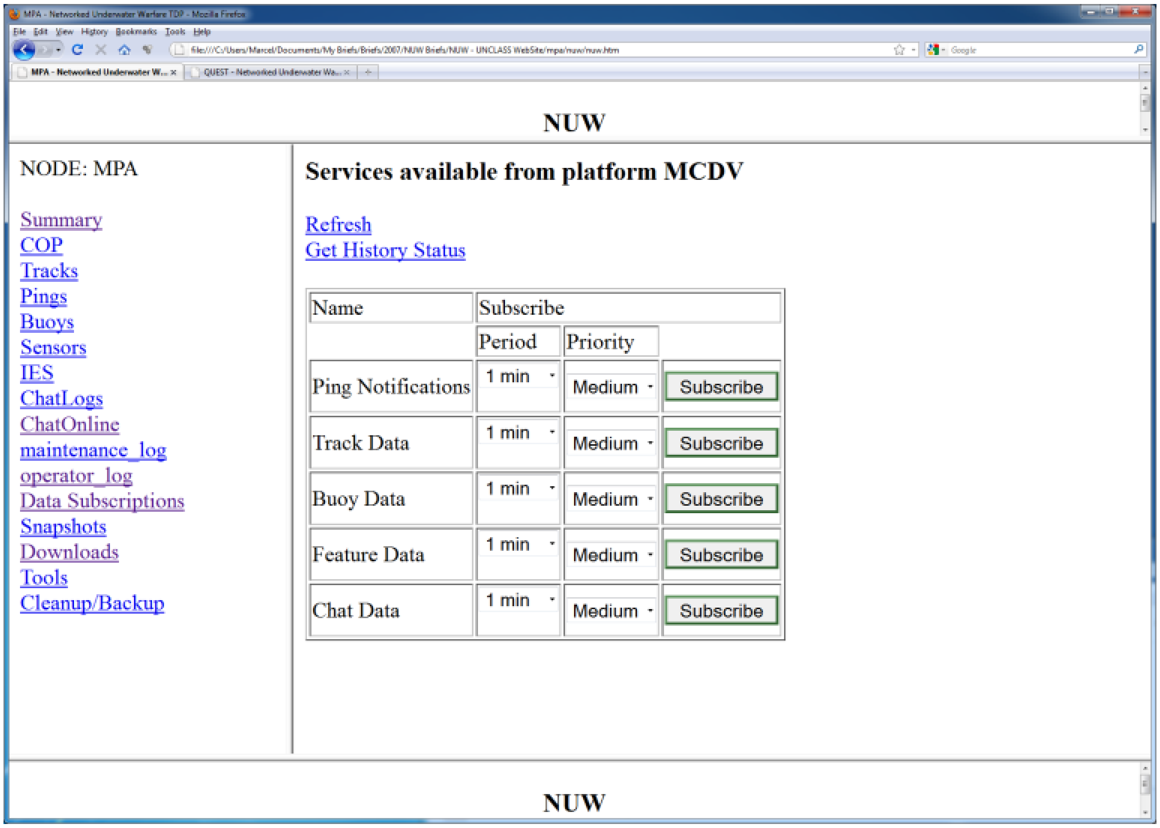

Figure 2 MPA Data Subscription Page for MCDV Data

The protocol used on the network was also considered. Most network transactions are TCP/IP (Transport Control Protocol/Internet Protocol) which is a point to point data transmission. TCP/IP is reliable but feeds each user individually so when a number of users require the same data more transmission bandwidth is required to serve each request. A more efficient way would be to use UDP/IP (User Datagram Protocol/IP). UDP/IP broadcasts the data simultaneously to all connected users. This can greatly reduce bandwidth but does not have the data recovery services of TCP/IP. The choice made in the NUW network was to primarily use UDP for direct data sharing between systems since the subnet of users were all interested in similar data. Thus the competition on bandwidth is over priority with the consequence that all platforms received the data as long as it was broadcast. It was felt that the possible loss of data was a manageable risk. Studies were undertaken to ensure this was an understood risk and that bandwidth was sufficient. For this, models of the SNR network with the expected data loads were created in MATLAB[10] and Extend[11]. Even though UDP was used, TCP/IP was used for web based services as this information (described later) contains information for specific users.

Table 2 Example Information Priority Matrix with Operational Phase

Decreasing Value →

Increasing Urgency ↓

	Must Have	**Good to Have**	**Nice To Have**
Search and Detection (I)	Sonograms Environmental Data Contact Data Source Information Ping Information Tactical Information	Receiver Information Email/Chat Main Blast Data Feature Data	Track Data
Localization and Classification (II)	Environmental Data Contact Data Track Data Tactical Information Source Information Ping Information	Email/Chat Receiver Information Main Blast Data Sonograms Feature Data	
Prosecution (III)	Source Information Ping Information Track Data Tactical Information	Contact Data	Email/Chat Feature Data Environmental Data Main Blast Data Sonograms Receiver Information
Post Prosecution	This has elements of both Search and Detection and Localization and Classification		

NUW Demonstration Trial

The NUW demonstration trial took place May 2007 in Emerald Basin, approximately 60 nautical miles off the coast of Nova Scotia. The demonstration involved 4 platforms in an IP network using SubNet Relay over UHF radio. The task force consisted of CFAV QUEST as a "poor man's" frigate, HMCS SUMMERSIDE (a Maritime Coastal Defence Vessel (MCDV)), the submarine HMCS CORNER BROOK (a diesel-electric submarine (SSK)), and a Convair 580 aircraft from Canada's National Research Council (NRC) acting as a CP140 Aurora Maritime Patrol Aircraft (MPA). All platforms were connected via satellite link[§] through CFAV QUEST to a reachback support centre hosted at the Canadian Forces Maritime Warfare Centre's (CFMWC) Battle Visualization Laboratory in Halifax (see Figure 3). Thus, as suggested in

[§] The Satellite Link utilized a Fleet 77 connection to DRDC where it entered CFXnet (Canadian Forces Experimentation network) to reach the CFMWC. The link was an encrypted 64 kilobit per second link and its use was transparent to the operators as QUEST acted as a bridge to complete the connection to reachback.

Figure 1, the aircraft communication to reachback would travel over SNR to QUEST where a connection to the satellite would automatically relay the information to the CFMWC.

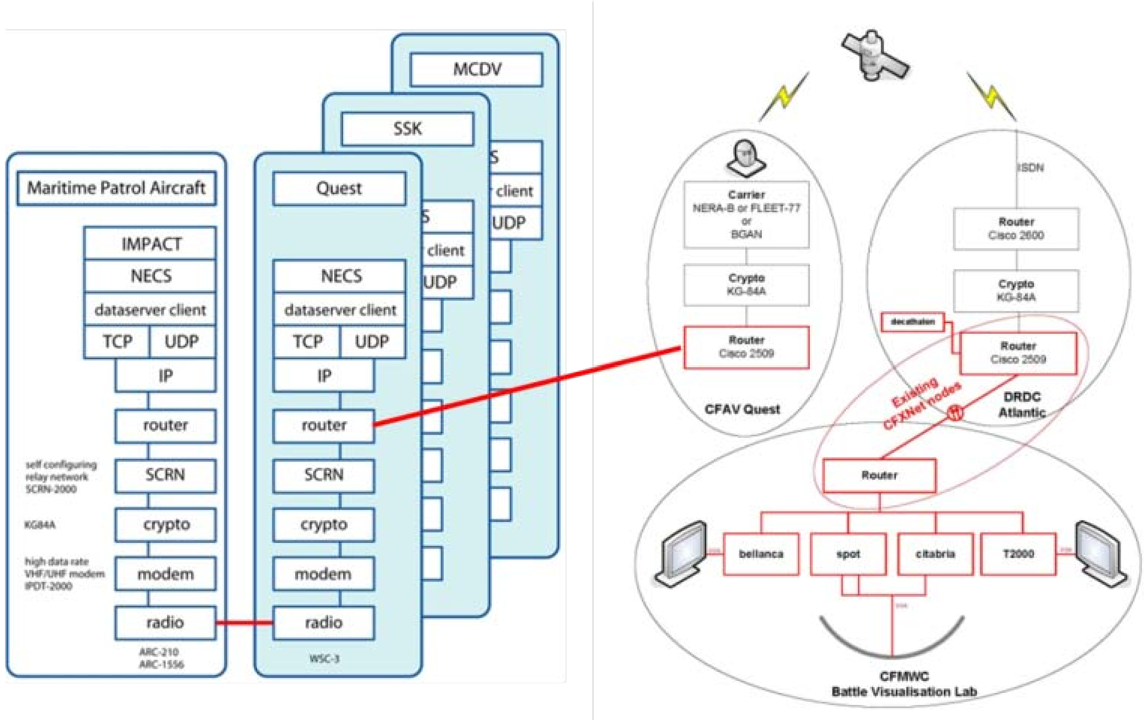

Figure 3 NUW Network. The SNR at-sea network showing the NECS and communication components is on the left and the satellite communication routing and components are on the right. The bridge on QUEST between SNR and the Satellite link is formed by connecting the routers

The network was set up as a peer-to-peer network so the trial did not rely on any one platform. This means there was no central control that defined the network, or its services. Thus, any node could drop out (or not show up) and the rest of the at-sea exercise could continue to collaborate and exchange data (the reachback connection could potentially be lost however that would not change the nature of the operation at sea). The loss of a platform was seen as a realistic scenario and the choice of peer-to-peer networking reduced the over-all risk to the demonstration trial.

A key element to the trial was the use of 2 sets of operators aboard QUEST. One set used only the information from sensors aboard QUEST while the second set had QUEST's sensor data as well as that provided over the network and could communicate via chat with the other vessels. Each set consisted of 2 operators – one compiling the picture while the other worked the lower level sensor data. Sufficient separation was maintained aboard so that they could not see each other's results. By using the same sensor data at the same time for the two sets one was able to observe the differences between networked and non-networked operators.

The trial occurred over several days, building complexity by adding connections to other platforms one at a time so that encountered problems could be addressed and the network could become more complex yet behave in an understandable way before full-scale demonstration commenced with a USN submarine joining the demonstration as a target.

The trial platforms and assets are summarized below:

1. CFAV QUEST; DRDC's research vessel emulated a frigate and was the task force command ship, the task force commander aboard was from the Canadian Forces (CF) Submarine Squadron (N32). QUEST's acoustic sensors were an SQR-19 towed array and sonobuoys (AN/SSQ-53(D)3 DIFAR). Four sonar operators were aboard from the Canadian Force's (CF) Acoustic Data Analysis Centre (ADAC). Additional non-acoustic sensors were QUEST's navigational radar, an AIS (Automatic Identification System) feed and XBTs (eXpendable Bathy Thermograph). The operators were divided into 2 teams: one team using only QUEST sensor information and the other sharing information with the rest of the task force.
2. NRC's 580 Convair aircraft was employed as an MPA. This choice was due to difficulty in scheduling a CP140 Aurora given their operational requirements. The pilots provided by NRC were ex-military and familiar with ASW operations. In preparation for the trial the aircraft was re-certified to drop sonobuoys. In addition to the pilots, TACNAV (Tactical Navigator) and sonar operators from CFB Greenwood's 14 Wing Maritime Proving and Evaluation Unit (MP&EU) flew aboard the aircraft to represent the balance of an MPA crew.
3. HMCS SUMMERSIDE was deployed with DRDC's Vertical Projector – 2 (VP2) [12] active sound source. This towed source gave the task force commander a multistatic capability. A major issue in multistatics is the exchange of ping characteristics and timing in order for other units to properly process the signals. This was not the case in the NUW network since the design was to freely exchange information. To the author's knowledge this was the first time a Canadian MCDV has participated in an ASW exercise
4. HMCS CORNER BROOK is a Canadian Victoria class submarine (SSK). It participated in the exercise, taking advantage of the COP picture before diving – and consequently, out of network contact. There was limited interfacing to its onboard sensors due to the scope of the project. The objective was in its operational use as part of the task force, communications, and the value of obtaining the COP prior to descent.
5. CFMWC Battle Visualization Lab hosted the reachback centre. This was a place for shore based expertise to engage in the operation and a demonstration of getting the COP to shore in real time.

Network Enabled Combat System (NECS)

The Network Enabled Combat System (NECS) is the sensor processing and display system present at each node (or platform) through which the operators interact, collaborate and build a common situational awareness. The system requirements were:

- An interface to sensors and processing. The sensor suite includes towed arrays (SQR19), sonobuoys (AN/SSQ-53(D)3 DIFAR), radar and AIS (Automatic Identification System).
- Acoustic displays for sonar analysis and to aid the operators in detection, localization and tracking.
- Methods for collaboration towards creating a Common Operating Picture.

- Generation and maintenance of system status notifications like which nodes or platforms are connected, their location and their equipment or sensor status.
- User-friendly tools that allow informal human interactions so that they can query, converse and exchange information such as chat, browsing of web pages and the exchange of files or other data.
- Components and software that are re-usable – such as offered in an open architecture. Potentially, many platforms and locations with different configurations could be involved so it has to be easy to enable different functionalities.

The obvious choice within DRDC-Atlantic was to use the System Test Bed (STB) [13] developed under the TIAPS TDP [3]. The STB offers an open architecture for information display and signal processing for a number of acoustic sensors. It is built using open source tools and with DISA's (Defense Information Systems Agency) Common Operating Environment (COE) Version 4.x [14] components for COP display and some track management functions[**]. The airborne version was "wrapped" around DRDC's Integrated Multistatic Passive Active Concept Testbed (IMPACT) system [15] for airborne processing. The systems were quite different in each of the locations as seen in Figure 4 - using a wide variety of operating systems and computers.

To satisfy NUW TDP net-centric requirements additional functionality was added to the TIAPS version of the STB:

1. Extension of the data management to handle multi-platform data sources and communication.
2. A chat service for operator interaction. This was very similar to twitter™ [16] in that the allowed length of a chat message was limited to 256 bytes to prevent operators from becoming too verbose and with the desire that short succinct messages were more likely read and auctioned in a timely manner.
3. A common chart was created. All instantiations of NECS on the network work on a consistent set of underlying data. On an individual basis, each station views only the layers of interest and selects the view range, etc. as applicable. What was important in the data sets was not that each node maintains a completely identical data set but that the parts of interest and importance to a particular operator are consistent with the rest of the team. This is in contrast to trying to replicate all data everywhere which can only be achieved with very large bandwidths.
4. The addition of a web pages service to enhance the data exchange between operators. The web pages were automatically published by the NECS, including chart images, detailed track information, chat pages, chat histories, status, and document file exchanges and publishing.

The web page publishing capability is, to the author's knowledge, unique for a tactical system. It allows the exchange of items that were not originally envisioned, such as orders, pictures and documents. Thus, this portal to information grants a great deal of flexibility to the system and can allow operators to quickly adapt to new situations. For example, during the NUW demonstration it was realized that there was no method for transferring XBT data between

[**] The STB has since been updated to remove dependence on COE components although they can still be used if desired. The STB is currently installed for some field trials as PLEIADES aboard HALIFAX Class Vessels, although without off board networking and with additional sonar capabilities than described here.

CFAV QUEST and the aircraft. A solution quickly evolved by scanning the XBT plot into an image document that was published on QUEST's webpage and then retrieved by personnel on the aircraft. Another advantage of a web service is that it provides the ability for disadvantaged units or extra terminals to be easily added to the operation since all that is required is a network connection and a web browser. Thus one can envision a scenario where a coalition vessel with no combat system could participate through a web-browser connected via SNR into the same network.

(a)

(b)

(c)

Figure 4 NECS (a) aboard CFAV QUEST (b) aboard the aircraft (c) at the shore based reachback

The NUW web pages were designed specifically for low bandwidth application [17] – hence the look was functional rather than eye catching as shown in Figure 5 through Figure 8. The entry page was a summary page (Figure 5). The summary page contains a summation of the current tracks, latest ping information, the most recent chat, status of the other connected platforms, and a link to the latest COP image as displayed on the platform's NECS. All pages were constructed with a site navigation area on the left for access to other pages containing COP histories, chat, chat history, data subscription setups, operator logs along with track data and more. Any of the web sites generated by any platform is quickly accessed by clicking on the vessel in the Platform Status area (labelled IES Summary). Thus, anyone on the aircraft could, for instance, connect to

CFAV QUEST by clicking on the word "QUEST" and then would be presented with QUEST's summary page. The connected web service (or "Node") was identifiable on all pages in the upper left corner of the page. This design allowed the network to operate as a peer to peer network yet made all the relevant web page data available to all. One NECS on each platform was chosen to generate the web pages for that unit.

The COP pages were generated by a full NECS publishing of the screen image at periodic intervals (set for 5 minutes during the demonstration) a sample of which is shown in Figure 6.

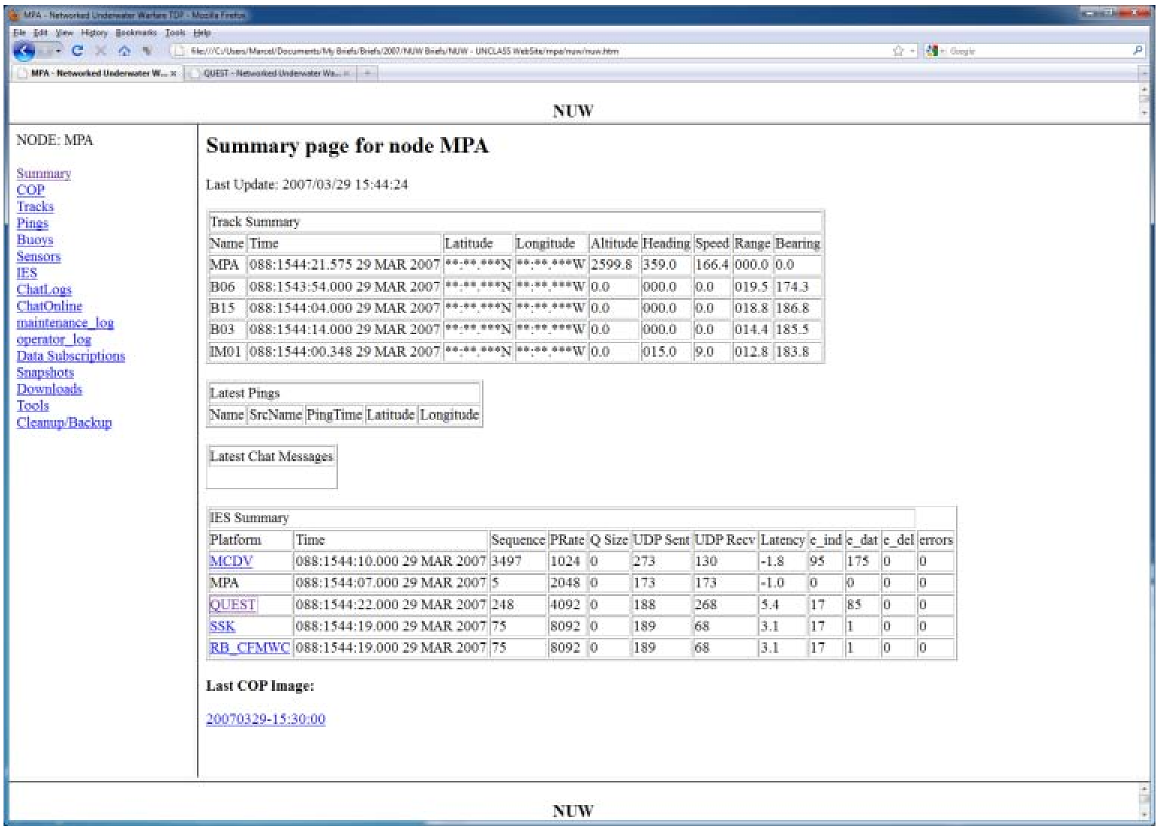

Figure 5 NECS entry page

Even though direct COP interactions could only be done at a full NECS station, the web pages provided the ability for others to join in the operation by adding additional information, giving suggestions, and gaining a sense of the operational tempo and, more importantly, provide awareness of the operational picture. An important method for collecting operator input was through the chat page shown in Figure 7 below. The page was very simple. There was a chat history shown of the last number of messages with a timestamp and a callsign identifier. There was a place to add a callsign so that others could recognize who was chatting and a single line to enter a line of chat into.

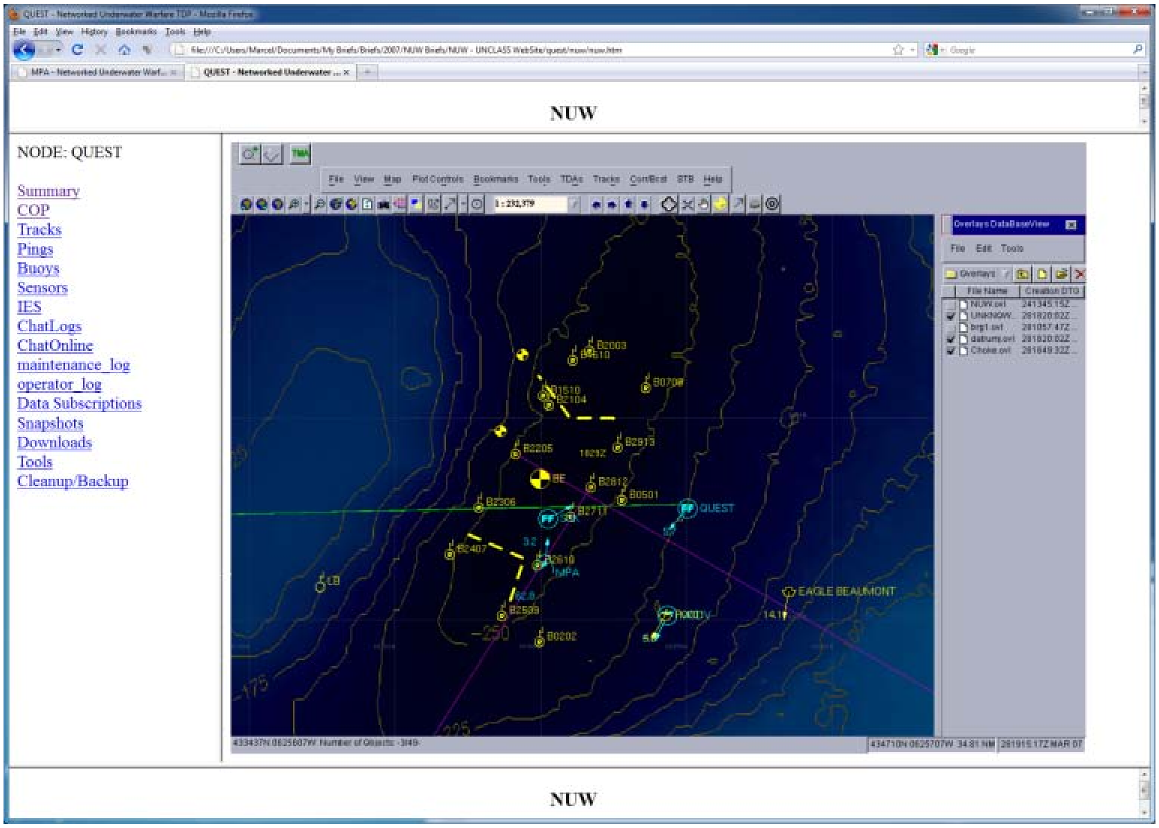

Figure 6 COP web page from CFAV QUEST

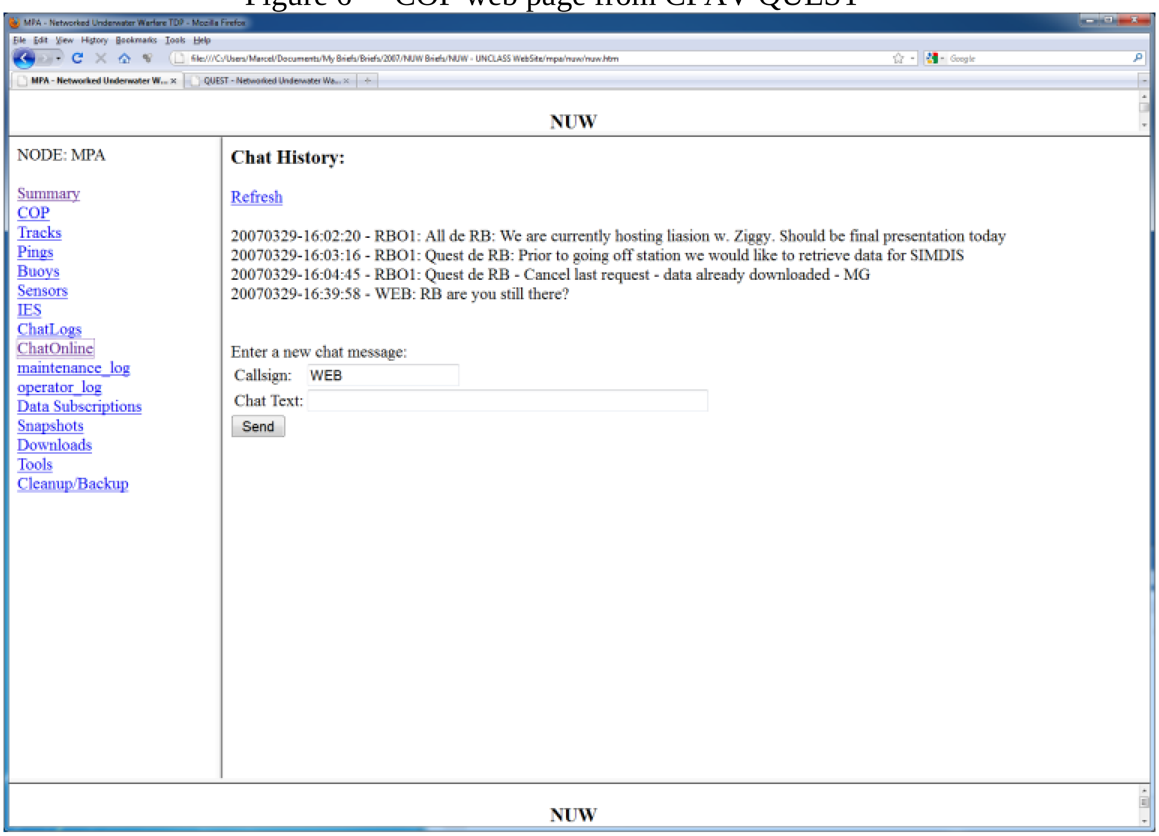

Figure 7 Chat Web Page

Equal in importance to chat is the operator log pages as shown in Figure 8. Operators could place or publish a document into the web service implemented aboard their respective platforms which others, in turn, could pick up. The importance was highlighted during the demonstration as the aircraft would start pulling documents from QUEST containing orders and acoustic data well before entering the operational area – thus becoming integrated into the operation immediately on arrival on station without a "catch-up" period to gain a picture of what was occurring.

Owing to the open architecture and NECS design approaches which delivered reusable code, many platforms and stations could be set up for the demonstration trial. In all there were over 20 displays connected to the network during the trial with 14 full NECS systems and 9 CPUs with web page browsers as shown in 0. Two were rapidly added during the trial. One was a quick fit prior to sailing to allow Command on the MCDV to participate more fully in the demonstration. The second was added by the task group commander aboard QUEST who had too much happening to handle the communications so assigned a person with a web station to the task.

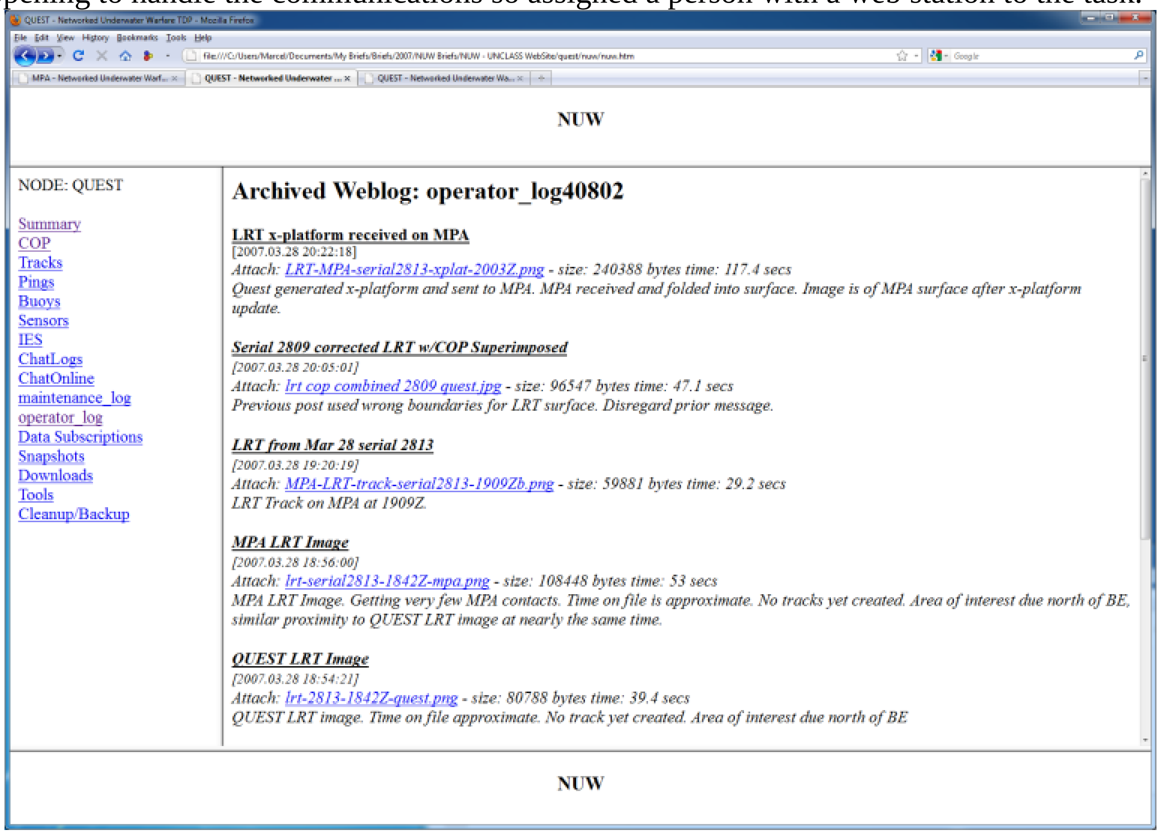

Figure 8 Operator Log page for retrieving files

Table 3 NECS and web browser locations in the NUW demonstration

Location	Description	NECS	Web Browser
CFAV QUEST	Stand-alone	2	
	Networked	2	
			3
HMCS CORNER BROOK	Headless	1	
	Laptop	1	
HMCS SUMMERSIDE		1	
	PC-Based	1	
			1
NRC Convair (MPA)	IMPACT	1	
	Laptop	1	
			2
CFMWC	Full NECS	2	
	PC-Based	2	
			3
Totals		**14**	**9**

*Shaded systems are attached to the NUW network

Achieving a Common Awareness

During the NUW demonstration a common situational awareness was achieved using the systems and networks to shared information. By design all operators worked on the consistent sets of data on the same picture. They interacted on the same picture and it was shared by all levels of command.

The shared information screen shown in Figure 9 was of benefit to sonar operators trying to detect and localize a target and to the task group commander wanting an immediate picture. Some examples of picture use are:

1. Cross fixes from shared data were easily performed. Possible target locations were identified where signal bearing lines from QUEST's towed array (in magenta) crossed those from sonobuoy data processed aboard the aircraft.
2. Blue Force tracking (self reporting of own track to other team members) was possible using the network. Each platform reported its own location into the network so, for instance, the fact that no radar was capable of tracking the aircraft did not matter since the aircraft continually updated its position through the network.
3. Operator/Platform engagement in the trial was continuous and at a high level of involvement. First because they had to be available to respond to the incoming chat but more because they were dealing with a continuous influx of data. It was observed more than once that the operators who were not networked would "go for coffee" when the ship went into a turn since a bent array meant the ship was blind. However, the

networked operator would stay at their station still having an awareness of the situation from other information feeds; hence they remained engaged even though the ship was technically blind. One of the results of this (shown in later analysis) is the force's increase in contact time with a target [18].

4. Operator confidence in the COP increases with corroboration. As the team of operators deployed across the network reaches consensus on the picture and the target their confidence increased more rapidly than the non-networked operators

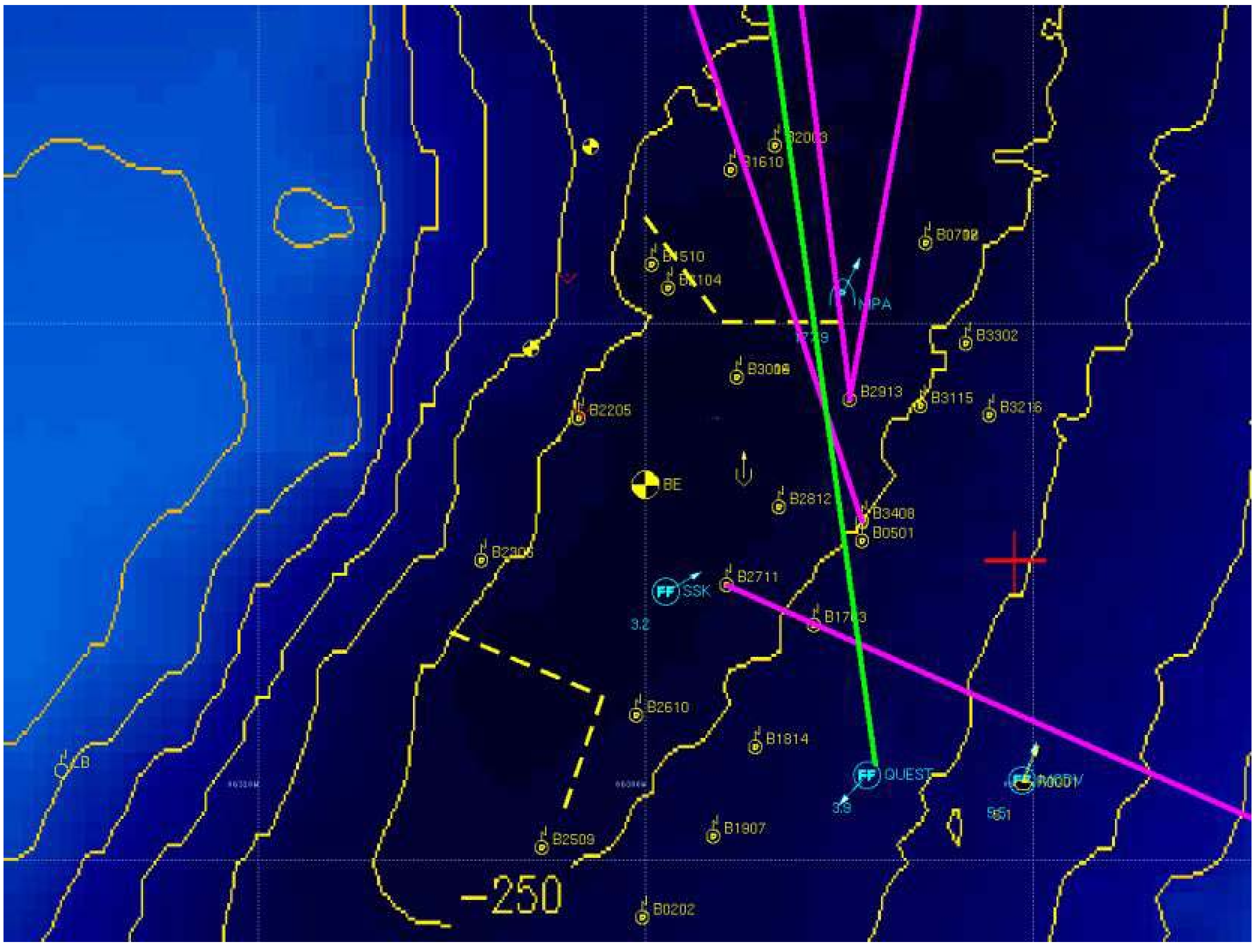

Figure 9 COP during NUW demonstration showing units (in blue, sonobuoys (yellow circles labelled B2205, B3216, etc.), sea bottom profile (yellow contours and blue shading) and cross fixes from more than one platform (green from towed array off CFAV QUEST and magenta from sonobuoy data taken from the aircraft)

The last point lends itself to the value of chat in an operation. Opening the communication channels between those solving the problem (ASW) allows for this increase in confidence. It was interesting to observe that even though chat is albeit an informal communication tool it did not take long for the operators to adopt a formal business style using radio-like jargon to convey information quickly and to compare notes.

The web page publishing capability of the combat systems (in this case NECS) was unique and used widely in the trial. Over a 3 day period the web page data served by CFAV QUEST to all users was 340MB. The portion served over just SNR to the submarine, MCDV and the aircraft was 45MB. Considering the size of most pages was minimal (less than 10kB), file sizes for a COP were typically 30kB, and that the bandwidth was limited this indicates that web use was large. An added benefit to the creation of the web pages is the ability to review the trial. At the end of the trial the entire website for each platform was placed on a single CD disc (500 MB). Thus, the website data itself can be easily accommodated in any future systems.

Conclusion

The NUW demonstration trial showed the art of the possible in net-centric warfare. It took the application of networking and networked systems and people to a real problem (ASW). The demonstration showed the common awareness and increase engagement that can be achieved through a shared picture and the enhancement chat brings to the operators performance. There is a need now to decide how to use the capabilities demonstrated. Such as how best to use a reachback centre once it becomes aware. The context for demonstrating the effectiveness of Net-centric operations was that of an ASW exercise including multistatic sonar operations. In particular, multistatic sonar operations demanded the ability to exchange "ping coordination" information between the various platforms. The results of the experiment, from a multistatic sonar perspective, are still under investigation.

What NUW also demonstrated was that it is possible to conduct an exercise using peer to peer networks on very low bandwidth. The bandwidth lesson is essential even though it is certain more bandwidth will be added to networks in the future. It also is equally certain that as bandwidth increases so will demand for data and services. The result will be that the warfighter will always be constrained to fit his war (requirement) in an allocated bandwidth slice. Information management is essential to deal with this reality.

The NECS components, developed under this project, have now been added to the STB software baseline. As a result, the tools remain available for future development and demonstration

Acknowledgements

The NUW TDP demonstration involved many individuals. The Author would like to thank members of the following organizations for their involvement and support:

- Technology Demonstration Section members and Mechanical services staff at Defence R&D Canada – Atlantic
- The crews of CFAV QUEST, HMCS SUMMERSIDE and HMCS CORNER BROOK
- The Office of Naval Research (Networked Underwater Warfare Technology TRDP Project Arrangement No. CA-N-04-001)
- National Research Council Institute for Aerospace Research
- Canadian Forces Maritime Warfare Centre (CFMWC)
- Canadian Forces Meteorological and Oceanographic Operations Centre (METOC)

- MARLANT N31, N37 and N6)
- Maritime Operations Group (MOG5)
- CFB Greenwood 14 Wing MP&EU
- Canadian Forces Experimentation Centre (CFEC)
- General Dynamics Canada

References

[1] David S. Alberts and Richard E. Hayes, *Power to the Edge: Command and Control in the Information Age*, 2003, 256 pages

[2] W.A. Roger, M.E. Lefrançois, G.R. Mellema, R.B.MacLennan, *Networked Underwater Warfare TDP - A Concept Demonstrator for Multi-Platform Operations*, 7th ICCRTS Conference, Quebec City, September 2002, 8p

[3] James A. Theriault, *Towed Integrated Active/Passive Sonar System Concept,* Defence R&D Canada – Atlantic, DREA Technical Memorandum 1999-093, July 1999

[4] M. Jorgenson, C. Reichelt, T. Johnson, Military Communications Conference, 2005. MILCOM 2005, 17-20 Oct, 2005, Atlantic City, NJ, published IEEE proceedings, p338 – 343 Vol. 1

[5] *Maritime Tactical Wide area Networking (MTWAN), ACP 200(B)*, published by Combined Communications-Electronics Board (CCEB), January 2007, 365p. See Chapter 12 E4.3 and Chapter 16 SubNet Technologies.

[6] Marcel Lefrançois, *Information Exchange Requirements for Networked Underwater Warfare*, Defence R&D Canada – Atlantic Technical Memorandum, TM2004-168, October, 2004, 102p.

[7] Marcel Lefrançois, Bill Roger, Ian Fraser, Anthony Isenor, Garfield Mellema, Nicole Collison, LCdr Bruce MacLennan, "Data Exchange Between Air and Surface Platforms in Networked Underwater Warfare," Paper presented at the RTO SCI Symposium on "Architectures for Network-Centric Operations", Athens, Greece, 20-22 October 2003, published in RTO-SCI-137, 12 pages.

[8] Marcel Lefrançois and Bill Roger, *Feature, Contact, and Track Definitions for Sonar Information Management in the Networked Underwater Warfare Technology Demonstration Project*, Defence R&D Canada – Atlantic Technical Note TN2003-213, December 2003, 5 pages.

[9] Kevin Hamill and Gary Inglis, *NUW Information Exchange Service Description*, Defence R&D Canada – Atlantic Contractor Report CR2007-197, July 2009

[10] Anthony W. Isenor, *A model of the subnetwork relay data transfers during the Networked Underwater Warfare TDP*, Defence R&D Canada – Atlantic Technical Memorandum TM2006-144, December 2006, 67 pages.

[11] Author unpublished model

[12] P.J. Barry, J.S. Hutton and J.B. Franklin, *Dual free flooding ring projector array*, Defence R&D Canada – Atlantic Technical Memorandum 92/214.

[13] Trent Johnson, *DRDC Atlantic System Test Bed (STB) Overview*, Defence R&D Canada – Atlantic Contractor Report CR2007-271, October 2007, 54 pages

[14] For Common Operating Environment (COE) or Global Command Support System (GCCS) see Program Executive Office C4I (PEO C4I) PMW 150 at peoc4i.navy.mil or Defence Information Systems Agency at www.disa.mil.
[15] I.A. Fraser, N.E. Collison, J.N. Maksym, *Multistatic Sonar R&D Based on the IMPACT Airborne Sonar Testbed*, 10th NATO International Sonobuoy Interoperability Conference (ISEC) 2002, Halifax, Nova Scotia
[16] Web site www.twitter.com
[17] Mark Thibodeau, *NUW Tactical Decision Aids*, Defence R&D Canada – Atlantic Contractor report CR2007-205, December 2008, 118 pages
[18] Mark A. Gammon and Marcel Lefrançois, *Networked Underwater Warfare Operational Effectiveness*, Defence R&D Canada TM 2007-352, December 2007, 72p