Interoperability Issues Encountered with Australian/US Navy Simulation Exercises

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ABSTRACT: *The Royal Australian Navy and the United States Navy, with significant support from the Australian Defence Science and Technology Organisation have conducted three interoperability exercises under the Coalition Readiness Management System Project Arrangement during the period 2001 – 2003. These have linked high fidelity training simulators located in Australia, manned by real ship's crews, with USN training simulators and real assets over a wide area network and used Distributed Interactive Simulation as the networking protocol. Interoperability issues that have arisen between different implementations of the DIS standard have been generally overcome during testing periods by developing gateways.*

1 Introduction

Australia and the United States entered into a formal Coalition Readiness Management System (CReaMS) Project Arrangement (PA) in 2001 [1], to demonstrate an interoperability training capability, with the long-term goal of establishing a persistent mission planning and rehearsal ability.

On the US side, this effort features the United States Navy's (USN) Battle Force Tactical Training (BFTT) system, which provides simulation interoperability using Distributed Interactive Simulation (DIS), scenario generation with exercise control, data collection and debrief capabilities. Based on a validated learning model, BFTT provides the USN Fleet with an efficient methodology for training crews aboard ships with their tactical equipment – to train like they fight.

On the Australian side, the Royal Australian Navy (RAN) employs DIS to link its major training simulators into the Maritime Warfare Training System (MWTS). Initially, training simulators for the FFG and ANZAC class assets have been linked in the first phase of the MWTS Project. These are located at HMAS WATSON in Sydney, the RAN's principal training establishment for surface warfare.

Three RAN/USN exercises have been run under the auspices of CReaMS:

- Phase One, the *Preliminary Interoperability Experiment* (PIE), took place from 26 - 29 November 2001 between the RAN/DSTO, USN, and Royal Netherlands Navy (TNO). This linked RAN training systems manned by ship crews with USN mockups located on the conference floor at the Interservice / Industry Training Systems and Education Conference (I/ITSEC) 2001 in Orlando and also TNO Computer Generated Force Systems at The Hague [2].
- Phase Two further demonstrated this capability in an expanded coalition warfighter training exercise held during February 2003. This *Encrypted Network Exercise* (ENE) was conducted between the Operations Room crews of HMAS ANZAC and ADELAIDE and their US counterparts [3].
- Phase Three investigated the feasibility of "ship-to-ship" simulation connectivity under the *Virtual Coalition Readiness* (VCR) exercise in September 2003 [4]. The ANZAC and FFG ship simulators were crewed by the actual ships' crews. HMAS WATSON, the Australian hub, coordinated the connectivity to the United States, while the Combat Direction Systems Activity (CDSA) in Virginia served as the US hub for the simulated exercise. Connected to CDSA were the Naval Undersea Warfare Center (NUWC) at Newport, Rhode Island; the Tactical Training Group Pacific (TTGP), in San Diego; and most importantly, a US Guided Missile Destroyer (the USS HOWARD) alongside in San Diego harbour. Staff from the

Commander Destroyer Squadron SEVEN and Commander Third Fleet also participated. The Royal Australian Air Force Air Defence Ground Environment Simulator (ADGESIM), developed by DSTO, also participated in the exercise.

The topology for the VCR exercise is shown in Figure 1.

Figure 1: Exercise topology for CReaMS Phase 3 Virtual Coalition Readiness exercise

DSTO, RAN and USN staff collaborated in simulation-related technical areas such as networking, encryption, data and intelligence links, and DIS implementation. In addition, an Objective Based Training system is under development, which will provide a quantitative assessment of the training achieved and crew readiness levels.

Each exercise has added technical and methodological complexity, and the lessons learned have been applied to the succeeding exercise. These CReaMS exercises have considerably extended RAN and DSTO knowledge of the requirements for interoperability between disparate systems. Further CReaMS exercises between Australian and the US are planned in the 2004 – 2007 timeframe.

The discussion will generally concentrate on the latest exercise, Virtual Coalition Readiness, since this built on the knowledge gained from the earlier exercises.

2 Technical Overview

The primary technical aim of the VCR exercise was to implement a distributed training environment at a classified level. An additional goal was to support the Team Training process. The VCR exercise allowed the exploration of different technology from the previous exercises in the areas of network bulk data transport, network peering and video conferencing technology, and refinement of the use of existing technology. The virtual communications architecture, encompassing Tactical Data Links, Global Command and Control – Maritime (GCCS-M), and emulated Battlegroup Command chat, was extended over that developed for the Phase One and Two exercises [2 - 3].

2.1 Network

The network design comprised a number of systems, each providing certain quality of service guarantees to its clients, and in turn relying on other network components. The main boundaries were the interface between the simulation systems and the classified WAN; the cryptographic interface; and the unclassified WAN service provider interface. Additional interfaces were used between the USS HOWARD and TTGP, namely Secure Internet Protocol Router Network (SIPRNET) and UHF radio communications.

2.2 Network Implementation

The simulation systems at HMAS WATSON consisted of the ANZAC Combat System Tactical Trainer (CSTT) and the FFG Integrated Operations Team Training Facility (IOTTF) and RAAF ADGESIM. Additional systems were used to monitor and log network traffic.

The cryptographic interface was provided by the Motorola Improved Network Encryption System (INES).

The earlier two CReaMS exercises [2 - 3] used ISDN links with CDSA operating as the central hub. This provided a direct router-to-router serial connection, resulting in an extremely flexible system, as the topology could be changed by having the routers dial different telephone numbers. However, costing variations in the international telecommunications market resulted in ISDN calls being expensive, especially when initiated from Australia.

For the VCR exercise, the ISDN links were replaced by an IP-based system that tunnels data through pre-existing bulk IP networks. As the operators of these networks purchase large quantities of bandwidth, the price is significantly lower. The Australian provider was the Australian Academic Research Network (AARNet), and the US provider the Defense Research and Engineering Network (DREN), which is operated by the US DoD.

2.3 Distributed Interactive Simulation (DIS)

The DIS protocol [5 - 6] was used to convey ground truth between the simulation systems. Both the enumeration and classified emitter databases were re-used from Phase Two.

Six DIS voice systems were employed:

- An ASTi system was used by the IOTFF [7].
- The Cooee system was used by the CSTT.
- Marine Digital Voice (MDV) was used by NUWC's Virginia class submarine simulators and also by CDSA for testing and monitoring purposes.
- Voice going to the USS HOWARD was received in DIS-format at TTGP by an Improved BFTT Digital Voice (IBDV) unit and converted into analogue signals and then re-transmitted over UHF radio, therefore stimulating the ship's radio.
- BFTT Digital Voice (BDV) was used by TTGP for game control purposes, and by the BFTT Operator Processing Console (BOPC) onboard the USS HOWARD.
- A customised commercial-off-the-shelf system was used by the ADGESIM [8].

2.4 Virtual Communications Architecture

The architecture enabling a simulated tactical data link between the CSTT and USS HOWARD employed protocol encapsulation, protocol transformation, and encryption.

The USS HOWARD is Link-16 based, whereas the CSTT has Link-11 capability. The configuration at HMAS WATSON was identical to that of Phase Two, whereby a Common Connectivity Device (CCD) provided an interface between the classified WAN, and the CSTT Naval Combat Data System (NCDS). The CCD encapsulated serial Link-11 messages within the Standard Interface for Multiple Link Evaluation (SIMPLE) protocol, for transmission over the classified WAN. Equipment at TTGP was used to translate Link-11 messages to and from Link-16 and transmitting them over UHF radio to the USS HOWARD.

Global Command and Control System – Maritime (GCCS-M) software is used by both the RAN and USN to merge multiple tactical data sources into a common operating picture. Data sources typically comprise ship-based radar, tactical data link tracks from other units, and incoming radio reports. A GCCS-M server was used to store, filter and manually adjust the input of tactical data. Tactical information was shared between TTGP and the USS HOWARD using a separate US DoD SIPRNET connection, with a *no foreign access* caveat (for non-US countries). As a result, the GCCS-M at HMAS WATSON was fed ground truth via DIS.

Battlegroup Command chat was emulated using PC-based Internet Relay Chat (IRC) software. Use of the Coalition Wide Area Network (COWAN) chat capability had been planned, as this system is used at sea, however not all sites had COWAN access.

3 Technical Interoperability Issues

This section provides analysis of how the various components of the distributed simulation exercise performed during the exercise.

3.1 Network

The Wide Area Network (WAN), comprising the AARNet and DREN, performed flawlessly during the event, with no significant traffic loss or congestion.

During testing, the INES units behaved as they did in the Phase Two exercise, where they would remain stable for a period of time (be it several minutes or several hours), and one or more INES units would then fail without reporting an error code. During the event week, the stability of the CDSA and WATSON INESs improved significantly. Towards the end of the event week, TTGP's INES failed several times.

3.2 Distributed Interactive Simulation

DIS was used for all three CReaMS exercises run to date. Details of its usage and interoperability issues encountered are described below.

3.2.1 Enumerations Standards

DIS provides a standard set of enumerations for entities, weapons, sensors, communication devices, environmental descriptors and other attributes [9] Australian systems generally employed the IEEE SISO list of enumerations while USN systems use a mix of BFTT and SISO enumerations. These are generally similar; however some minor differences were noted. For example, the Carrier Abraham Lincoln was listed differently in the SISO and BFTT enumerations. Spurious entity enumerations were also noted in the ENE exercise: an incorrect enumeration for an ANZAC ship was noted and Reference Points were incorrectly attributed to Australia (they have no country ownership).

For the earlier exercises, enumerations differences caused significant confusion and lost productivity with databases having to be rebuilt during the testing phases. Australia deployed several specific virtual ships in the exercise, for example, but the USN's BOPC, a key element of the BFTT system was initially only able to simulate a generic ANZAC ship, rather than the specific one used for the PIE exercise.

Progress was finally made once a complete list of enumerations was compiled, agreed upon and managed. For the most recent VCR exercise, there were no problems experienced in the use of the agreed list of entity enumerations or the emitter database.

Several simulation systems behaved unexpectedly upon receipt of non-game enumerations:

- The USS HOWARD was configured to receive DIS traffic on port 6993 and this could not be modified to port 3000 used by the other systems.
- Some USN systems ignored site IDs greater than 2600, whereas the simulators at HMAS WATSON were configured to use a site ID of 13000 to indicate Australia (country 13 in the SISO enumerations listing) – [10].

3.2.2 PDU Types

The types and numbers of PDUs used in the exercise for the first session of a day are shown in Table 1.

Table 1: PDU distribution – VCR Day Three Session One (0615-0900 AU-EST, 11 September 2003).

PDU Type	Number	Fraction (%)
Entity State	441,372	27.88
Fire	0	0.0
Detonation	0	0.0
Simulation Management	7,072	0.45
Electromagnetic Emission	41,694	2.63
Transmitter	106,058	6.70
Signal	826,103	52.18
Receiver	92,844	5.86
IFF	56,064	3.54
Underwater Acoustic	862	0.05
BSEE	3,729	0.24
BMP	7,246	0.46
Total	**1,583,044**	**100.0**

Here, BSEE indicates BFTT Supplemental Electromagnetic Emission PDU and BMPE indicates a BFTT Multi-pulse Emission PDU). Clearly the Entity State and Communications PDUs form the majority of the traffic. Note that although no Fire and Detonation PDUs were generated on this day, they were observed on other days of the exercise.

DIS voice and entity traffic for the whole day of the exercise are shown in Figure 2. There was an exercise pause between about 0900 and 1030 to facilitate data backups and on-line data analysis.

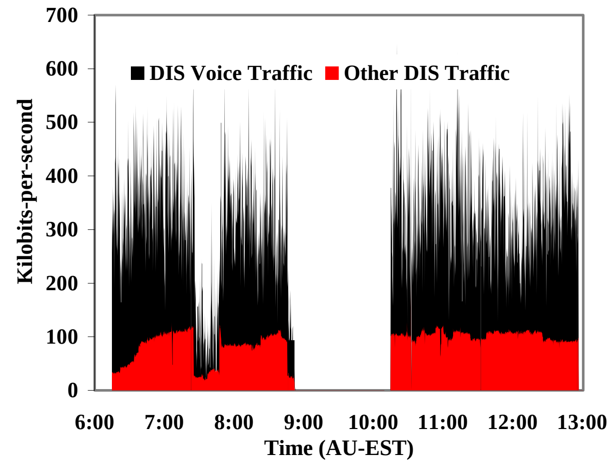

Figure 2: DIS Voice and Entity Traffic for Day 3 of the VCR Exercise

3.2.3 PDU Issues

In general, the RAN systems employed PDUs compliant with the latest IEEE standard. USN systems, however, employed some additional experimental PDUs namely:

- BFTT Supplemental Electromagnetic Emission (number 235) used to convey radar emission information. This is used to avoid the need to populate an additional database with radar information.
- PDU BFTT Multi-pulse Emission PDU (number 236) used to convey information for multi-pulse radar systems. This is a PDU recently developed by the BFTT Program.

These PDUs were generally ignored by the Australian systems and flagged as erroneous.

Several simulation systems behaved unexpectedly upon receipt of non-standard PDUs and non-game enumerations. Problems encountered included:

- The AEGIS Combat Training System (ACTS), onboard the USS HOWARD, supported only DIS version 5 PDUs and ignored DIS version 6 PDUs.
- The ADGESIM was found to send non-standard Electromagnetic Emission PDUs, whereby various fields were set to zero, and non-standard IFF PDUs, whereby the event IDs were set to zero.
- NUWC's On Board Team Trainer (OBTT) experienced problems with simulation management Start and Freeze PDUs, sent by the ACTS as it was restarted. The OBTT was also found to fail upon receipt of BFTT Supplemental Electromagnetic Emission and Radio Communications PDUs on port 3000.

- Some systems were configured incorrectly. For example, a P3C maritime patrol aircraft entity, generated by the CSTT, inappropriately fired an underwater decoy.

The majority of these interoperability issues were resolved using gateway software, developed by CDSA, to filter and translate PDUs. For example, a gateway was developed to translate DIS version 6 PDUs to version 5 PDUs for the Aegis Combat Training System.

3.3 DIS Voice

Throughout all three CReaMS exercises, successful voice communications have been the most challenging task. This is primarily due to the vagueness of the DIS standard regarding the population of Transmission PDU fields.

Some systems require only the frequency field to be set, whereas others require the modulation parameters to be set. Systems such as the Cooee (used in the CSTT) require the receiver's frequency to be identical to that of the transmitting simulators. The DIS standard does not explicitly define how encrypted communications are to be implemented, nor does it describe how receivers should interpret transmissions from the centre of the world that, by convention, are propagation-less. As a result, each voice system may be built to a different interpretation of the standard.

These difficulties can be summarised as:

- Voice traffic from the MDV systems at NUWC and CDSA was not received by the ASTi voice system (used in the IOTTF), but received by other systems. CDSA identified the cause of this problem following the exercise: DIS PDU traffic sent by MDV contained non-zero values within the padding fields, whereas the default configuration of ASTi causes such PDUs to be ignored.
- In the final week of testing, the Cooee system was found not to be receiving voice traffic from any of the other voice systems, including the IOTTF. As a work-around, it was suggested that the operators switch to and from secure communications. This had a positive effect, and communications were available for the event week. The fault was suspected to be due to an operating system buffer overflow, and it was advised to increase Cooee's buffer size for future exercises.
- Intercom voice traffic from the IOTTF was sent over the DIS WAN to all other sites. The average bandwidth consumed by these intercoms was approximately 250kbps. Along with the intercom traffic, additional voice traffic on non-games channels was found to be generated by the IOTTF and CSTT. Examination of the voice traffic showed these Signal PDUs to contain ambient noise, suggesting that some radios were left unmanned in voice-on-transmit mode.

It is desirable for communications systems to have an "interoperability testing" mode, which gives the operator notification when transmissions are being sent on the channel, but are discarded due to incorrect modulation or encryption settings. Site-based gateway software would also be useful for the DIS Voice systems. Translation software could solve the modulation and timestamp issues, along with filtering of unnecessary traffic, such as the IOTTF intercoms.

3.4 Virtual Communications

It was identified during Phase Three planning, that the CSTT (ANZAC simulator) set the simulation bit, found within tactical data link messages, to indicate that the NCDS was operating in simulation mode. The USS HOWARD was known to discard messaging with the simulation bit set.

Emulated Battlegroup Command chat performed well throughout the testing build-up and event week. The only major problem faced by the HMAS WATSON crews was that in addition to the emulated chat, the US sites were using DoD SIPRNET chat. SIPRNET chat is classified SECRET-NOFORN (no non-US access) and therefore was not available at HMAS WATSON.

The use of IRC, whilst stable, is not tolerant to INES failures. When the INES failed, all participants had to reconnect to the server, and even though the IRC clients were configured to automatically reconnect, there was often a delay in this process. The IRC protocol is different to DIS, and although each chat message includes a time-stamp, there was no automated method to integrate these into the after action review process. The development of a "chat message" to DIS Comment PDU gateway was considered for Phase Three, but not implemented.

4 Conclusions

This complex VCR training event completed the initial goals and objectives of the CReaMS Project Arrangement. The encrypted simulation included tactical data link and voice communications; Battle Group internet-like "chat" circuits; air, surface and subsurface "contacts"; and the ability to manoeuvre and conduct realistic operations. Immersed in this synthetic maritime warfare environment, the officers and sailors undertaking training were solving problems, making decisions, taking actions, and relying on other coalition team members, just as if they were at sea.

From a technical perspective, the AARNET and DREN connection was reliable, whilst the INES was not. Identification of more robust and dependable cryptographic equipment is required. Interoperability issues with DIS and DIS Voice have been identified. Gateway software, hosted by CDSA, provided a way to resolve many of the interoperability issues. Systems that fail, or behave unexpectedly, upon reception of non-standard PDUs, require modification to be made more tolerant. Likewise, systems emitting non-standard PDUs need to be corrected.

Through the CReaMS series of exercises, numerous DIS interoperability issues and ambiguities within the standards documents have been identified. The majority of these interoperability issues were resolved using gateway software to filter and translate PDUs. These issues have since been reported to the SISO DIS Specialist Group, for further investigation, and eventual inclusion into a revised DIS standards document.

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6 Author Biographies

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PETER ROSS graduated from RMIT University in 2001 with a Bachelor of Applied Science, majoring in computer science. Mr Ross joined the Air Operations Division in 2003, and works in the Advanced Distributed Simulation Laboratory; researching communications and interoperability issues in the area of Advanced Distributed Simulation.

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