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10 Mar 2010

From: Commanding Officer, Naval Research Laboratory  
To: Chief of Naval Research (Code 331 L. Couchman)

Subj: ADVANCED DAMAGE CONTROL (DC) COMMUNICATION FINAL  
TECHNOLOGY DEMONSTRATION REPORT

Encl: (1) One copy of the subject report

1. Enclosure (1) is forwarded for your review and comment. This project was funded by the Office of Naval Research (ONR) under the Future Naval Capabilities (FNC) EPE-FY07-01/ Total Ship Survivability Damage Tolerance and Recoverability program.
2. Improving Damage Control (DC) communications on Navy ships has been a goal for many years. Many different communications technologies have been conceived and demonstrated, but few have improved capabilities or proved to be survivable in some DC environments. Additionally, past communication technologies have relied on "voice only" capability, which has limited opportunity to significantly improve DC communications within the confines of a ship during DC action.
3. The Advanced DC Communication program successfully demonstrated and validated the efficacy of using a wireless mobile ad-hoc network (MANET) topology in a shipboard DC environment. The demonstrated communication system was found to improve situation awareness and help overcome and rectify the present error prone methods of reporting and tracking damage control information. The demonstrated technology can be used either as a standalone system or be integrated into any fixed wireless local area network (WLAN) infrastructure. The technology demonstration also validated the importance to include data and video imaging capability within the DC communication system to enhance overall DC performance. This was the first multi-team test series conducted onboard the Navy's fire test ship, ex-USS *Shadwell* where DC communications was not an impediment to overall DC performance.
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A handwritten signature in black ink, appearing to read "Warren W. Schultz".

WARREN W. SCHULTZ  
By direction

Subj: ADVANCED DAMAGE CONTROL (DC) COMMUNICATION FINAL  
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**ADVANCED DAMAGE CONTROL (DC) COMMUNICATION  
FINAL TECHNOLOGY DEMONSTRATION REPORT**

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## ACRONYMS

1-MC	Main Communication (General Announcing Circuit)
AC	Alternating Current
AP	Access Point
ATM	Asynchronous Transfer Mode
CIC	CoCo Interoperable Controller
CIS	CoCo Interoperable Server
COMP	Cryptographic Overlay Mesh Protocol
CONUS	Continental United States
COTS	Commercial Off-The-Self
CSMC	Combat Systems Mission Control
DC	Damage Control
DCO	Damage Control Officer
DC Comms	Damage Control Communication
DC DataLink	Damage Control Data Link
DDA	Damage Decision and Assessment
DSA	Digital Signature Algorithm
FDE	Fleet Doctrine Evaluation
FIPS	Federal Information Processing Standardization
GQ	General Quarters
ICOMM	Interior Communications
IMR	Indoor Mesh Router
IP	Internet Protocol
IR	Infrared
LAN	Local Area Network
LED	Light Emitting Diode
MANET	Mobile Ad-Hoc Network
MW	Megawatt
NAVSEA	Naval Sea Systems Command
NRL	Naval Research Laboratory
ONR	Office of Naval Research
PC	Personal Computer
PDA	Personal Digital Assistant
PEAT	Propelled Extinguishing Agent Technology
PKI	Public Key Interchange
PPT	Personal Productivity Tool
QAWTD	Quick Acting Water Tight Door
RoIP	Radio over Internet Protocol
RPO	Repair Party Officer
SHA	Secure Hash Algorithm
SPP	Sound Powered Phone
SSC	Ship Mission Center
SSL	Secure Socket Layer
TCP	Transmission Control Protocol
TMA	Tactical Mesh Router
TRG	Tactical Radio Gateway
TSCEI	Total Ship Computing Environment Infrastructure
TTA	Technology Transfer Agreement
UDP	User Datagram Protocol
VIP	Very Important Person
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
WLAN	Wireless Local Area Network
WTS	Water Tight Scuttle

# ADVANCED DAMAGE CONTROL (DC) COMMUNICATION FINAL TECHNOLOGY DEMONSTRATION REPORT

## 1.0 BACKGROUND

### 1.1 Current DC Communication Shortfalls

Improving Damage Control (DC) communications on Navy ships has been a goal for many years. Many different communications technologies have been conceived and demonstrated, but few have improved capabilities or proved to be survivable in some DC environments.

Over the past 16 years, a number of Fleet Doctrine Evaluation (FDE) tests have been performed on the ex-*USS Shadwell* [1]. These tests have demonstrated various damage control systems and technologies, identified training requirements for Navy personnel and improved Navy doctrine associated with firefighting. One DC competency that has continually been found to be problematic is DC communications [2-3].

There are a number of factors that contribute to the problems associated with DC communications, which include:

- The physical geometry and materials used for ship construction particularly when wireless technologies are employed
- Psychological stress, which is compounded by reduced visibility and the firefighters limited experience with actual shipboard casualty events
- Physiological stress due to heavy workload and heat strain, placing considerable cardiovascular and cardiopulmonary demands that are exacerbated by excessive fluid loss, vasodilation of vessels in the skin and muscle and elevated breathing rates.

These noted stress responses decrease cognitive performance, which degrades the firefighter's task-focused thinking, firefighting performance and communication abilities. Additionally, past communication technologies have relied on "voice only" capability, which has limited opportunity to significantly improve DC communications within the confines of a ship during DC action. In order to help mitigate these consequences and improve DC communication, a new approach is needed to simplify the process and include the ability to provide voice, data and video imaging capabilities during the conduct of shipboard damage control.

## **1.2 IP Convergence – The Solution, and the Problem**

The Internet Protocol (IP) is now the global standard for data communications, and it continues to supplant most circuit-based technologies as the networking protocol of choice for streaming applications (i.e. real-time voice and video). As such, it is essentially the only common integration point characteristic of typical user nodes, routers, gateways and most other internetworking products. It is difficult to identify a networking application or technology that has not already hewed toward IP-centricity.

The main problem with this convergence is that IP is not currently fully functional to the point where it can enable communications between users and systems without undue restrictions.

Challenges that exist in current IP network deployments include:

1. **Identity Management** – selecting names and addresses for resources across the network so that they can be effectively discovered, cataloged and utilized.
2. **Security Assurance** – securing network traffic from intercept, exploitation, and forgery, as well as protecting network-level systems and interfaces.
3. **Mobility Management** – efficiently maintaining network performance for systems, users and networks as they dynamically change locations and link connectivity.
4. **Resiliency** – insuring that network control is fully distributed, avoiding single points of failure and utilizing redundant communication paths where available.
5. **Performance** – limited support for streaming applications, perpetuating inappropriate transport protocol mechanics and lack of adaptation to underlying link technologies.
6. **Topology** – sharp distinctions between user nodes and infrastructure nodes limit the allowable network architectures to pre-planned hierarchies.

For enhanced DC Communications, an advanced architecture will be needed to help improve IP functionality both for user terminal and internetworking products (i.e., routers and gateways). This will help to improve overall network capabilities while ensuring 100% compatibility with existing applications, protocols and link layer technologies that may support DC Communication operations.

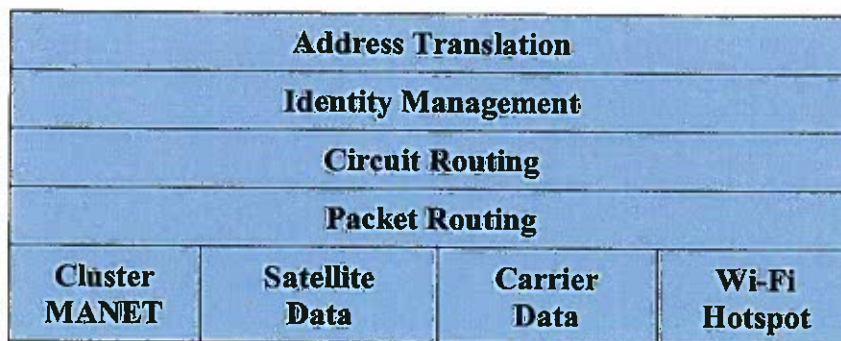
## **2.0 ADVANCED DC COMMUNICATION TECHNOLOGICAL APPROACH**

### **2.1 Commercial Off-the-Self (COTS) Software**

The EPE-FY07-01/ Total Ship Damage Tolerance and Recoverability, Advanced DC Communication developmental team decided early on that the best technological approach to product development had to be based on a commercial off-the-self (COTS) solution in order to help minimize risk and enhance transition opportunity. Based on a review of the technology options available, it was decided that the Cryptographic Overlay

Mesh Protocol (COMP) developed by CoCo Communications Corp, alternately referred to as the CoCo® Protocol, could provide the optimum baseline technology for demonstrating an enhanced shipboard DC communication capability [4]. The CoCo Node is the product that enables secure, mobile and an easily-managed resilient mesh network. The CoCo Node operates as a “shim” within the boundaries of the IP layer of networked systems. In keeping with modular communications software engineering practices, the CoCo Protocol solution comprises its own internal stack architecture inside the confines of the IP layer on the target system. The CoCo Node creates an additional “sub-stack” in the space traditionally reserved for IP itself. This architecture makes the CoCo Node internally modular, and thus easily maintained, modified and extended. It also enables the system to process, modify, or pass-through both inbound and out bound traffic on a packet-by-packet basis.

Standard Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) interfaces are maintained above the “Address Translation” component, while standard data link subsystems operate under their respective transport adaption managers, augmenting IP with several CoCo-specific extensions (see Fig. 1).



**Fig. 1 – CoCo Node: Internal Software Architecture**

Within the CoCo Node product, “Identity Management” is based on pre-placed X.509-based certificates. These certificates are also part of the security system, establishing the basis for Public Key Interchange (PKI) cryptography utilizing the open Secure Sockets Layer (SSL) library. All certificates are authenticated using a common root authority provisioning server at configuration time. Once the certificates are in place, the identity management system is enabled and the basis for arbitrarily strong cryptography is in place. At the administrator’s option, the system encrypts hop-by-hop (link) traffic, the end-to-end (virtual circuit) traffic, or both, using keys unique to the endpoints.

Naming, addressing and address translation is handled by the upper layer in the CoCo Node architecture. The CoCo Node allows the IP layer to present a single, static IP address to all local and remote applications, freeing them from understanding the complexities of the particular network implementation and configuration. Application processes all see a user-defined IP address space that is typically configured to make the entire CoCo network appear as a single, flat, IP subnetwork. Nodes need not change their CoCo IP addresses no matter how the network and its underlying links change over time.

IP “Packet Routing” is enabled by a purpose-built mobile ad-hoc networking (MANET) routing protocol implementation which is responsible for insuring connectivity, managing a clustering system for scalability and supervising handoff and failover management for established virtual circuits.

The “Circuit Routing” layer within the CoCo Node allows system performance to be optimized with respect to streaming applications, including multicast streaming such as that required for audio-conferencing and distributed video surveillance. Operating in a manner akin to Asynchronous Transfer Mode (ATM) virtual circuit management, this component enables differentiation according to transport protocol differentiation and enables stateful routing decisions. The resulting combination of both circuit and packet routing abilities provides the CoCo Node a resilient handoff ability that is more typically characteristic of cellular systems than classic IP networks.

For DC Communications, network security is considered a critical component of any viable network solution. The current CoCo technology leverages the open-SSL libraries in order to provide a range of selectable security mechanisms including PKI with Diffie-Hellman key exchange, end-to-end and hop-by-hop cryptography and a secure key hash generation algorithm. It employs Digital Signature Algorithm (DSA) keys and defaults to 128-Advanced Encryption Standard (AES) encryption using Secure Hash Algorithm (SHA)-1. The key and hash algorithm selection can be modified at linking time when the Node image is built, employing any selectable component from the available binary libraries. The current default selections have been certified in accordance with the Federal Information Processing Standardization (FIPS) 140-2.

Because all nodes retain standard IP functionality, the CoCo Node provides an incrementally deployable solution. Although deploying a CoCo Node to every terminal and internetworking device in a network provides particular optimizations and functionality, it is possible to integrate CoCo “clouds” as access networks or portions of an established, ordinary, IP network. This lowers the entry barrier for the CoCo Node deployment and allows the CoCo technology to use standard IP networks to provide “backhaul” if necessary between CoCo-enabled network enclaves. Additionally, the CoCo Node has been designed to be autonomous once it has been initially configured and deployed. This is especially advantageous for DC applications since it enables automated, agile network control for self-configuring, self-optimizing and self-healing operation.

## **2.2 Radio Interoperability**

Shipboard damage control operations often include external assistance from other operating units. Since it not known what communications devices may be employed by the assisting units, it is desirable to have interoperability with non-IP communication systems. The CoCo Communications technology has extended the IP-centric view of systems interoperability to also include non-IP systems via radio and voice gateways.

These gateways are IP devices, essentially CoCo routers, which support additional interfaces for integrating telephone, radio, and other voice systems into any CoCo network.

By integrating radio transmissions and other voice traffic via Ear and Mouth (E&M) analog electrical interfaces, the CoCo system provides a capability of bridging disparate radio frequencies and systems, while also supporting the direct integration of standard Voice over IP (VoIP) users as well as cell phone and landline telephone users in a peer-to-peer fashion.

This capability allows one or more “talk groups” to be created as virtual conferences at any point in a CoCo network and allows each conference to be routed to any CoCo device user, analog audio interface, or broadcast radio domain that is reachable on the CoCo network.

CoCo’s voice interoperability solutions link different radio and IP networks together regardless of frequency or distance to allow for communications during emergency disasters, combat and peace time missions. The radio interoperability provides an easy to deploy, easy to use, secure solution for connecting distributed voice and radio networks that could be used both at the casualty scene and remote command centers.

### **3.0 COMMERCIAL OFF-THE-SHELF PRODUCTS**

The COTS products that were used during the Advanced DC Communications program were based on CoCo technology.

#### **3.1 COTS Software**

##### **3.1.1 CoCo Node**

The CoCo Node software builds cutting edge networks that enable people in any mobile or fixed environment to create instant networks and share information securely and reliably.

The CoCo Node enhances existing networks, is self-configuring for easy administration and runs on PCs, laptops, PDAs, and smart phones. When a device’s connectivity is degraded, the CoCo Node provides the necessary handoff services to keep the device’s IP applications running. Networks built with CoCo Node operate in a fully distributed fashion, with no centralized infrastructure or single points of failure.

### 3.1.2 CoCo Communicator

The CoCo Communicator is a voice, video and data soft-phone application designed for use on PDAs and PCs in mobile or tactical environments.

The CoCo Communicator provides push-to-talk audio conferencing, full duplex peer-to-peer dialing, scrolling ticker messages and, optionally, phone calls to landline and wireless phones. A simple user interface with large buttons lets the user accurately select conferences, network participants and cameras from a list for one touch dialing or fixed camera selection (see Fig. 2).



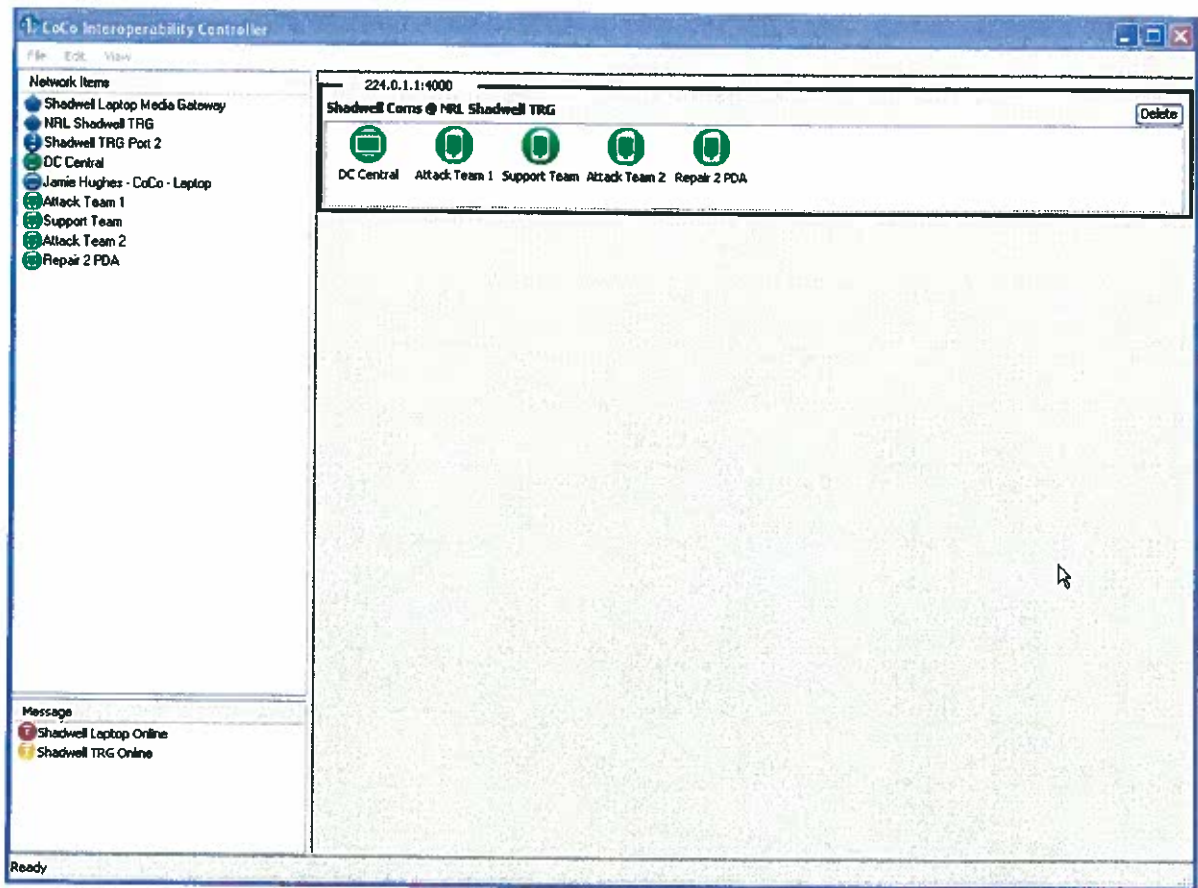
**Fig. 2 – CoCo Communicator**

### 3.1.3 CoCo Interoperability Server (CIS)

The CoCo Interoperability Server (CIS) is a software process that manages audio bridging between radios, phones, handheld devices and personal computers loaded with the CoCo Communicator application. It provides an easy-to-use conference solution that connects all members of a group together seamlessly to create controllable, interoperable conferences. While the actual audio bridging and routing is handled in a distributed fashion, the CIS process provides a control point for the creation and maintenance of the multicast talk-groups. Multiple, redundant CIS processes can run on any deployed CoCo network.

### 3.1.4 CoCo Interoperability Controller (CIC)

The CoCo Interoperability Controller (CIC) is an application used to control the CIS to create or delete an unlimited number of conferences, monitor conference participation in real time, drag and drop radio and phone assets into conference, and create broadcast ticker messages. Its drag-and-drop graphical user interface allows the control of the CIS software process (see Fig. 3).



**Fig. 3 – CoCo Interoperability Controller (CIC)**

CIC can run on the same platform as CIS or on other networked systems. Multiple, redundant CIC processes can be used to control conferences on any deployed CoCo network.

### **3.2 COTS Hardware**

#### **3.2.1 CoCo Indoor Mesh Router (IMR)**

The CoCo Indoor Mesh Routers (IMR) are powered by the CoCo Node to form a self-organizing, self-healing mesh network that can provide a secure, globally scalable mobile ad-hoc network (MANET).

The IMR is an indoor, wireless router with the capability to provide secure connectivity to IP-based devices, such as cameras, personal computers, servers, phones and radio networks (see Fig. 4). The IMR can connect to other devices to expand the coverage area with other types of wired/wireless devices, creating a single, seamless wireless network without geographic or topological limits. Via its wired Ethernet interfaces, the IMR can integrate to other MANET or IP networks to support remote voice, video and data applications for tactical and fixed infrastructure networks.



**Fig. 4 – CoCo Indoor Mesh Router 2110**

### 3.2.2 CoCo Tactical Mesh Router (TMR)

The CoCo Tactical Mesh Routers (TMR) is a wireless, battery-powered device which enables users to easily and quickly deploy self-organizing, secure mobile mesh networks anywhere coverage is needed (see Fig. 5). TMRs have an 8-12 hour battery life before they require recharging.



**Fig. 5 – CoCo Tactical Mesh Router 2310**

The TMRs provides secure connectivity to CoCo devices and CoCo integrated systems, such as IP cameras, personal computers, servers, VoIP phones and other wired/wireless devices. The TMR creates a single, seamless wireless network that securely deploys with a touch of a button in under one minute for tactical deployment. The TMR automatically creates and configures reach and reachback links for secure transmission of voice, video and data traffic.

### 3.2.3 CoCo Tactical Radio Gateway (TRG)

The CoCo Tactical Radio Gateway enable different radio systems to interoperate with each other in a joint CoCo network (see Fig. 6). The TRG provides local and network-based audio conferencing and bridging functionality.

Built to rugged U.S. Coast Guard specifications, the TRG is weatherproof and can withstand extreme environments. A user can connect up to three radio networks or

frequencies instantly by connecting a representative radio for each. The TRG's built-in wireless, wired and optionally, cellular network connections provide access to any IP network resources. A user can join landline, cell phones, or any PC-based device on its network. TRGs come with a built-in, rechargeable 8 hour battery. In addition a user can deploy multiple TRGs to connect an unlimited number of radios to extend network coverage and can connect multiple TRGs to support remote radio over IP (RoIP) applications.



**Fig. 6 – CoCo Tactical Radio Gateway 3300**

#### 3.2.4 Motorola Symbol MC-75

The MC-75 is a ruggedized handheld device for voice, video and data applications (see Fig. 7). The personal productivity tool (PPT) buttons and touch screen are designed for use with gloves in fast-paced DC operations. It incorporates a camera that was specially integrated into the DC Comms (Damage Control Communication) system for the Advanced DC Communication exercises to support the display of mobile video camera feeds in DC Central or any Repair Station.



**Fig. 7 – Motorola MC-75 with Imbedded Video Camera Capability**

### 3.2.5 Laptops/PCs

Installing CoCo Node software on generic Windows XP laptops and PCs enables them to act as routers, conference controllers, or CoCo Communicator platforms (see Fig. 8).



**Dell E6400 XFR**



**Panasonic Toughbook Model 29**

**Fig. 8 – Windows XP Laptops and PCs**

## 4.0 SOFTWARE CUSTOMIZATION FOR ADVANCED DC COMMUNICATION

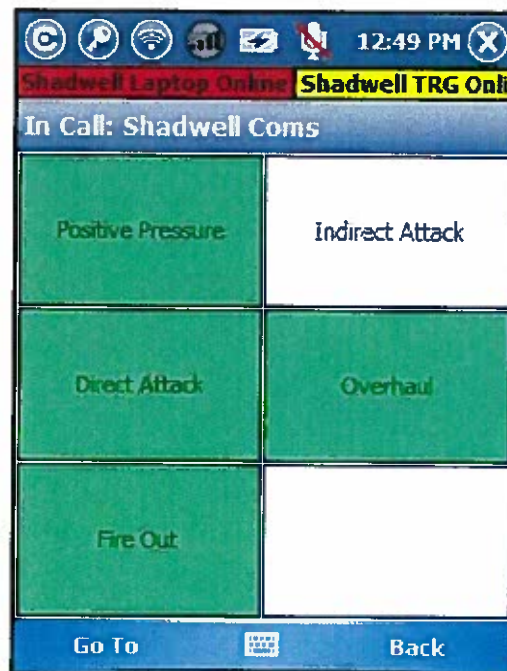
To enhance operational capabilities beyond the standard CoCo COTS offerings, the Advanced DC Communication program developed two additional software applications:

- Damage Control Communications (DC Comms) for handheld PDAs to feed this information back to the DC Comms displays, and
- Damage Control Data Link (DC DataLink) to consolidate and display DC information in central locations.

These two applications are standard IP network applications, running over the CoCo network, which incorporate specialized DC functions only at the user interface layer.

### 4.1 DC Comms Application

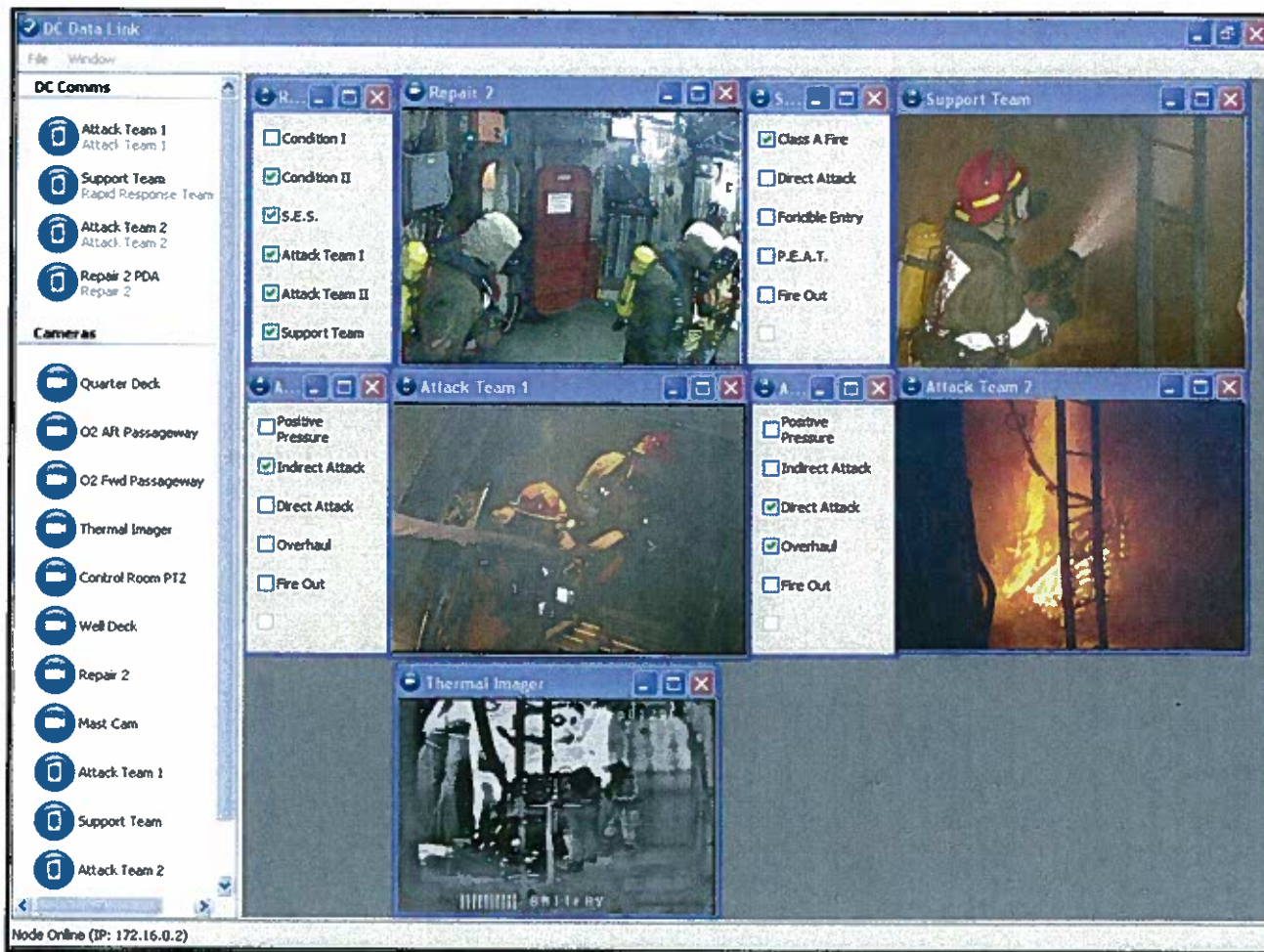
DC Comms (Damage Control Communication) allows status reporting from remote teams to central command and control sites. It serves as a mission-defined visual checklist for the team leader and relays status data back to DC Central or any Repair Station for display. The large touch-screen soft-buttons allow easy operation even when dressed in protective gear. The button labels are defined in a text file on each PDA and are automatically synchronized with a display screen in DC Central and/or the germane Repair Station. The mission-specific button set can be selected or customized by non-technical personnel (see Fig. 9).



**Fig. 9 – PDA DC Comms Screen with Action Buttons**

## 4.2 DC DataLink Application

The DC DataLink (Damage Control Data Link) application was designed to display information from the DC Comms application and integrated fixed or mobile video sources. CoCo Communicator-equipped PDAs that have been enabled with DC Comms are displayed in the upper left panel of the DC DataLink application control screen. All network video resources including fixed cameras and the mobile PDA cameras can be viewed (see Fig. 10).



**Fig. 10 – DC Central DataLink Display**

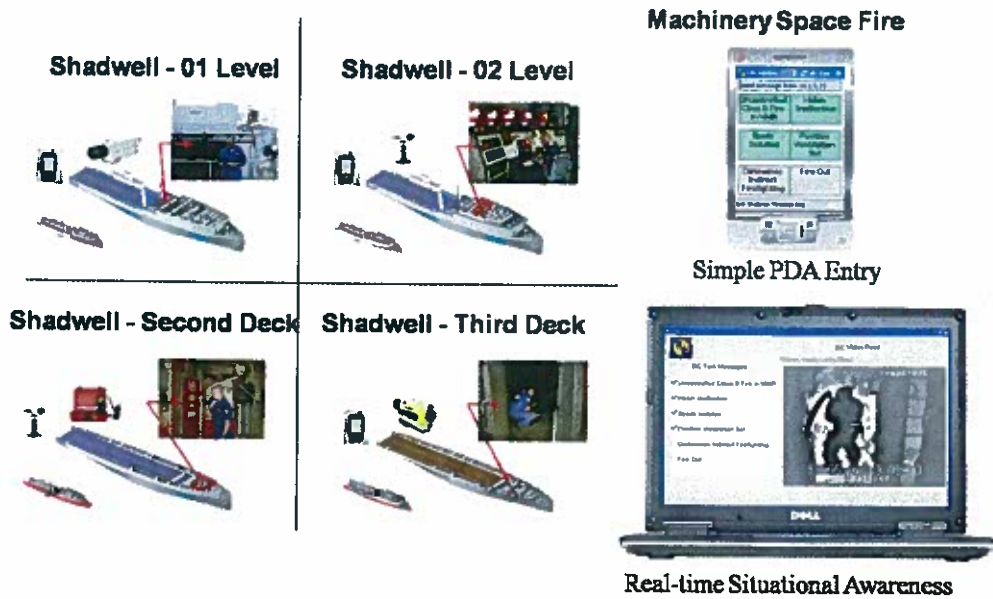
The screen shot above depicts DC Comms data representing four deployed DC teams with three different mission profiles. Real-time, concurrent display of their status was visible while video feeds from both mobile and fixed cameras are shown to enhance situational awareness. Integration of an infrared (IR) camera is shown at the bottom of the DC DataLink display which continued to be effective when the visual-light cameras were obscured due to smoke in the casualty areas.

## 5.0 FY 08 ADVANCED DC COMMUNICATION ACCOMPLISHMENT

The FY08 Advanced DC Communication technology demonstration focused on component level testing and determining the viability of using a mobile ad-hoc network (MANET) technology approach in a shipboard environment. The technology demonstration was separated into two phases:

- Phase one included voice and video transmission from various locations in the ship that included a topside location overlooking the Hangar Bay test area (SHADWELL – 01 Level), the Control Room (SHADWELL – 02 Level), the Repair 2 area (SHADWELL – 2<sup>nd</sup> Deck) and the Machinery Space test area entrance (SHADWELL – 3<sup>rd</sup> Deck). During this part of the demonstration various communications devices were used that included PDAs, a handheld radio and portable laptop computers. Additionally, various camera types were used that included the fixed SHADWELL digital cameras, COTS wireless cameras and a thermal imager. In all instances the cameras were provided with a wireless interface into the MANET system (see Fig. 11).
- Phase two included a Machinery Space fire demonstration that featured a single attack team “DC action” button display and simultaneous infrared (IR) camera video image capability. The fire threat scenario included a 10 megawatt (MW) flammable liquid spray fire that had to be fought indirectly through a topside access located at the Machinery Space upper-level entrance point. This particular fire scenario was chosen to further demonstrate the new Machinery Space Fire Doctrine work that was recently completed by NAVSEA and NRL and to further test the capability of indirect firefighting water sprays to extinguish a flammable liquid spray fire threat [5]. As can be seen in Figure 11, the fire attack Team Leader was able to employ simple data message updates to DC Central via the touch screen buttons on his PDA, which automatically conveyed updates to the DC Central laptop computerized checklist. The infrared (IR) video image was also presented to further enhance real-time situation awareness to the DC command structure.

The technology demonstration also included an Internet virtual private network (VPN) connection between the Navy fire test ship, *ex-USS Shadwell* and the NRL Chemistry Division building located in Washington DC. This was done to demonstrate the MANET platform’s capability to simulcast DC information to a remote site and in a secure fashion. Beyond being a convenience for the VIP observers who witnessed the technology demonstration, the secure Internet VPN connection demonstrated the additional advantages that a MANET FIPS 140.2 certified system could provide by enabling real-time DC information transfer to remote locations such as a Battle Group Command Center or a Continental United States (CONUS) Technical Command Center during an actual Fleet DC incident.



**Fig. 11 – FY08 Advanced DC Communication Accomplishment**

## **6.0 FY09 ADVANCED DC COMMUNICATION TEST OBJECTIVES**

Appendix A provides a copy of the Technology Transition Agreement (TTA) that has been established between the Future Naval Capabilities (FNC) EPE-FY07-01/ Total Ship Survivability Damage Tolerance and Recoverability program office of the Office of Naval Research (ONR) and the Naval Sea Systems Command (NAVSEA) acquisition program for DDG 1000, PMS 500. For the DDG 1000, ship design specification contains a requirement to have a backup communication capability to support damage control and selected ship control functions in the event the Interior Communications (ICOMM) or the Total Ship Computing Environment Infrastructure (TSCEI) is not operational or degraded due to a weapon hit. A traditional sound powered phone (SPP) system has been specified to satisfy this requirement for a limited number of spaces, which includes the Ship Mission Center (SMC), Secondary SMC, the Bridge, machinery spaces, DC assembly areas and AFT steering. It is believed that total reliance of the secondary SPP system may not be adequate for effective DC communication coverage during a major shipboard DC incident. It is for this reason that the Advanced DC Communication program supported the development of a portable standalone wireless communication system that could supplement the proposed SPP system and provide an effective means for communicating voice, data and video imaging information from the damage scene to the DC command structure when the ship's primary communications network is lost or degraded.

The FY09 final technology demonstration continued to build on lessons learned during the FY08 technology demonstration and expanded the communication system capabilities to include the following enhancements:

- Upgraded PDA software to enable multiple team function capability
- Integrated mobile camera into the handheld PDA to allow real-time, team by team event viewing
- Expanded DC DataLink to simulcast multiple communication events to DC Central and the Repair Station
- Integrated the functionality of the MANET system with a fixed wireless local area network (WLAN)

The test objectives for the FY09 Advanced DC Communication demonstration was to validate the efficacy of a MANET system with the noted enhancements while confronting a complex multi-team casualty scenario using voice, data and video imaging during the casualty events. The demonstration was also designed to review the ability of the system to use multiple types of communication devices in a peer-to-peer fashion and its ability to integrate its functionality with a fixed wireless local area network (WLAN).

## **7.0 TEST SETUP**

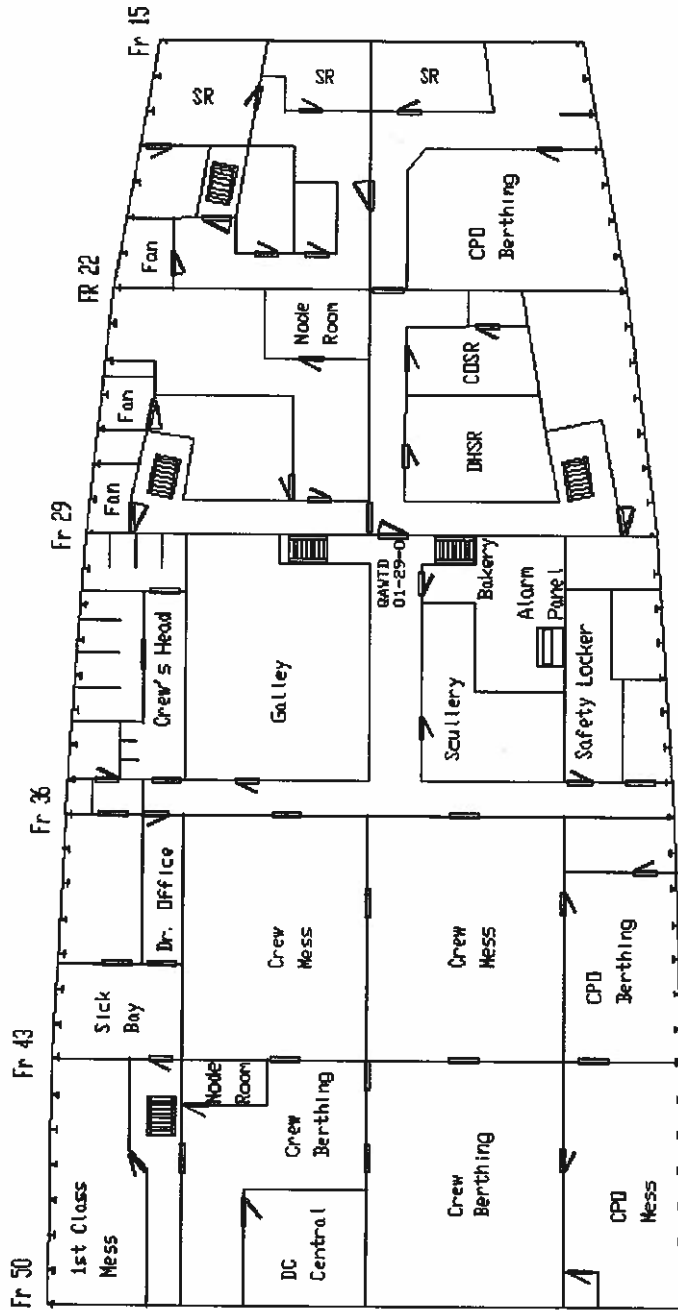
### **7.1 Test Area Description**

The Advanced DC Communication demonstration was conducted in compartments and passageways located between frame 15 and frame 50 from the 01 Level down to the 3<sup>rd</sup> Deck on the ex-*USS Shadwell*.<sup>1</sup> Figures 12 through 15 provide an overview of the test area and compartment designations.

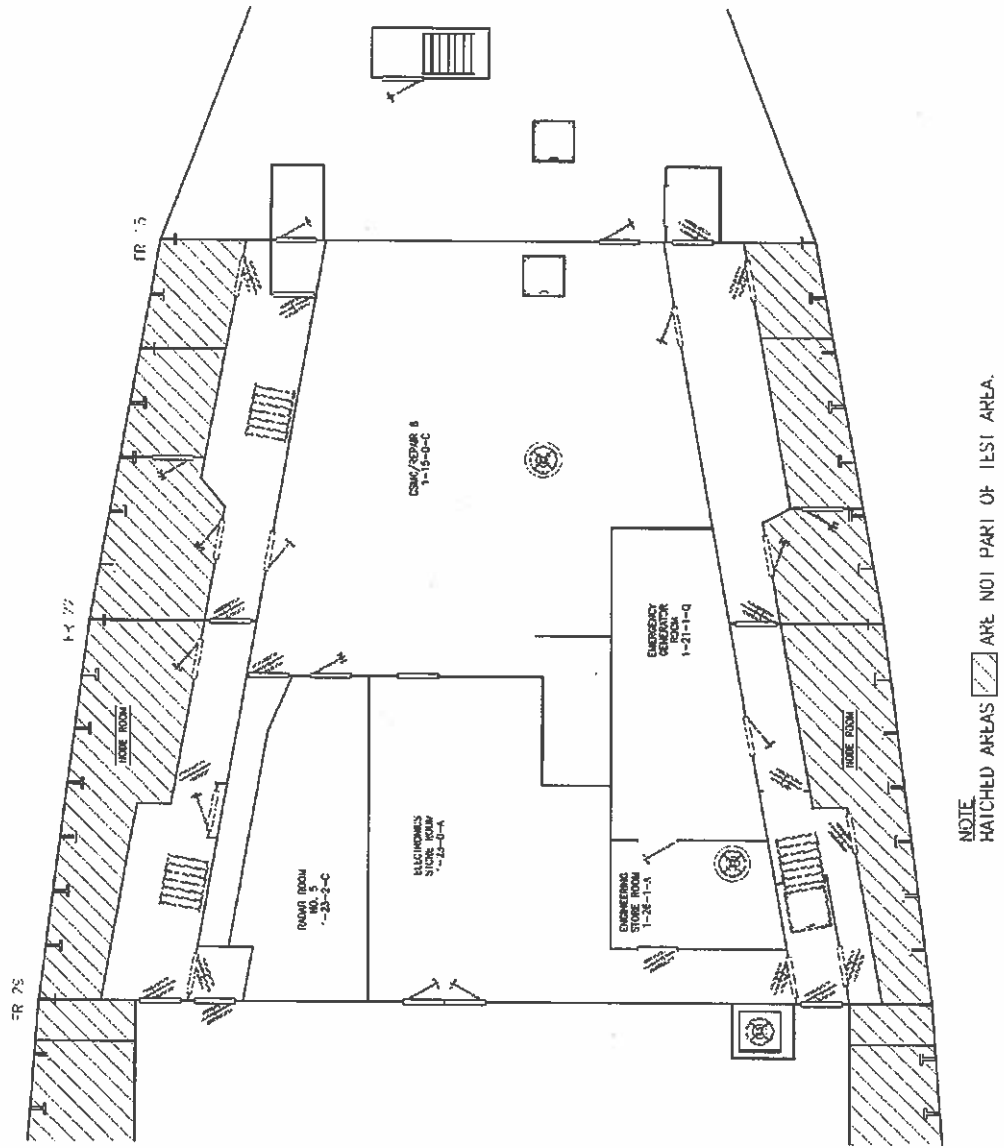
This test area was also used during the DDG-1000 Engineering Development Model (EDM) testing, which was designed to evaluate the autonomous fire suppression system (AFSS) design and damage control manning requirements for DD(X) during a combat damage scenario. [6]. As with other Fleet damage control exercises conducted onboard the ex-*USS Shadwell*, the DD(X) AFSS Combat Damage EDM testing again highlighted the problems associated with DC communications and specifically noted that a DC communication system, which relies solely on “voice only” capability, will most likely continue to be problematic and impede effective DC performance.

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<sup>1</sup> The term “frame” relates to the transverse frames that are attached to the keel and extend from the keel outward around the turn of the bilge and up to the edge of the Main Deck. Frames, beyond being strength members, also help to identify location of compartments. Frames are numbered sequentially in increasing order relative to the bow of the ship. The distance between the transverse frames onboard the ex-*USS Shadwell* is generally 1.22 m (4 ft).



**Fig. 12 – Plan View of 01 Level Test Area**



**Fig. 13 – Plan View of Main Deck Test Area**

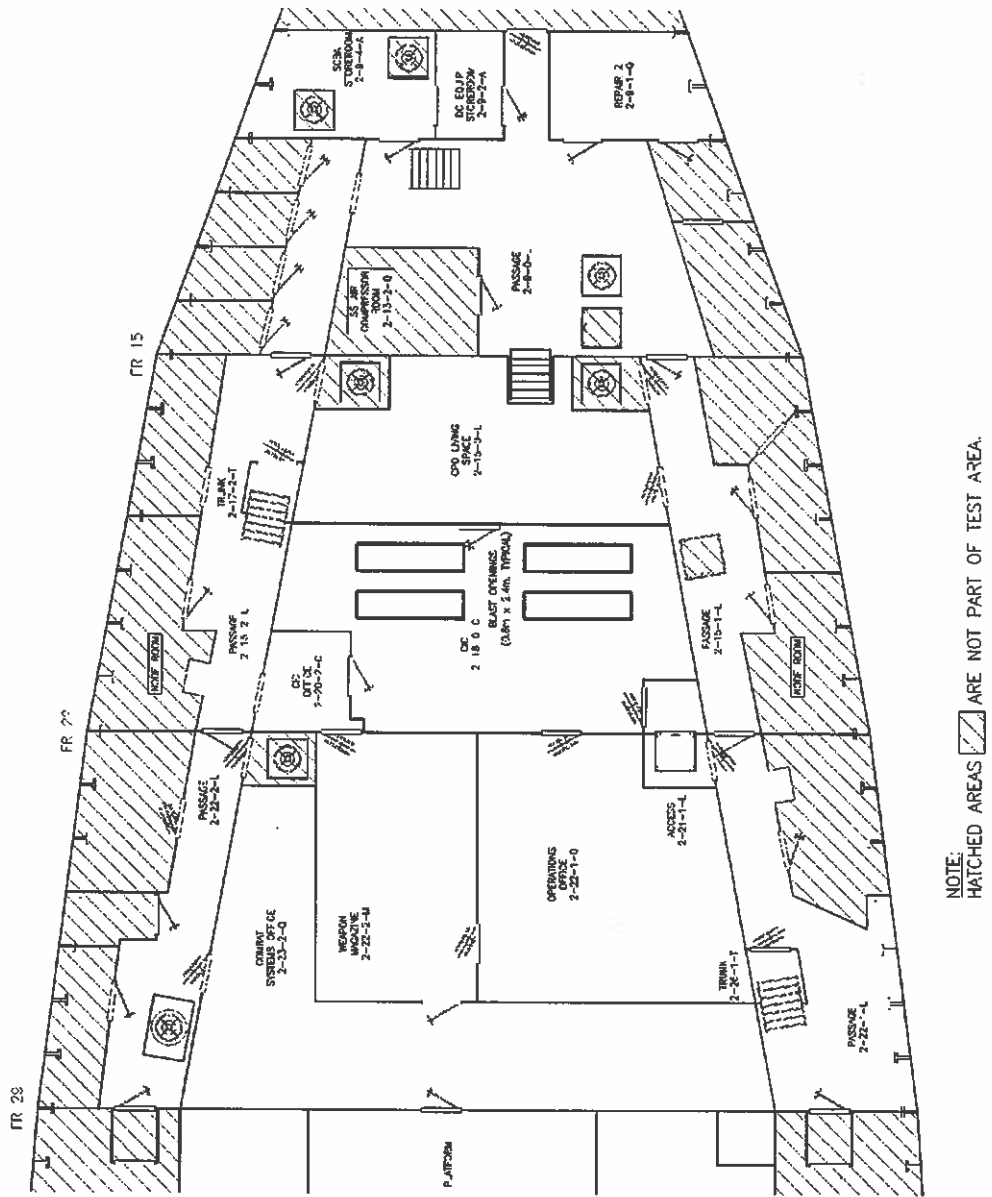
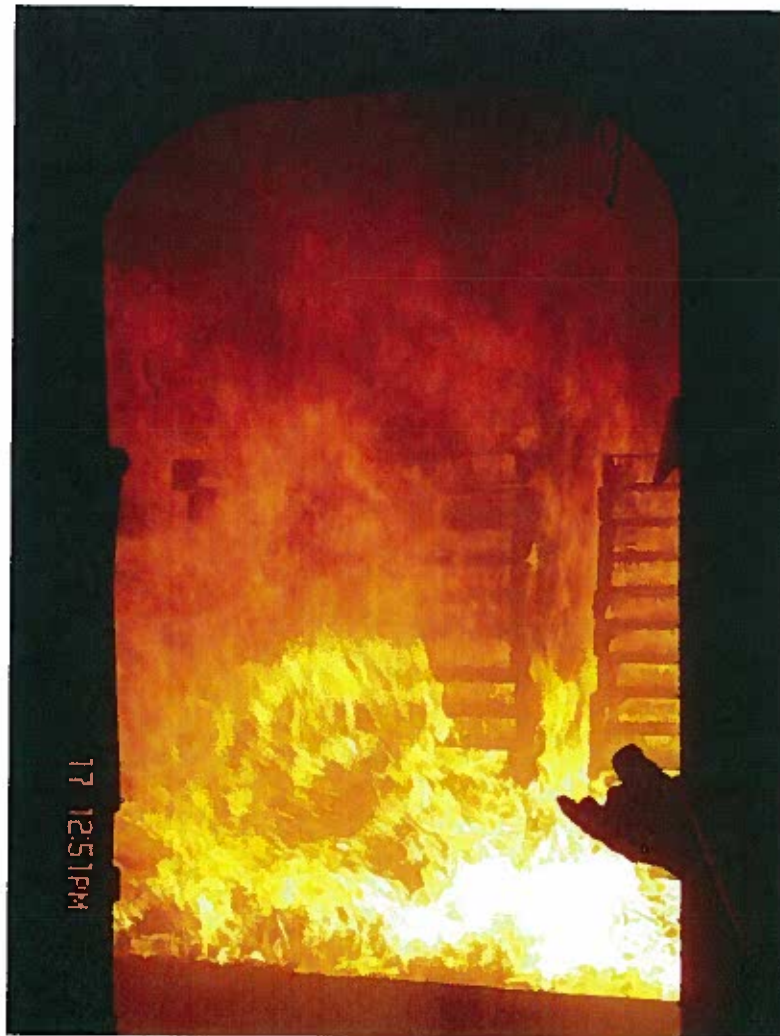


Fig. 14 – Plan View of 2<sup>nd</sup> Deck Test Area



The Communications Center, compartment 3-16-0-C (Fig. 15) was used as the primary fire compartment. The compartment had a total volume of approximately 191 m<sup>3</sup> (6,729 ft<sup>3</sup>). The fire threat consisted of a Class B (flammable liquid) 3.5 MW heptane spray fire and an adjacent Class A (flammable solid) 8 MW fire consisting of twenty-four wood pallets for a combined heat release rate of 11.5 MW. Figure 16 provides a view of the Communication Center fire threat. The Class A materials were shielded to help prevent water sprays from directly hitting the seat of the Class A fire during any indirect firefighting action. Vertical and horizontal fire spread potential was not evaluated during the Advanced DC Communication fire test evolutions.



**Fig. 16 – Communication Center (3-16-0-C) Post-Flashover 11.5 MW Fire Threat with Upper Layer Compartment Air Temperatures Approximately 740° C (1364° F)**

## **7.2 Firefighting Equipment**

The scope of the current investigation was limited to evaluating the performance of the Advanced DC communication equipment that was utilized during the real-scale shipboard casualty events. Standard Navy 3.8 cm (1.5 in) handlines were used to support both the indirect and direct firefighting attack operations. Personal protective clothing such as firefighting ensembles (FFEs), helmets, firefighting boots, gloves, anti-flash hoods and self-contained breathing apparatus (SCBAs) were used in accordance with current Fleet guidance.

## **7.3 *Shadwell* LAN**

The *Shadwell* LAN was used for collection of test data during the subject evaluation. This LAN is a blown fiber gigabit Ethernet system installed between the 02 Level Control Room (02-36-0) and all node rooms throughout the designated test zone. Data was collected over the *Shadwell* LAN for post test manipulation and was made available for real time viewing.

## **7.4 *Shadwell* WLAN**

The *Shadwell* Wireless Local Area Network (WLAN) consists of twenty-three (23) access points (AP's) deployed from frame 29 and forward on the main, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> Decks and forward of frame 50 on the 01 Level. Each AP is located in a NEMA enclosure with a gigabit switch and power strip. The distribution of the 23 AP's provides total wireless coverage of the test area. The 23 AP's have a common Ethernet backbone that transfers data to and from the wireless clients. AP's are cabled to and connected to edge switches of the gigabit Ethernet system at node rooms located throughout the test area and onto the *Shadwell* LAN, where the data are distributed throughout the ship.

## **7.5 *Shadwell* Sensors**

Instrumentation was installed in the primary fire compartment to measure the germane temperature profiles. The data was collected by the *Shadwell's* data acquisition system for post test review.

### **7.5.1 Thermocouples**

Type-K thermocouples were used to monitor air and fire temperatures in the fire test compartment. One thermocouple tree was located in the fire compartment to measure compartment air temperatures. The tree was located at approximately center of the compartment and consisted of two thermocouples located at 1.1 m (3.5 ft) and 2.4 m (8 ft) above the deck. Additional thermocouples were also assigned to the combined Class A and Class B fire locations to monitor progression of the fire. The thermocouples were suspended above the fuel source at approximately 0.3 m (1 ft) above the seat of the fire.

## 7.5.2 Data Collection

Data from the installed instrumentation was routed through node rooms on the 2<sup>nd</sup> and 3<sup>rd</sup> Deck and then transmitted across the *Shadwell* LAN to a data acquisition system in *Shadwell* Control Room. The data was displayed in real time to enable the Control Room fire test team to monitor the progression of the fire and the DC communication evolutions. Following completion of each test, the data was stored on portable media for post test analysis and reduction.

## 8.0 TEST RESULTS

The CoCo Node was the network routing element that enabled the creation of the damage control MANET system during the Advanced DC Communication real-scale exercises. It ran on all laptop computers, routers, gateways and hand-held personal digital assistants (PDAs). The CoCo Communicator and DC Comms application software ran on all handheld PDAs. The CoCo Communicator and DC DataLink application were installed on the laptop computers located at Repair 2 and DC Central. AC-powered routers (CoCo IMRs) were used to establish a wireless mesh network from Repair 2 to DC Central via the ships wired Ethernet network and to provide a wireless interface for selected ex-*Shadwell* fixed cameras and thermal imagers. Four battery-powered TMRs were used to expand and maintain the wireless mesh network where neither AC power nor wired Ethernet was available due to simulated shipboard damage effects in the primary damage area. A TRG was maintained in the Repair 2 DC assembly area and was used to provide interoperability between the shipboard Wire-Free Communications WIFCOM “walkie-talkie” voice radios and the CoCo enabled VoIP network incorporating laptop and PDA users.

During the FY09 Advanced DC Communication exercises the Repair Party Officer, Attack Team 1, Attack Team 2, and the Rapid Response Investigator/Support Team Leader PDA(s) included portable video cameras with concurrent soft button and voice functionality. The laptop computer located in DC Central enabled the DC Central Watch Team to view the DC DataLink application and communicate with the various Repair Party Teams using the laptops’ built-in speaker and microphone.

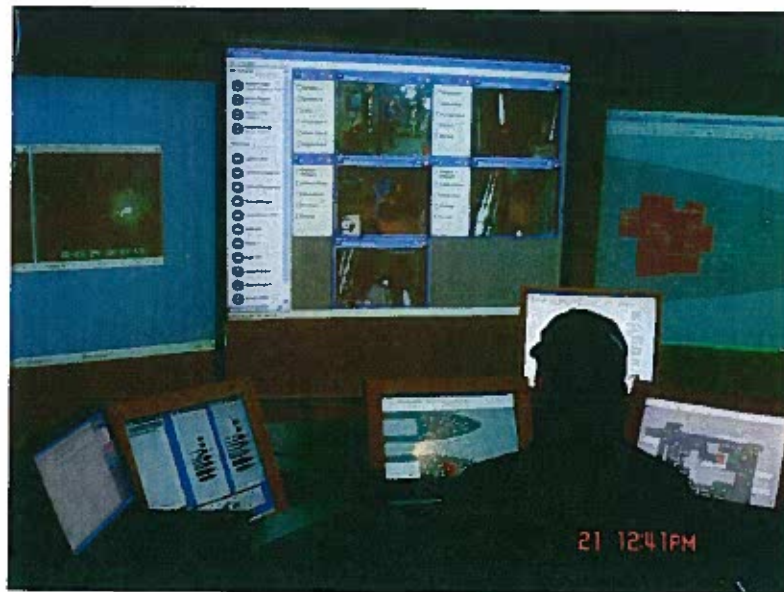
The individual PDA “DC Action” soft buttons were tailored to be mission-specific for the Repair Party Officer (RPO) and each of the Team Leader’s area of responsibility, specifically:

- Repair 2 RPO “DC Action Button” options – (set Condition I GQ, set Condition II DC, activate Smoke Ejection System (SES), dispatch Attack Team 1, dispatch Attack Team 2, dispatch Support Team)
- RRT/Support Team “DC Action Button” options – (verify damage location, conduct forcible entry, conduct initial first aid response (portable extinguisher or PEAT grenade), complete electrical and mechanical isolation, report fire out)

- Fire Attack Team “DC Action Button” options – (verify positive pressure ventilation (PPV) set, commence indirect attack, commence direct attack, complete overhaul, report fire out)

During the conduct of the Advanced DC Communication exercises, the DC Central Watch Team would make a general announcement on the ship’s 1MC based on any casualty alarm condition noted by the *ex-Shadwell’s* supervisory control system. At that time the Rapid Response Team (RRT) was dispatched to investigate and verify the alarm condition. The Damage Control Officer (DCO) would then set Condition II DC, which would man the Repair 2 (Gold) damage control organization consisting of two additional Attack Teams and a Support Team.

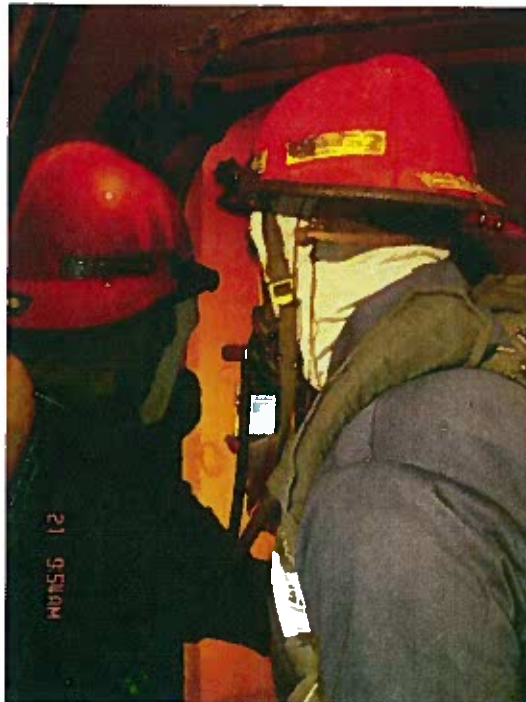
Since one objective of the FY 09 Advanced DC Communication demonstration was to verify the efficacy of the MANET system during a complex, multi-team casualty event, the fire threat was designed to represent a post-flashover fire condition that would necessitate multiple DC team interactions working concurrently. For the 3<sup>rd</sup> Deck Communication Center (compartment; 3-15-0-C) fire exercise, these requisite DC competencies included DC Central and Repair 2 command oversight, initial investigation by the RRT, an indirect fire attack from the Main Deck CSMC/Repair 8 (compartment; 1-15-0-C) via Water Tight Scuttle (WTS 1-18-0), Support Team actions to facilitate smoke control, hose handling, and forcible entry functions and a direct fire attack into the Communication Center via Quick Acting Water Tight Door (QAWTD 3-22-3). Figures 17 through 21 provide representative views for these varied DC actions.



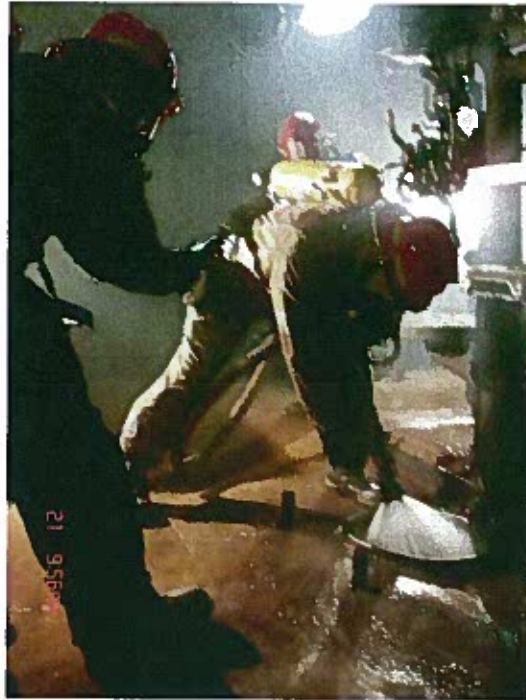
**Fig. 17 – *ex-USS Shadwell* DC Central (01-47-2-C) with DC DataLink and Supervisory Control Systems Operating**



**Fig. 18 – Repair Party Officer with PDA at the Repair 2 (2-9-0-L) DC Assembly Area**



**Fig. 19 – Rapid Response DC Investigation with PDA at the Communication Center Entrance Door (QAWTD 3-22-3)**

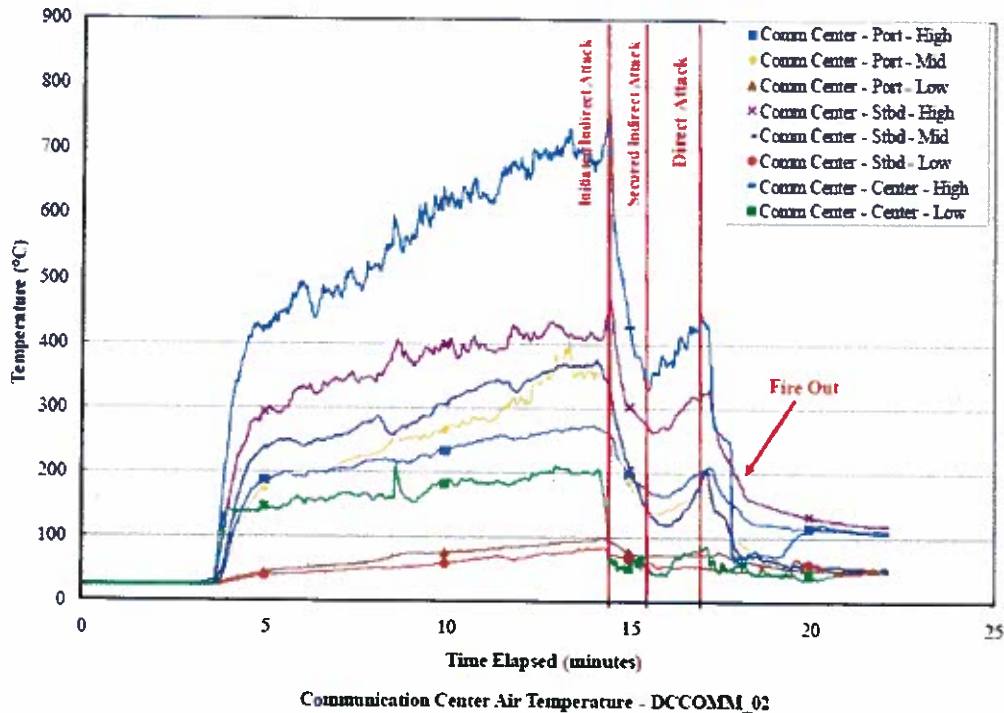


**Fig. 20 – Attack Team 1, Indirect Fire Attack with PDA via the CSMC/Repair 8 Flush Deck Scuttle (WTS 1-18-0)**



**Fig. 21 – Attack Team 2, Direct Fire Attack with PDA from the Communication Center Entrance Door (QAWTD 3-22-3)**

Figure 22 provides a representative time-temperature curve profile for the Advanced DC Communication fire attack evolutions.



**Fig. 22 – Time-Temperature Curve Profile for the Communication Center Fire Attack**

The Advanced DC Communication’s DC Comms and DC DataLink software applications utilizing the CoCo MANET system performed as designed, enabling robust, secure and mobile voice, data and video communications to all participants throughout the damage control exercises conducted. This was the first multi-team test series conducted onboard the Navy’s fire test ship, ex-*USS Shadwell* where DC communications capability was not an impediment to overall DC performance. Although voice communications were available to all DC teams during the exercises, there was consensus among all of the Fleet test participants that including data and video communication significantly simplified the DC communication process, significantly enhancing their operational efficiency with respect to DC tasks. The ability to use data and voice also noticeably improved situation awareness throughout the damage control organization and enabled all team members to focus on their requisite DC functions. It is believed that the ability to provide reliable voice, data and video imaging capability was the primary reason for the improved performance related to DC communication operations.

## 9.0 SUMMARY AND CONCLUSIONS

The result of the ONR sponsored Advanced DC Communication program is a realization of a new Damage Control capability that allows the U.S. Navy to do more with less. The demonstrated communication system improves safety and effectiveness by enhancing the ability of the DC Teams to operate efficiently in challenging environments. It also replaces cumbersome and error prone methods of reporting and tracking damage control information and allows the DC organization to focus on higher-order DC functions.

The Fleet participants found the new Advanced DC Communication technology very easy to use and particularly liked the ability to send simple mission-specific updates via the DC Comms data link application. They also believed that the additional video imaging capability from the scene significantly helped to improve situation awareness and reduced the need to transmit additional DC information updates, which are typical with the existing DC communication hardware and methodologies.

The use of the simple mission-specific “DC Action” soft-buttons were assessed to be preferable to a more tedious menu-driven type of approach or using the legacy DC potting methodologies for conveying and transmitting the requisite “controlling” and “immediate” DC actions. The DC action button software application can be easily tailored to meet any conceived DC need and can be quickly expanded to meet other DC functions such as flooding and CBR-Defense. A more in-depth menu-driven application may be found to be more suitable for conveying and transmitting any follow-on “supplemental” actions, or for soliciting more detailed information relating to compartment “Kill Cards”, system drawings, and/or equipment restoration/maintenance related procedures and documentation.

In the primary damage area where AC power and the wired Ethernet were not available, the DC teams were able to quickly reestablish the MANET system with the use of the portable battery-powered TMRs. The TMRs have three light emitting diodes (LEDs – green, yellow and red), which signify when each TMR has established and/or regained connectivity within the MANET system.

The Advanced DC Communication system technologies can transition either as a standalone backfit/forward fit outfitting item or be integrated into any fixed wireless local area network (WLAN) system. The DC DataLink application can be modified to suite any DC function and, if desired, to be integrated into exiting damage control information systems such as the DDG-1000 Damage Decision & Assessment (DDA) system.

The previously executed Damage Control – Automation for Reduced Manning (DC-ARM) program had noted that DC Communications continues to be the “Achilles’ Heel” for the damage control organization and DC performance [7]. If adopted, the demonstrated Advanced DC Communication technologies could be an important first step in helping to finally resolve this significant and on-going capability shortfall for the Warfighter.

## 10.0 ACKNOWLEDGEMENTS

The authors wish to extend their grateful appreciation for the dedication and work performed by the CoCo engineers and in particular the tireless efforts of the on-site field engineer Mr. Jamie Hughes. The authors would also like to acknowledge the superb effort and valued insight provided by Fleet participants, who included: LS1(SW) T J Leaman (NRL S&T 117), MR3 John Pirozzi (NRL S&T 117), MN1 David Lannie (NRL S&T 117), YN2 Kenneth Turner (NRL S&T 117), HM1 (FMF) John Dalton (NRL S&T 117), AD3 Labrandon Long (NRL S&T 117), MC2 (AW) Jerald Campbell (NRL S&T 117), LS2 Mark Talavera (NOSC Pensacola), AE2 James Carter (NOSC Pensacola) and PSSN Kris Adams Pre-Commissioning Unit (PCU) DDG-107.

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**APPENDIX A**

**FNC TECHNOLOGY TRANSITION  
AGREEMENT (TTA)**

**FOR**

**ADVANCED DC COMMUNICATION**

## **TTA Assessment**

- **Product:** EPE-FY07-01  
Advanced Damage  
Control  
Communications
- **Assessed by:** Unknown
- **Date of Assessment:** 2-28-08
- **TTA Assessment:** Level A

**FNC TECHNOLOGY TRANSITION AGREEMENT FOR  
ADVANCED DC COMMUNICATIONS**

This technology Transition Agreement (TTA) is between the Future Naval Capabilities (FNC) Damage Tolerance and Recoverability (EPE – FY07-01) Program of the Office of Naval Research (ONR) and the Naval Sea Systems Command (NAVSEA) Acquisition Program for DDG 1000, PMS 500. The following briefly describes the respective program and mutually commits each organization as set forth herein. This agreement shall be reviewed annually, with both S&T management and program office management representatives participating.

**1.0 DESCRIPTION OF TECHNOLOGY OR CAPABILITY TO BE DELIVERED**

DDG 1000 specification contains a requirement that a backup communication capability be provided to support damage control, and ship control as a minimum in the event ICOMM or TSCEI is not operational due to a weapon hit. A traditional sound powered phone (SPP) system has been specified to satisfy this requirement for a limited number of spaces (SMC, Secondary SMC, Bridge, Engine Rooms, DC Assembly Areas and Aft Steering) but it will not provide an effective damage control communication capability in the event of major damage to the ship. The Advanced DC Communications Program supports development of a portable, standalone wireless voice communication technology that will supplement the proposed SPP system and provide an effective means of communicating from the damage scene to the DC command structure in the event of loss of the ships primary communications network. The systems (TRL 4) to be demonstrated will be portable, standalone, self-healing and reconfigurable and will not interface with the ship's existing LAN or PDAs to communicate/transmit data. Key technologies to enable this capability include the following commercially available components:

1. Portable Multi-Radio Gateway (PMRG) - A watertight case that contains a radio bridge, handheld radio and a Wi-Fi access point, the PMRG establishes an on-board network.
2. Portable Edge Network Router (PENR) – A hand-portable, battery powered device that routes wireless communication across the mesh.
3. Commercially available PDAs (These PDAs would be provided with the devices above as a standalone kit.)

In a damage situation the DC organization would establish a command point, where they would set up the PMRG. Each team member would carry a PDA and 3-5 PENRs depending on team size to take with them as they investigate the damage. As the team members move through the damage areas there PDAs would alert them when they need to put down another PENR, triggered by the device recognition that it is no longer within range of other devices. SPPs or radios from a ship rendering assistance when connected to the PMRG through the radio bridge will be able to communicate with the PDAs provided in the kit on the same channel.

**This FNC will develop a procurement spec that will enable acquisition programs to procure this system without further development.**

The ability of the individual to execute two way text/voice/symbol data transmission between DCA and Team Leader while wearing personnel protective equipment (PPE) will also be evaluated.

This program will also help minimize risk by adopting an engineering development model (EDM) type approach for communication system/CONOP development by providing full-scale validation testing in a real-scale damage control shipboard environment on board the Navy's fire test ship, ex-USS *Shadwell*.

**2.0 TARGET ACQUISITION PROGRAM**

The DC communication technologies are targeted to the DDG 1000 program that will be delivered to the ship as an initial SCN outfitting item or as OPN. The estimated ROM funding for procurement is \$150K/ship.

Key PMS 500 programmatic decision points include:

1. Component Technical Review - 4Q/FY08
2. System Cost and Target System Selection - 3Q/FY09
3. Budget line/POM Programming Decision - 4Q/FY09
4. Identify target DDG 1000 hull - 4Q/FY09
5. Decision to install - FY10

**3.0 ACQUISITION PROGRAM TECHNOLOGY NEED**

The ORD requires that the DDG 1000 be designed to control the spread of damage and restore mission capability in a reduced manning environment.

**4.0 INTEGRATION STRATEGY**

The Advanced DC Communications technologies are targeted to the DDG 1000 program under a mission systems equipment (MSE) procurement contract, P.E. 0604300, project 32464 applies. FY08-FY11 funding are notional numbers for system and software integration. FY12 and follow-on are procurement funding numbers for PDA(s).

Funding	PE Number	FY07	FY08	FY09	FY10	FY11	FY12	FY13
S&T (6.3)		983	418	493				
Transition (6.46.5)	0604300 Project 32464		50	150	200	150	143	858

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7.0 TECHNICAL DETAILS AND PROGRAMMATICS

7.1 Technology – Current Status

1. Status Summary – The FY 07 effort evaluated the ability to communicate data and video across the electrical distribution system but it was determined that the impact on the existing electrical distribution would be a major cost driver in implementing this technology. It was determined that communication bridges would be required to be installed across switchboards and circuit breaker panels to ensure system integrity. These results refocused this program on identifying standalone systems which could be provided to the ships as an outfitting item.
2. Risk Analysis - Table 7.1 summarizes the technology risk areas and risk mitigation strategies for the Advanced DC Communications program.

TABLE 7.1 RISK SUMMARIES FOR ADVANCED DC COMMUNICATIONS

RISK AREA	RANK	TECHNICAL ISSUES	MITIGATION PLANS
Interference/band width limitations of WLAN VoIP upon loss of ships power	Med	Shipboard/damage event interference and "fading" issues related to WLAN transmissions	Evaluate coverage capabilities within the confines of the ship during damage control events and quantify results for optimization

8.0 TECHNOLOGY DEVELOPMENT STRATEGY

The technical approach for the Advanced DC Communications program will be to develop final prototype technology designs (hardware/software) and integrate the technologies into a redundant, damage tolerant system topology and conduct full-scale testing on board the Navy's fire test ship ex-USS *Shadwell*.

9.0 EXIT CRITERIA

Table 9.1 identifies the exit criteria for the Advanced DC Communications program. The progression of TRL from 4 to 6 will be tied to program milestones and exit criteria as shown below:

TABLE 9.1 EXIT CRITERIA FOR ADVANCED DC COMMUNICATIONS PROGRAM

DATE	MILESTONE	TRL	GOAL	EXIT CRITERIA
Q4 FY08	Complete component level testing	4	Down select technologies and system	Voice messaging should receive Mean Opinion Score (MOS) <sup>1</sup>

			interfaces and validate metrics for performance	> 4 and Perceptual Evaluation of Speech Quality (PESQ) <sup>2</sup> >3, all text and video image transmitted in entirety < 5 seconds
Q4 FY08	Complete COCO Communications software evaluation	4	Validate ability of software engine to interface with existing SPP system and various handheld radios	Conduct full-scale demonstration to validate seamless operation between SPP and other handheld radios
Q3 FY09	Complete system level integration testing	5	Validate system performance in a realistic shipboard damage environment	Complete CONOPS development
Q4 FY09	Complete system performance installation guidelines	6	Complete ship design documentation	Complete SHIPMAIN requirements
Notes: <ol style="list-style-type: none"> <li>1. MOS is an international standard (ITU-T-P.830) for subjective measurement of voice quality</li> <li>2. PESQ is an enhanced perceptual quality measurement for voice quality in telecommunications. PESQ was specifically developed to be applicable to end-to-end voice quality testing under real network conditions, like VoIP.</li> </ol>				

**10.0 PROGRAM PLAN / MANAGEMENT**

The Advanced DC Communication system will be integrated and demonstrated on the Navy' fire test ship, ex-USS *Shadwell*. Table 10.1 provides a POA&M for program execution. It should be noted that this program commenced in FY 07 and will complete in FY 09.

**TABLE 10.1 ADVANCED DC COMMUNICATIONS POA&M**

TASK NUMBER	TASK DESCRIPTION	LEAD ORGANIZATION	SUPPORTING ORGANIZATION	START-COMplete	BUDGET
1	Characterize PDA functional/performance requirements	TAI	NRL/MTS	Month 1-3	\$40K

2	Define Shadwell communications upgrade requirements	NRL	MTS	Month 1-3	\$300K
3	Define/document the performance requirements for the DC Backup system	MTS/TAI	NRL	Month 3-6	\$42K
4	Component hardening and validate "mobile" AP capability	MTS	NRL/TAI	Month 1-9	\$350K
5	Define backup communication functions & test	MTS/TAI	NRL	Month 2-9	\$225K
6	Define software engine to interface with existing communications systems	COCO	NRL/MTS/TAI	Month 10-19	\$418K
7	Design validation testing	NRL	MTS/TAI	Month 25-31	\$398K
8	System Implementation/transition plan	TAI	NRL	Month 25-31	\$75K
9	Briefs/Approvals	NRL	CSC/LM/SPAWAR	Month 1-31	\$20K
10	Develop Procurement Specification	TAI	NRL	Month 25-31	\$50K
	<b>Total Project</b>	--	--	<b>31 Months</b>	<b>\$1,918K</b>


#### 11.0 TRANSITION ROADMAP


To facilitate transition to the DDG 1000 program, the Advanced DC Communications program will install a communication network in the DD(X) AFSS EDM test area. This testing will be conducted in the FY07/09 time frame and will include technology concepts that are being considered by the DDG 1000 Design Agent.

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