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THESIS

**INTERNETWORKING: AIRBORNE
MINE COUNTERMEASURES
C⁴I INFORMATION SYSTEMS**

by

Steven Mitchell Graves

December 1996

Principal Advisor:

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C⁴I INFORMATION SYSTEMS**

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Submitted in partial fulfillment
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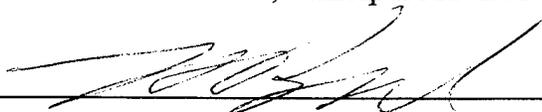


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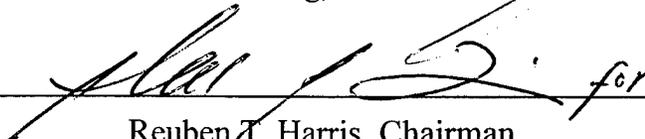
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ABSTRACT

Airborne Mine Countermeasures (AMCM) Command Control Communication Computer and Intelligence (C⁴I) baseline currently consists of stand-alone tactical decision aids. Information such as aircraft position, equipment status, and abbreviated mine-like contact reports cannot be transferred in any form other than voice from/to the MH-53E helicopters while conducting Airborne Mine Countermeasures operations. There are currently no methods to transfer sonar video or single-frame imagery of mine-like objects between any Mine Warfare (MIW) units in a near-real-time manner. Delays lasting several hours are frequently encountered before the results of a "rapid reconnaissance" airborne minehunting mission are made available to the rest of the fleet and/or MIW community. In order to improve command and control, the AMCM Mine Warfare community must integrate all of its C⁴I assets onto a tactical internet.

This thesis presents a tactical internet for AMCM with an open, standards-based modular architecture. It is based on the TCP/IP network model using common protocols and interfaces. Command and control will significantly improve as this network will provide a methodology to transfer critical information between AMCM C⁴I assets and tactical networks world-wide. Results from a comprehensive laboratory prototype demonstration using commercial off-the-shelf (COTS) equipment are presented along with lessons learned. Laboratory results show that this system works and can be deployed for testing at sea.

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I. INTRODUCTION

A. OVERVIEW

The Helicopter Mine Countermeasures Squadron (HM) Commander currently has no method to automatically monitor airborne mine countermeasures (AMCM) mission performance, track aircraft position, or to relay time-critical information between the AMCM MH-53E helicopter assets and the HM Squadron's Mobile Operations Center (MOC). Often there is a two-to-four hour delay before any information from post-mission analysis (PMA) is forwarded from the HM Squadron's MOC to the MCM Commander via standardized message formats. This delay is tactically unacceptable as it undermines the basic premise of using AMCM assets for rapid reconnaissance in that it is not rapid.

As a result of this lack of capability, operational command and control is not optimized and rests on voice communications for data transfer. Non-development-item (NDI) and commercial-off-the-shelf (COTS) equipment and software is available today which, when coupled in a coherent architecture with existing MH-53E AMCM systems, can:

- Automatically monitor mission performance
- Provide flight following and track AMCM asset positions
- Be used to report mine-like contact locations
- Process real-time full-motion sonar video, and
- Provide near-real time single frame sonar imagery.

This system provides near-real time mission analysis, improves command and control, and the enhances the overall effectiveness of the AMCM assets. Thus a great improvement in MH-53E AMCM capabilities is technically feasible.

B. PURPOSE OF RESEARCH

The purpose of this thesis is to identify an AMCM C⁴I Information System architecture which will provide complete connectivity between all airborne and ship and/or shore based AMCM C⁴I assets. This system will lay an interoperability foundation - both within the MIW community, and externally, with the Navy and other Joint components. High levels of availability, scalability, compatibility, and flexibility will be achieved as a result of the information system's network based architecture. The design limits risk and complexity by using open standards as common interfaces between modular system components, regardless of whether those components are development items or not, and thus provides an evolvable baseline.

This thesis will outline the technical feasibility of a internetworked Internet Protocol (IP) compatible AMCM C⁴I Information System using commercial-off-the-shelf (COTS) and non-development item (NDI) equipment available today. This thesis also reports initial proof-of-concept testing over radio frequency (RF) environments. Numerous configuration options are available as the individual components within the system can be interchanged easily within the modular architecture. The AMCM C⁴I Information System outlined in this thesis is capable of automatically monitoring the performance of AMCM assets, transferring mine-like object position information, and providing real-time sonar video and mine-like object imagery from Navy MH-53E helicopters to the MOC in ranges up to and including over-the-horizon. The system will enable real-time computer-aided mine-like object detection and eliminate unnecessary delays in processing critical

time-sensitive information. This system also provides avenues for further addition of automatic target recognition processes to the airborne sensor. In summary, the purpose of the AMCM C⁴I Information System is to provide complete connectivity between airborne and ship/shore based AMCM C⁴I assets.

C. SCOPE OF RESEARCH

This research presents the requirements, architectural design, initial integration and a proof-of-concept demonstration of an experimental prototype AMCM C⁴I Information System. A laboratory demonstration shows the conceptual as well as technical viability of the concepts presented within this paper. The initial proof-of-concept demonstration sets the stage for further testing and evaluation of the airborne operational data link design that is presented in this thesis. This thesis examines the following research questions:

1. What are the requirements of an AMCM C⁴I Information System?
2. What is the appropriate system architecture for the AMCM C⁴I Information System?
3. How can the AMCM C⁴I Information System be used effectively during AMCM operations?
4. What are some effective systems engineering tradeoffs between existing technology and operational requirements?
5. How can the AMCM C⁴I Information System be used to transfer video/imagery data?
6. How will technology currently under development impact AMCM C⁴I Information System?
7. Is it possible to demonstrate a simple working prototype?

This thesis provides answers to all of these questions.

D. LIMITATIONS

All of the equipment used for the proof-of-concept demonstration was loaned by vendors. As a result, some of the equipment is not exactly the same as the equipment which is specified for use in the final airborne configuration. Further, the lab experience shows that some equipment is mismodularized and has the wrong interfaces. Specifically, these interfaces are limited to serial connections only since the desired local-area network (LAN) interfaces were not provided. As a result, several different kinds of serial-to-LAN connections had to be used. However, the overall architecture remains consistent as both versions comply with the architectural standards described within this thesis. Additionally the sonar imagery from the sensor itself is simulated by using a VHS video cassette tape of sonar sensor data as the input data source.

Finally, the unexpected termination of orders and equipment to complete this project precluded a fully planned end-to-end demonstration test at sea using MH-53E assets. This unfortunate decision has precluded rapid testing and deployment of a working system to fleet mine-hunting helicopters that lack the connectivity needed to properly perform their assigned mission.

Round-the-clock effort was able to record the knowledge gained in this thesis in the two weeks permitted between change of orders and graduation. The author and advisors remain optimistic that these setbacks are temporary and the solutions provided in this thesis may yet be reimplemented. Fleet need for such solutions is clearly critical.

E. THESIS ORGANIZATION

The thesis is organized as follows: Chapter II defines the problem statement. Chapter III describes AMCM C⁴I Information System Architecture, which provides the big picture of the overall solution. Chapter IV presents the AMCM

Tactical Internet. Chapter V describes the common networking interfaces. Chapter VI describes the requirements perspective and outlines the systems engineering trade-offs necessary to achieve near-real time results. Chapter VII discusses the related work and the current relationship with the AMCM C⁴I Information System. Chapter VIII presents the recommendations for future work. Chapter IX presents the demonstration results. Chapter X presents the lessons learned and conclusions.

II. PROBLEM STATEMENT

A. INTRODUCTION

This chapter defines the AMCM MH-53E command and control problem and provides a baseline assessment of current AMCM C⁴I systems.

B. COMMAND AND CONTROL PROBLEM

The ability to make sound and timely decisions is the key objective of the command and control process.

The defining features of command and control problem - uncertainty and time - exert a significant influence on decision making. As knowledge about a situation increases, our ability to make an appropriate decision also increases. [Ref. 1:p. 24]

In amphibious, expeditionary, and littoral warfare operations, the mine warfare tactical picture is a critical component of the overall tactical picture. Each group commander needs an accurate and timely view of where he can and cannot safely sail. The AMCM component of the MIW forces is a critical component to this tactical picture.

Proper command and control improves a commander's situational awareness. Proper command and control enables the commander to understand a situation, select a course of action, issue directives, monitor on-going operations and effectively evaluate the results. Proper command and control also maximizes search effectiveness and minimizes the risks of mine detonation against friendly shipping.

1. MIW Community

Command and Control is significantly impaired in the MIW community due to the lack of a community-wide, fully integrated C⁴I system that is also fully interoperable with the larger group commander's C⁴I system. Communications connectivity must extend to the individual asset level for Mine Warfare (MIW) command and control to be optimized. For example, information such as asset position, status, etc. is essential to enable timely and tactically efficient deconfliction between MIW assets.

2. AMCM Community

The MIW command and control problem is aggravated by the AMCM community's lack of a cohesive, interoperable C⁴I system. AMCM surveillance "minehunting" missions have a high percentage of mission time dedicated to searching. Invariably multiple units are involved in each operation. However, the AMCM assets used in mine-hunting and the surface/EOD based assets used to disable/destroy the mine have no means to transfer information other than voice. Therefore a considerable amount of time passes between initial detection and actual notification of prosecution asset, since multiple information hand-offs are required. These hand-offs are further delayed by the time it takes to complete the mission (after spotting the contact on the sonar video), helicopter transit time from the operating area to the base, transfer of the sonar tape from the helicopter to the MOC, review of tape during post-mission analysis, drafting the message to pass the information, and finally the time it takes to transfer the message to the prosecuting asset itself.

Therefore, these delays are extensive and operationally significant since the AMCM Commander does not have an effective and efficient means to share

critical time-sensitive MIW information with MCM, SMCM, MHC, and EOD commanders.

C. BASELINE CAPABILITIES

The AMCM community's C⁴I baseline currently consists of stand-alone tactical decision aids (TDA) such as the Mission Planning System (MPS) and the Post-Mission Analysis (PMA) Workstation. Also, Mine Warfare Environmental Decision Aids Library (MEDAL), the mine warfare segment to the Joint Maritime Command Information System (JMCIS), has not yet been integrated with the MH-53E AMCM aircraft to provide position location information (PLI) or mission status information from the AMCM helicopter sensors. Information such as position, equipment status, and abbreviated mine-like contact reports currently cannot be transferred in any form other than voice to or from the airborne MCM helicopters while conducting AMCM operations. Voice transfers of data are not preferred as they are manpower intensive and error-prone in high-stress environments.

There is currently no method to transfer sonar video or single frame imagery of mine-like objects between units in a real-time manner. Figure 2.1 shows the current C⁴I communications baseline. The digital sonar data is instead converted to video and stored on magnetic digital tapes during AMCM mine-hunting operations. Sonar operators mark contacts with a joy stick by pressing a button as the contacts appear on a waterfall type display screen. The tapes are removed from the aircraft upon landing and are reviewed. The marks are reviewed and a decision is made whether the mine-like contact is valid and should be reported to the Mine Counter-measures Group, which includes the MCM Commander, the EOD divers, SMCM assets etc., or be dismissed as a non-mine-like object. This process requires several hours to complete following each mission.

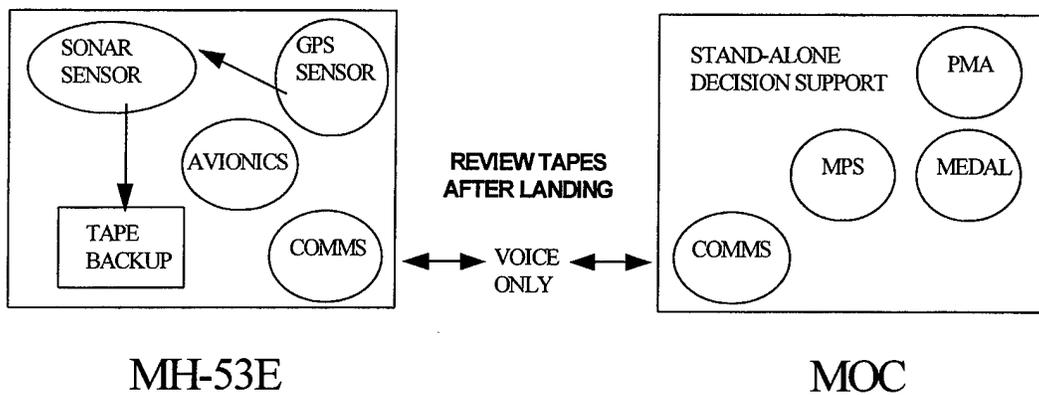


Figure 2.1. Existing Baseline for Minesweeping Helicopter Connectivity

D. BASELINE NAVAL C⁴I SYSTEM

Naval C⁴I systems are "the information systems, equipment, software, and infrastructure that enable the commander to exercise authority and direction over assigned forces." [Ref. 1:p. 24]

C⁴I systems need to facilitate information flow throughout the force, not just up and down the chain of command. They need to be designed from the ground up to be part of an architecture that can be easily integrated with other operational systems, software, and databases. C⁴I systems support the four basic functions: [Ref. 1]

- **Collecting.** The gathering and formatting of data for processing.
- **Processing.** Filtering, correlating, fusing, evaluating, and the displaying of data to provide overview of situation.
- **Distributing.** Forwarding execution or background information to appropriate locations for further analysis or use.
- **Protecting.** Safeguarding the information from attempts to exploit, destroy or corrupt it.

E. FOCUS FOR SYSTEM DESIGN

The AMCM C⁴I assets must be integrated and internetworked so that they can be effectively used together. Once assets are properly integrated onto a local-area network (LAN), with an overall goal of complete connectivity with other MCM MIW assets, then optimal C⁴I integration can be achieved. The focus must be on building a communications network that interconnects the AMCM C⁴I assets into a cohesive system, which includes both the MOC and any airborne MH-53E.

The system must use standard data element definitions so that it is widely compatible and not limited to any specific decision support system or sensor.

F. SUMMARY

The AMCM community needs to fully integrate the AMCM Helicopter Squadron's C⁴I assets. This can be realized through the development of an integrated Internetworked AMCM C⁴I Information System. A great opportunity currently exists in the AMCM community to take advantage of a clean slate in forming a real-time AMCM C⁴I Information System. Architecturally, there are virtually no legacy systems to incorporate as minimal compatibility currently exists between AMCM C⁴I programs such as MEDAL/JMCIS and other programs such as the Mission Planning System (MPS). As a result, there are no systems which require monumental reconfiguration efforts in order to achieve compatibility. Previous attempts at solving the C⁴I problems facing AMCM have always resulted in the concentration of efforts toward developing a data link to send information back from the helicopter to the MOC. Often data links are designed that are sensor/hardware specific and cannot be used with other sensors or mission systems (stovepipes). They are costly and difficult to upgrade as they are mission specific and tend to use proprietary hardware/software configurations. Inevitably, the wrong focus has yielded the wrong solution.

The Airborne Mine Countermeasures (AMCM) community needs a communications network that interconnects the AMCM C⁴I assets into a cohesive network, independent of what is to be carried over it. Once connected, data can be transported via any method and received at the other end as long as it is in a format that is compatible.

III. SYSTEMS ARCHITECTURE

A. INTRODUCTION

This chapter presents the Internetworked AMCM C⁴I Information System architectural model. It explains the design concepts of the internetworked AMCM C⁴I Information System architecture.

B. AMCM C⁴I ARCHITECTURE

The Internetworked AMCM C⁴I Information System architecture is based on a network-centric design that is inherently modular and allows the exploitation of open standards and common interfaces. By dividing the problem into two parts (the network and modular end systems) the issues can be broken down between:

1. What is the proper network?
2. What is the proper design, specification, and configuration of the modular end-systems that are to be attached to the network?

The AMCM C⁴I Information System presented in this thesis is composed of multiple mobile local-area networks (LAN) interconnected via a radio-based wide-area network (WAN). The MH-53E helicopter is first equipped with a mobile LAN designed to fit onto a removable pallet. The MOC must also be fitted with a LAN. The MH-53E and MOC LANs are then interconnected via a radio WAN. Within the modular design of the network, open standards and common interfaces will be used to ensure performance and interoperability between the component parts on each of the LANs.

1. Network-Centric

The tactical internet is obviously the central focus of a network-centric system design. The overall system is composed of sensors and processors attached to the network as shown in Figure 3.1. The network-centric approach avoids the temptation to build the system around any central component - where failure or obsolescence would require replacing the entire system. Instead, the network itself is used to eliminate bottlenecks, single points of failure, and serial connectivity.

2. Modular

The AMCM C⁴I Information System has a modular design. The system can be divided into sensors, processors and communications modules that are attached through open interfaces to the network. Modular architectures are flexible, scalable, reliable and have improved performance.

3. Common Interfaces

There are numerous ways to interconnect the end systems on a network. Interfaces are needed to physically connect end-systems to the network. Protocols are required to provide integrated services and to manage components. Data must be defined and packaged so that it may be delivered and subsequently unpackaged in a way it can be used effectively. Common interfaces are required to ensure compatibility between end systems so that the data can be wrapped, sent over the network, received,

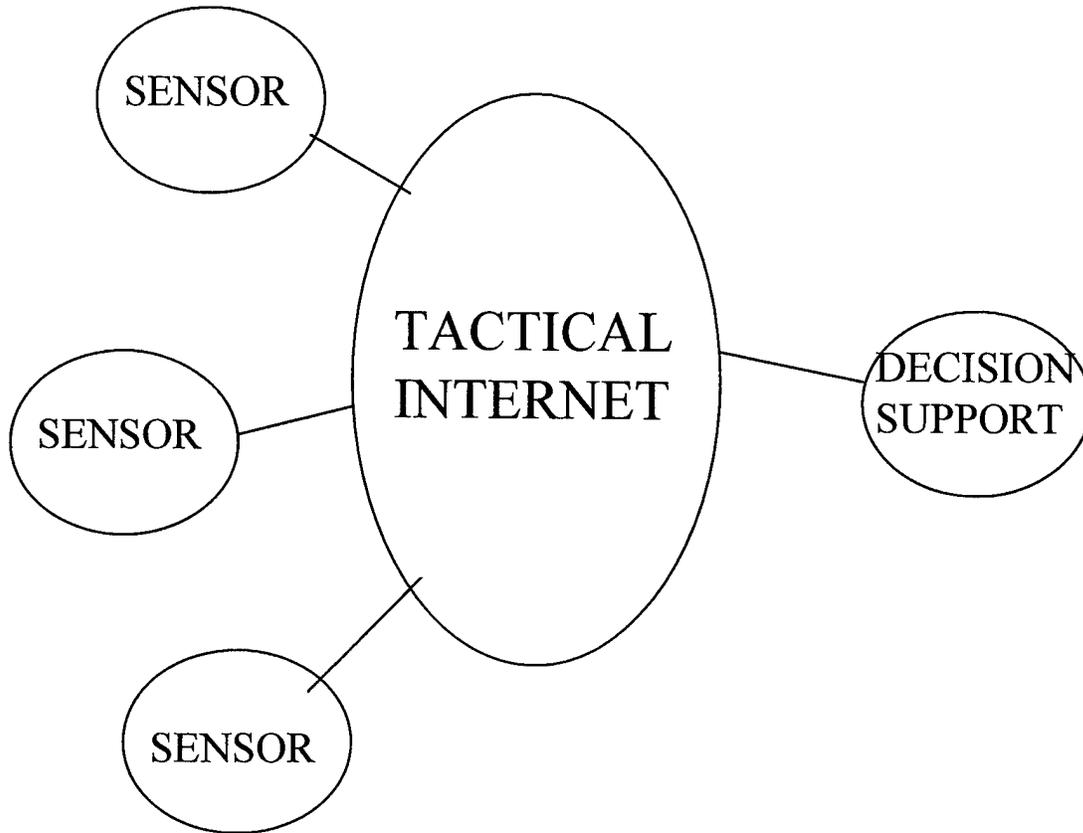


Figure 3.1. Network-Centric Approach to Multiplatform Connectivity

unwrapped and then used in a satisfactory manner over and over again, all over a tactical internet. These common interfaces are shown in Figure 3.2.

Common Interface:	Standard Type:
Common Data Definition	Data Standard
Local-Area Network (LAN) Hardware Interface	Network Standard
Transmission Control Protocol / Internet Protocol (TCP/IP)	Network Standard
Electronic Mail (E-Mail) Envelope Definition	Network Standard
Simple Network Management Protocol (SNMP) Agents.	Network Standard

Figure 3.2. Common Interfaces for Network-Centric Approach

C. OPEN STANDARDS

The AMCM C⁴I Architecture proposed in this thesis uses open standards. Open standards are publicly documented. As a result, they are nonproprietary and supported by numerous vendors. Open standards promote interoperability between products made by other vendors. Open standards also promote competition, which reduces costs and improves product quality as vendors compete among each other. Finally, open standards encourage growth as components can be readily added which are compatible with the current system regardless of the original vendor or contractual source.

D. SUMMARY

The AMCM C⁴I systems architecture has a network centric modular design that uses common interfaces and open standards. Other attempted solutions that

connect proprietary non-networked systems in serial will continue to fail. A networked approach can connect all platforms and equipment in the AMCM system.

IV. AMCM TACTICAL INTERNET

A. INTRODUCTION

A tactical network provides connectivity between the modular sensors, processors, and decision support equipment. The AMCM C⁴I Information System proposed here consists of a local-area network (LAN) in each of the MH-53E helicopters, LAN in MOC and radio-wide-area network (WAN) to interconnect MH-53E-LAN to MOC-LAN. The interconnection of these LAN groups forms an internetwork, or what is more commonly referred to as an internet. Such a localized internet is not connected to the global Internet.

B. ROUTER BASED

The AMCM Tactical Internet is a classical router-based internet as shown in Figure 4.1. The AMCM router-based network will consist mainly of point-to-point connections between the MH-53E LANs and the MOC LAN. The radio communications/cryptological equipment is attached to the network via the routers. Routers are devices that interconnect networks that are either WAN or LAN. Routers provide intercommunications between networks with multiple protocols. [Ref. 2] The router examines the network address of each packet. It checks the address against its internal tables and determines the best way to send the packet to the next router or destination network. Those packets that contain a network address different from the originating processor's address are forwarded or "routed" to that network. Routers also have network management, compression, and filtering capabilities. Routers can be used to maintain direct control of the path the packet takes from sender to receiver.

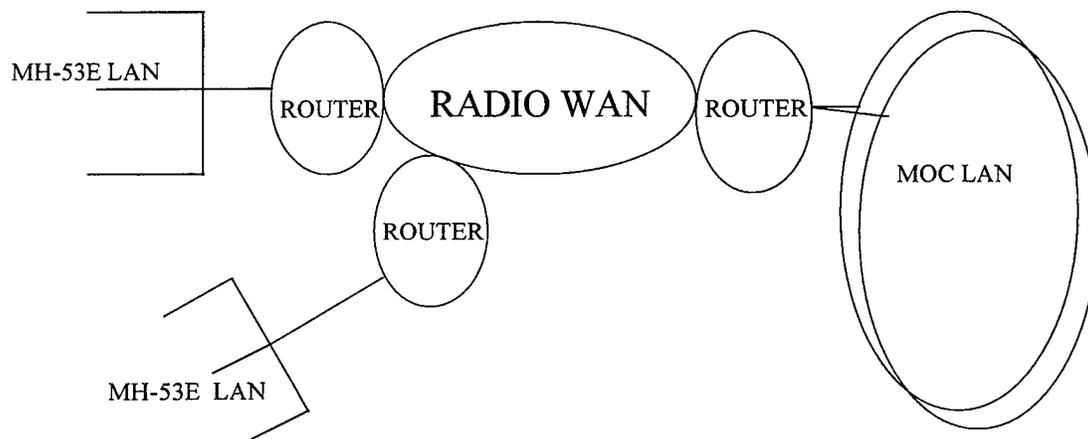


Figure 4.1. Tactical Internet Topology

C. MH-53E HELICOPTER LAN

Internally, the MH-53E helicopter LAN uses an Ethernet (IEEE802.3), which is a carrier sense multiple access/collision detection (CSMA/CD) 10Base-T network which provides 10 Mbps throughput at the physical layer. An Ethernet hub is used to interconnect the end systems and the router as shown in Figure 4.2. Scalability is inherent as numerous Ethernet hubs can be attached to each other. The MH-53E LAN components will also host a management agent software program to communicate with a central management station. The MH-53E LAN router/hub components can be mounted on a palletized rack. Therefore the LAN is portable and can be removed as required.

D. MOBILE OPERATIONS CENTER (MOC) LAN

The MOC LAN uses an Fiber Data Distributed Interchange (FDDI) backbone which provides 100 Mbps throughput. Two or more FDDI/ Ethernet hubs are attached to the backbone to provide the routers and end systems with easy access to the network as shown in Figure 4.3. To ensure the highest levels of availability, installation of a dual fiber-optic ring network, with dual-attach station (DAS) and duplicate sets of router/radio frequency communication equipment are recommended. The dual fiber counter-rotating rings allow network self-healing after cable or equipment malfunctions. DAS is the attachment of critical equipment via two independent connections to the network. Duplicate router/communication equipment is recommended to provide redundant communications paths in the event of a single system failure. The MOC LAN will also host the Network Management Station. Each of the remote LANs will have management agents that will be polled and controlled by the management station in the MOC.

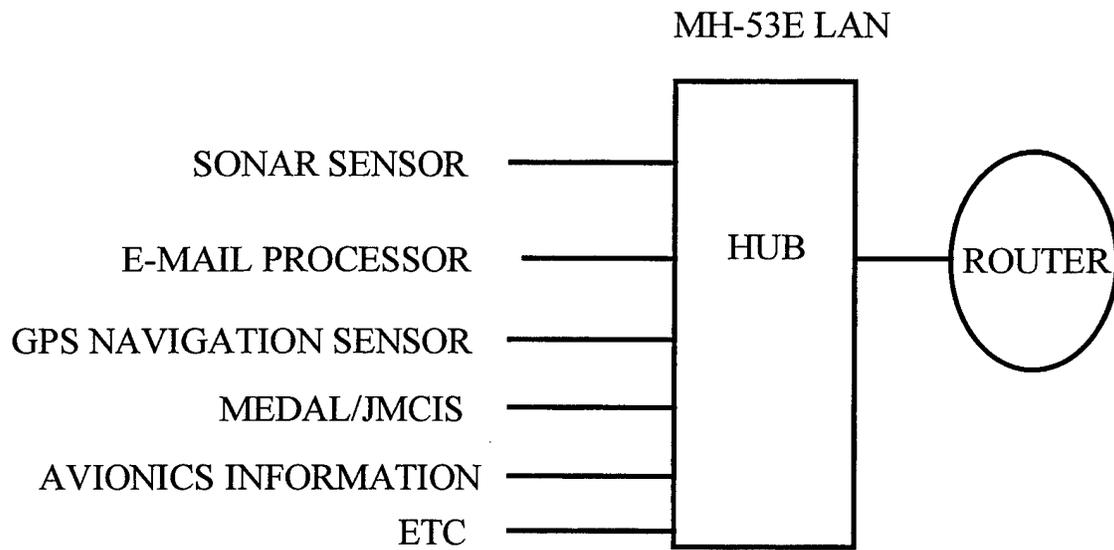


Figure 4.2. Proposed MH-53E LAN

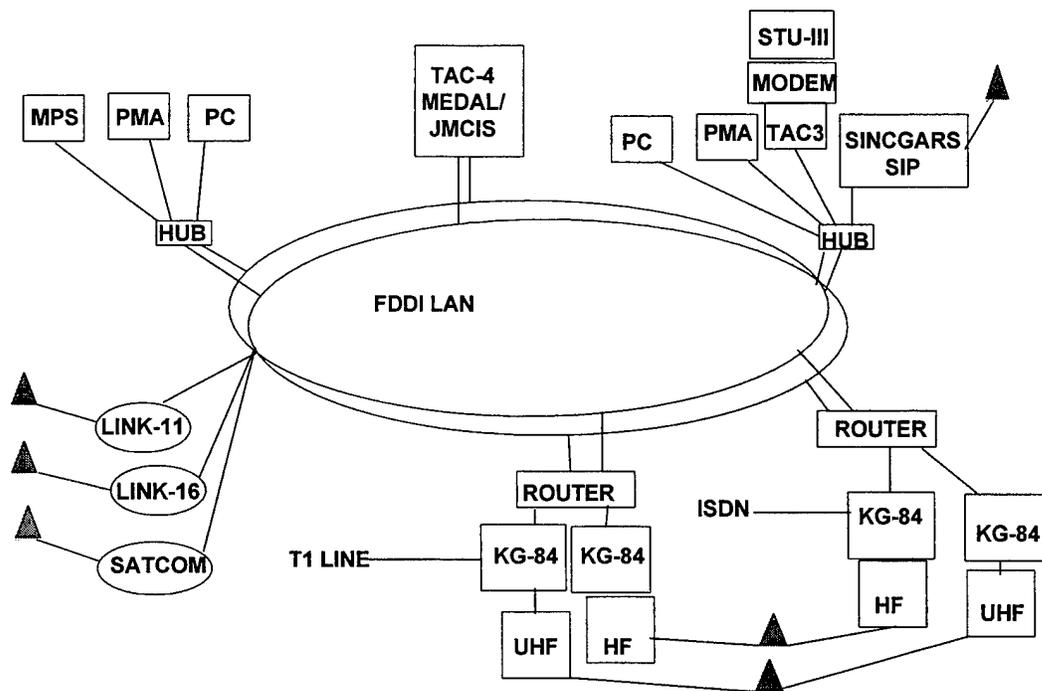


Figure 4.3. Proposed Mobile Operations Center (MOC) LAN

E. RADIO-BASED WAN

The wireless radio-based WAN environment requires different design and protocol considerations over the standard "wired" LANs internal to the MH-53E and MOC. Although network protocols do not care whether fiber, copper, or wireless physical media is used to pass information, most network protocols are specifically designed for optimal use over wired networks. To ignore the unique characteristics of wireless mobile transmissions can lead to the development of a network with terrible performance even though it is logically correct. At this time there are no widely accepted, reliable, multicast transport layer protocols that can be implemented over a wireless radio-based WAN. In order to avoid the implementation of a wireless networking catastrophe, which might have resulted from using standard cabled network design and protocols, the AMCM radio-based WAN is treated as a point-to-point transmission channel until the protocol standards for true radio-based WANs are widely implemented. This approach is reliable and well understood.

1. Interim Solution

As an interim solution, point-to-point AX.25 packet radio-based connections are used to interconnect the MH-53E LANs to the MOC LAN as shown in Figure 4.4. AX.25 is a data link layer protocol that is the *de facto* standard for amateur packet radio, used extensively over radio-based networks world-wide since the 1970's [Ref. 2]. AX.25 is the data link layer protocol used by the Naval Research and Development (NRaD) Battle Force Electronic Mail System currently being distributed throughout the navy. Throughput over radio-based networks can vary according to the bandwidth allocated to the channel. High Frequency (HF) radios with a 3KHz bandwidth commonly support 2400 bps.

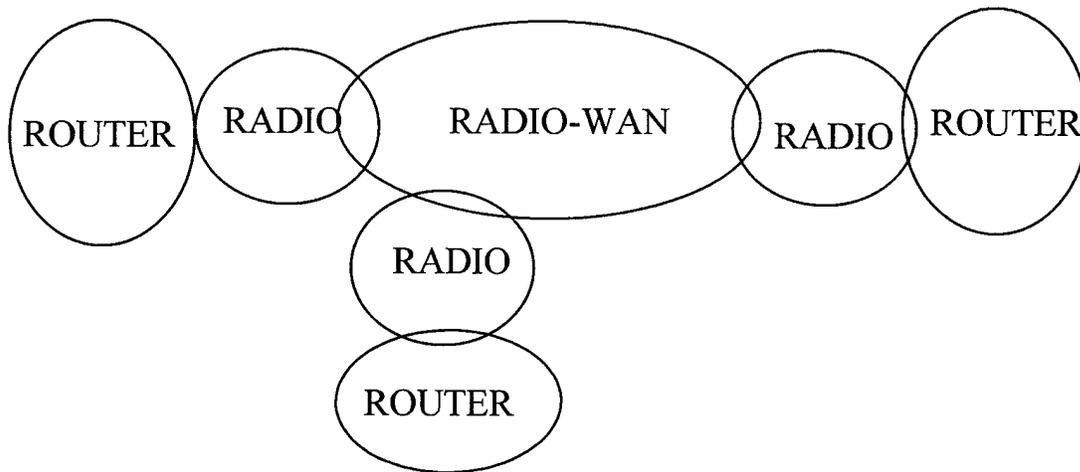


Figure 4.4. Radio-Based WAN Topology

2. Growth Path

Standard networking protocols will continue to be used internally on the wired MH-53E and MOC LANS. The transition from standard wired network to wireless networking protocols is made within the router. As a result, to upgrade to a reliable-multicast set of network/transport protocols requires minimal effort and cost as only the portions of software used to connect the routers to each other over the radio-based network will have to be changed. Multicast protocols will make the radio-WAN much more scalable and robust. To get there, the routers need multicast Internet Protocol (IP) and multicast routing protocols such as the multi-cast version of Open Shortest Path First (M-OSPF) upgrades. The key issue is that these upgrades do not affect any of the sensors in the aircraft, the decision support processors in the MOC, or the content/format of the data being passed over the radio-based WAN itself. It simply improves the performance of the WAN by providing a reliable multicast-capable network.

F. SUMMARY

The AMCM tactical Internet can be implemented today. An overview of the router based tactical internet with the modular end systems attached is shown in Figure 4.5.

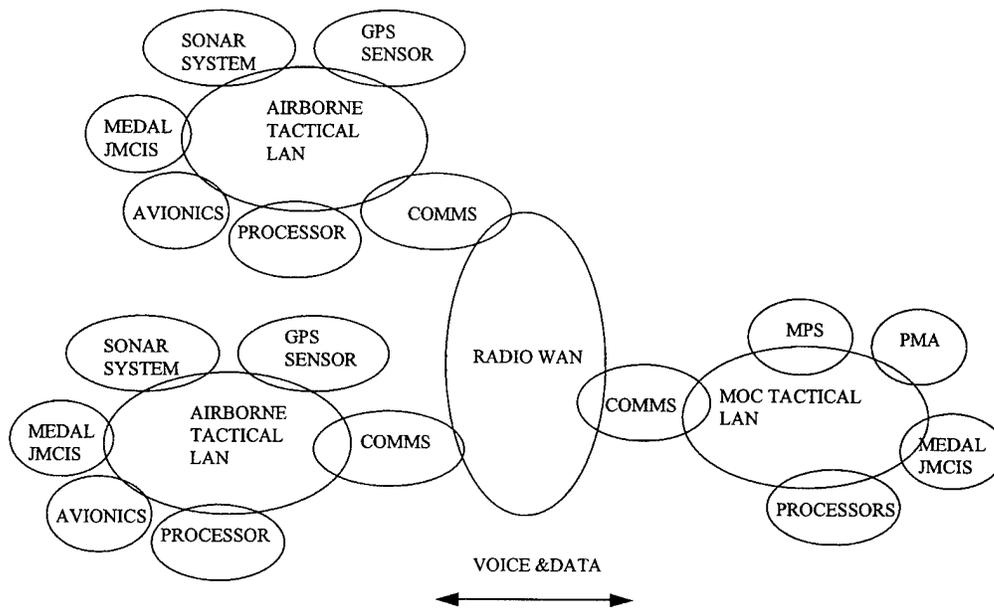


Figure 4.5. Proposed AMCM Tactical Internet

V. COMMON NETWORKING INTERFACES

A. INTRODUCTION

The Internetworked AMCM C⁴I architecture consists of five common interfaces to attach end systems to the tactical internet. These interfaces include:

- Local-Area Network (LAN) Hardware Interface
- Transmission Control Protocol / Internet Protocol (TCP/IP)
- Electronic Mail (E-Mail) Envelope Definition
- Common Data Definition
- Simple Network Management Protocol (SNMP) Agent

By using these interfaces, the AMCM C⁴I Information System will be interoperable with tactical networks world wide.

B. LAN HARDWARE INTERFACE

The local-area network (LAN) hardware interface is used to connect the modular components to the LAN. The hardware interface ought to remain consistent throughout the overall system as much as possible in each of the LAN environments in order to:

- Provide a high level of interoperability
- Reduce costs
- Provide a path to connect upgrades or additional equipment

- Leverage technology - compartmentalize the development items (such as the sonar) behind the LAN interface, so that changes to the development item will not impact the rest of the network.

The recommended MH-53E LAN hardware interface is the IEEE 802.3, 10Base-T Ethernet set of standards to reduce costs and improve interoperability. Serial connections such as RS232, RS449, RS530 between components ought to be limited and progressively eliminated as these degrade system modularity and flexibility.

A more complex LAN is required for the MOC as it will be used to communicate with the MH-53E LANs as well as the ship-based or ground-based environment where it is physically located. The MOC LAN will have a multitude of potential connections such as phone, fiber, Integrated Services Digital Network (ISDN) / Broad Band ISDN, satellite and possibly even other radio connections. Therefore, both FDDI and Ethernet hubs are recommended for use to provide common LAN hardware connections for the assorted equipment. Such hubs are commercially common and inexpensive.

C. TCP/IP

The second common interface is the Transmission Control Protocol Internet Protocol (TCP/IP) set of protocols common to the commercial Internet. IP is introduced in RFC791 [Ref. 3] and TCP is introduced in RFC793 [Ref. 4]. TCP/IP is an open, standards-based network architecture that is divided into layers and protocols.

1. TCP/IP Network Architecture

Networks are organized as a series of layers to reduce complexity. The purpose of each layer is to provide services to the layers that are above it, without the upper layer having to manage the details of how the lower layer actually

provides the services. Each layer has protocols, i.e. sets of rules that govern how the services are provided. These layers and associated protocols are "stacked" on top of each other. Each layer passes information to the layer immediately below it until the lowest layer (i.e. the physical layer) is reached. There the information is put onto a physical medium and transported over the network. The physical medium can be wireless, twisted pair, fiber, cable, etc. The TCP/IP network architecture is arranged as follows:

<u>Layer</u>	<u>Protocols</u>
Application	SMTP, MIME, SNMP
Transport	TCP
Internet	IP
Physical/data link	Ethernet (IEEE802.3), FDDI/ AX.25 ¹

2. Layers and Protocols

The Physical/data link layer provides the transfer of information from the host to the network. The Internet (internetwork) layer permits a host to inject packets into any network and have them travel independently to the destination, possibly over different networks. The packets may arrive in any order, as they will be sorted as required at the receive end. The internetwork layer defines an official packet format and protocol called IP (Internet Protocol). The job of the internetwork layer is to deliver packets where they are supposed to go across multiple networks.

¹SMTP is Simple Mail Transfer Protocol (RFC822). MIME is Multimedia Internet Mail Extensions. SNMP is Simple Network Management Protocol. 802.3 is the IEEE committee that standardizes CSMA/CD LAN protocols. FDDI is Fiber Distributed Data Interface, AX.25 is by Amateur Radio Relay League, Newington, CT.

The layer above the internetwork layer in the TCP/IP model is the Transport layer. This layer allows source and destination hosts to carry on a conversation. The Transmission Control Protocol (TCP) is a reliable connection-oriented protocol. TCP was specifically designed to provide a reliable end-to-end byte stream over an unreliable network, which means it guarantees an in-order, bit perfect data transfer from sender to receiver. The sending TCP process takes an incoming data stream and divides it into packets and passes them to the internetwork layer. The receiving computer TCP receives packets from the network layer and reassembles the packets into a data stream. TCP adds support to detect errors or lost data and to trigger retransmission until the data is correctly and completely recovered. TCP also provides flow control to ensure the packets don't arrive faster than the receiver can manage them. All TCP connections are point-to-point. TCP does not support multicasting or broadcasting. However, since TCP is the most common transport protocol, TCP provides a base which will allow an easy upgrade to a reliable multicast transport layer protocol in the future. Numerous protocols are being developed to augment TCP and are designed to be compatible with TCP's current design.

The final layer is the Application Layer. It contains the high-level protocols such as Simple Network Management Protocol (SNMP), Simple Mail Transfer Protocol (SMTP), Multipurpose Internet Mail Extensions (MIME), and Secure Multipurpose Internet Mail Extensions (S/MIME).

The TCP/IP protocol suite is the *de facto* standard of the networking world. It is robust. It dynamically adjusts routing of packets to accommodate failures in the network channels. TCP/IP allows data to pass over very large networks with little management. Other network protocols and dissimilar equipment are emphatically not recommended.

D. ELECTRONIC MAIL DEFINITION

The third common interface is the e-mail definition. Electronic mail makes it possible to easily encapsulate the desired information inside an addressable envelope and transport this information to more than one destination.

1. User Agents and Daemons

Electronic mail (e-mail) systems normally consist of two subsystems: the user agent which enables users to send and read e-mail, and the message transfer agent, which move the message from sender to receiver. The e-mail message transfer agents (e-mail daemon) are usually pre-installed on a processing platform as part of the e-mail system included with the operating system. The message transfer agents are daemons responsible for delivering mail through the system, transparent to the user. The user agents are typically local programs that act as a graphical or command based interface with an e-mail system. Automated user agents are also widely available which can assemble data into a complete message and forward the message to the e-mail daemon for delivery.

2. Envelope

The e-mail envelope contains all the information needed for transporting the message including destination address, security, and priority. The enveloping information is independent of the content of the message itself. The envelope simply encapsulates the message and provides the necessary routing information for the message transfer agents. The message inside the envelope contains the header and the body. The header provides control information for the user agent and the body contains the contents of the message itself.

3. SMTP & MIME

In 1982 the ARPANET e-mail proposals were published as RFC821 (transmission protocol) [Ref. 5] and RFC822 [Ref. 6] (message format) [Ref. 7:p. 644]. Both of these have since become the *de facto* Internet standards. Today, RFC821 is commonly known as Simple Mail Transfer Protocol (SMTP). E-mail systems

have evolved since RFC822 began as basic ASCII text e-mail. Multimedia extensions have been added to support numerous application requirements. RFC1521 [Ref. 8] presents the Multipurpose Internet Mail Extensions (MIME). MIME is based on the RFC822 format, but adds structure to the message body and defines encoding rules for non-ASCII messages such rich text, imagery, or video. Therefore, MIME messages can be sent using the existing native e-mail programs and protocols. All that must be changed are the sending and receiving user agent programs which can easily be done at the user level. MIME messages may include the following type and subtype as shown in Figure 5.1 [Ref. 7:p. 655]:

TYPE	SUBTYPE	DESCRIPTION
Text	Plain	Unformatted text
	Richtext	Text including simple formatting commands
Image	Gif	Still picture in Gif format
	JPEG	Still picture in JPEG format
Audio	Basic	Audible sound
Video	MPEG	Movie in MPEG format
Application	Octet-Stream	An uninterpreted byte sequence
	Postscript	A printable document in postscript
Message	RFC822	A MIME RFC822 standard message
	Partial	Message has been split for transmission
	External-body	Message itself must be fetched over the net
Multipart	Mixed	Independent parts in the specified order
	Alternative	Same message in different formats
	Parallel	Parts must be viewed simultaneously
	Digest	Each part complete RFC822 message

Figure 5.1. MIME E-mail Message Types and Subtypes Defined in RFC1521

Since our project goal is to maximize the number of COTS standard e-mail processes used in order to minimize the amount of custom software required, we can map all the AMCM C⁴I data needs into these generic formats. MIME protocol extensions provide RFC822 common addressable envelopes that may contain text based MCMR reports, mine-like contact positions, aircraft flight-following/ position location information (PLI), imagery and even video.

4. Message Assembly

Finally some custom software is needed to gather information from various sensors and processors located on the MH-53E LAN and send the information to the e-mail user agent for assembly inside the body of the message. This information may include a JPEG sonar image of a mine-like object, TARLOC position, aircraft PLI, time stamp etc. The software processes may be programmed to automatically trap information from various sensors/processors at a desired interval or only when tasked to do so by the user. For example, when the sonar console operator marks a mine-like contact by pressing the priority write button on the sonar console, all applicable information is then trapped and forwarded to the e-mail user agent for assembly. The user agent program receives information from the various sensors which it then encapsulates with the mine-like object video or image (binary large object) file inside the addressable e-mail envelope. The message is then constructed using any combination of the following format types shown in Figure 5.2.

TYPE	SUBTYPE	INFORMATION CONTAINED
Text	Plain	GPS: (Latitude, Longitude, Date, Time, Altitude, Heading, Navigational Error) A/C: (Identification, Heading, Skew, Mission) Sonar: (Type, Speed, Depth, Altitude) Contact: (MILC #, Type of Mine, etc.) Environmental: (Bottom Conditions, etc.)
Image	JPEG	Sonar imagery (snippet) in JPEG format
Video	MPEG	Sonar video in MPEG format
	External-body	A Video Segment/ Image/Description of this contact can be retrieved if desired.
Multipart	Mixed Text, Image, etc.	Plain Text: lat/long, time, A/C ID, MILC# Image: JPEG image of MILC

Figure 5.2. AMCM C⁴I Information System Message Structure

Other messages may be constructed as well including reports such as MCMR-12, MCMR-16, and Flight Following PLI Report by using the text type. By using the External Body subtype, large files (Video/Imagery) do not need to be transferred to all recipients. Recipients may be notified where these files are stored (i.e. in the MOC) and they may transfer these files securely from the storage site as needed as long as they have the proper access.

5. Secure E-mail

In addition to using KG-84C to provide link encryption over the radio WAN, e-mail may also be encrypted between nodes on each LAN as several alternatives can be used to provide e-mail security. If desired, e-mail over the radio-based WAN between the MH-53E user agent and the MOC user agent can also use these tools to provide data confidentiality and authenticity. There are least four competing choices of secure e-mail. These include Pretty Good Privacy (PGP), Secure Multipurpose Internet Mail Extensions (S/MIME), MIME Object

Security Services (MOSS), Message Security Protocol (MSP) designed for X.400. Fortunately, the issue is modular as only the participating e-mail user agent's are affected, none of the sensors or decision support software. Therefore any of these secure e-mail methods can be selected with little downside.

(S/MIME) was recently developed to add privacy, authentication, and tamper-proof parameters to MIME (RFC1521). Prior to S/MIME, no authentication, confidentiality, or data integrity properties were provided in SMTP, RFC822, or MIME. However, S/MIME provides secure communications between disparate or even unknown mail platforms. S/MIME is based on RSA Public Key Cryptography Standards (PKCS) [Ref. 9] and provides a digital signature and a digital envelope. A digital signature provides authentication and a digital envelope encrypts the contents of the message. This ensures message can only be read by the intended recipient. The digital envelope uses an adjustable cipher length key with an algorithm like DES or RC2. Numerous vendors have adopted this standard including Microsoft, Lotus, Netscape and Qualcomm. For example, Qualcomm's Eudora Version 3.0 E-mail program added S/MIME to the application layer. Mastercard and Visa also use the same PKCS #7 Cryptographic Message Syntax standard as well.

6. X.400

Two years after RFC821/822 was presented, X.400 appeared as CCITT recommendation, which was again modified in 1988. X.400 is based on ASN.1 encodings, not text like SMTP, RFC822, and MIME. After a decade of competition, e-mail systems based on RFC822 are widely used, whereas those based on X.400 have mostly disappeared (despite this fatal defeat, X.400 is surprisingly proposed as the e-mail standard for SPAWARs MIW C⁴ISR Systems Architecture). Numerous compatibility problems remain between 1984 X.400 and 1988

X.400 versions. The reason for RFC822's overwhelming success is that X.400 is so poorly designed and complex that it is difficult to implement well [Ref. 7:p. 646]. MIME is a direct result of the difficulty involved attempting to bring X.400 to the commercial market. In the end, it was easier to fix SMTP and develop MIME instead. X.400 message addresses also require lengthy attribute fields which are unnecessary and far more cumbersome than the normal *username@hostname.subnetwork* format on used by RFC822/MIME/ SMIME. However it is possible to send e-mail between X.400 and RFC822-based e-mail systems, though conversion between is required and most commonly done using special gateways. However such a gateway might easily be put into the MOC to access the X.400/DMS customers as required, while MIME should be used over the rest of the radio-based portion of the WAN in order to reduce address overhead.

In theory, all that can be done with MIME can also be done with X.400, but the user base and product support are not as widespread for X.400. Given the choice between a simple widespread working model and a supposedly wonderful but non-working X.400 system, most implementers chose RFC822 (including NRaD which uses Qualcomm's Eudora, a RFC822 based e-mail program for its Battle Force E-mail system). The bottom line is that an IP-based network carries IP datagrams and is not concerned whether the e-mail application is based on RFC822, MIME, S/MIME, X.400 or all of the above. However, any e-mail application must be easy to implement, or it won't be used effectively. Therefore the proposed AMCM system is based in RFC822 and MIME.

E. COMMON DATA DEFINITION

The purpose of using common data definitions is to ensure that the information can be input, read, modified, and used on multiple platforms, independent of manufacturer or operating system. It is absolutely essential that the data elements

be defined consistently throughout MIW and other communities. Standard data definitions and image formats must be used in order to interchange information over a cross-platform, community-wide, relational database. Common data definitions provide data interoperability between sensor, processor, decision support modules and the user. For example, minehunting information gathered from multiple sensors is used by the Target Location (TARLOC) program to calculate mine-like object locations. This calculation can be done by a processing module on the AMCM platform itself, by a processing module in the MOC, or by a JMCIS/MEDAL station without requiring any conversion, as long as the data is properly defined. This can only be done seamlessly if the sensor data is provided in the proper format prior to entry into the TARLOC program. The most expedient and efficient method is to put the information in the proper format at the entry-level point to the network. For example, the data elements that must be properly defined to catalog and calculate a contact's location using TARLOC includes minelike contact number (milc#), timestamp, position (latitude & longitude), altitude (alt), navigational error (e or σ), aircraft heading/skew, sonar speed/depth and cable length as shown in Figure 5.3.

milc#	time	Lat	Long	e σ	A/C hdg	A/C skew	A/C alt	sonar speed	sonar depth	cable length
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Figure 5.3. Timestamp Data Elements

These data elements, once properly defined, may be grouped into the text type category for message composition and included as an e-mail message.

Additional types of data such as imagery, audio and video may be attached and forwarded as well.

JMCIS is an example of a tactical decision aid that uses such data definitions. It uses a common operating environment with strict data definitions to ensure interoperability between segments such as MEDAL. AMCM C⁴I Information System will include JMCIS/MEDAL as a node on the network in order to achieve the tactical interoperability objectives desired. To do so seamlessly, the JMCIS data element definitions must be used as much as possible. Because the JMCIS data element definitions are used by the originating host to draft the original mine-like contact reports, the data is compatible for MIW MEDAL database entry as soon as the mine-like contact is determined to be valid without requiring data element conversion.

F. SNMP

Simple Network Management Protocol (SNMP) presented in RFC1448 [Ref. 10], provides a systematic way of monitoring and managing a computer network. The SNMP managed network model consists of four components: [Ref. 7:p. 632]

1. Managed Nodes (which contain management agents)
2. Managed Stations
3. Management Information (which runs a management platform)
4. A management protocol

These components are examined in the following sections.

1. SNMP Agent

To be directly managed by SNMP, the node must be able to run a SNMP management process called an SNMP agent. Each agent maintains a local database of variables that describe its status and affect its operation. All of these variables (objects) are maintained in the Management Information Base (MIB). The typical managed nodes include routers, bridges, hosts etc. However, any device that is capable of communicating information on its own status may also be part of a SNMP managed network. SNMP agent "kits" are available for numerous devices, including uninterruptible power supplies. Kits may also be developed for sonobouys, radio navigation receivers, modems, radios, even in sonar console processors.

2. SNMP Management Station

Network management is done from management stations which are nothing more than computers running special management software. The management stations contain processes that communicate with the agents over the network by issuing commands and eliciting responses. The complexity of this system resides in the management station. This keeps the agents as simple as possible and minimizes the workload on the device hosting the agent software. The management station is able to interact with the agents using the SNMP protocol. By using SNMP protocol, the management station is able to query the agent and if authorized, change the variables that describe the state of the agent. Normally the management station sends a request to the agent asking for information or commanding it to update its state. The agent usually replies with the information or confirms that its state has been changed as requested. Errors can also be reported if a incorrect variable is used. Seven different message types can be sent using SNMP. Six are from the initiator and the seventh is the response message from the agent as shown in Figure 5.4 below: [Ref. 7:p. 643]

MESSAGE	DESCRIPTION
Get-request	Requests the value of one or more variables
Get-next-request	Requests the variable following this one
Get-bulk-request	Fetches a large table
Set-request	Updates one or more variables
Inform-request	Agent-to-manager message describing local MIB
SnmpV2-trap	Agent-to-manager trap report
Response message	Response to request message

Figure 5.4. SNMP Message Types

Assets on a SNMP managed networks can be monitored and remotely managed from a central location.

G. SUMMARY

Common interfaces are critical to the success of the any information system. The commonly defined data elements allow data to be read and used on different TDA's, databases, processors etc. without requiring conversion or manual reentry. The LAN hardware interfaces ensure compatibility and flexibility between the modular components. The Envelope Definition defines the wrapper, whose contents may be in text, imagery or even video segments. TCP/IP and SNMP Protocols are used to manage the network and provide compatibility to access information over networks worldwide. The AMCM C⁴I Information System architecture can accommodate any sensor or decision support computer that subscribes to these interfaces, i.e. any system that has built-in or added Internet compatibility.

VI. REQUIREMENTS PERSPECTIVE

A. INTRODUCTION

This chapter presents the overall mission requirements and the tradeoffs involved in achieving these requirements.

B. OVERVIEW

Given many requirements, it is important to keep the larger goal in mind at all times and to translate local actions into global results. However, it is also imperative to realize that there is no single larger picture. There are numerous larger pictures to consider, each larger than the predecessor. For example, a local-area network may be formed by integrating the C⁴I assets in the Mobile Operations Center (MOC). Another local-area network (temporarily palletized) can be formed by integrating the C⁴I assets on board the AMCM helicopter. Finally, integration of various communications and cryptographic equipment into each of these LAN's to form a radio-based wide-area network that passes data between the mobile MH-53E LAN and the mobile operations center (MOC) LAN forms an even wider information system. Finally, the system may be further expanded as additional MH-53E mobile LAN's and shore-based LAN's are added to the overall system. The picture will continually evolve and grow in scope. However, to ensure that the system is not limited beyond the immediate mental focus of the designer, the system must be designed from the most basic level to use open standards and an open architecture so that it is scalable and flexible at all levels, now and in the future.

C. SOLVING THE RIGHT PROBLEM

Part of the system design problem is the fact that system will be constantly upgraded in ways that no single individual can foresee in any detail. Thus the rule:

"Part of systems engineering design is to prepare for changes so that they can be gracefully made and still not degrade the other parts" [Ref. 11:p. 5]

Unfortunately, many solutions are often offered that can solve the wrong problem correctly. Systems Engineering involves solving the right problem. This thesis has established that the proper focus is on the data, not the data link. The solution to the problem is based therefore on determining what data flows are required between each LAN.

D. STATED REQUIREMENTS

The MIW C⁴I Requirements Document states that "as a minimum, a data link will provide the following:

- a. MCM asset position
- b. Parameters to compute trailback and offset of MCM gear.
- c. MCM equipment settings/performance data, when sweeping.
- d. Sensor video and/or digital sonar image data, when hunting (primarily for unmanned systems)" [Ref. 12:p. 2]

Sensor video and /or digital sonar image data is also listed as a periodic or as- needed transmission under the MIW C⁴I Requirements Document. Video is not stated as a clear requirement. The wording of the statement,"video and/or digital sonar image data," implies that imagery is an acceptable substitute for video.

PMS-210, (the AMCM Program Executive Office), has stated that the priorities for the system are as follows:

1. Real-time aircraft position/location information (PLI),
2. Near-real time sonar data,
3. Over-the-horizon range is desired.

"Sonar data" includes mine-like contact position information and imagery of mine-like objects or video if possible.

E. TACTICAL OBJECTIVES

Before examining the differences between video and sonar imagery, we shall reconsider the purpose of the AMCM squadron. In many cases AMCM acts in the role of precursor sweeping and fast reconnaissance. The sonars employed by the AMCM assets are for search and not classification. Therefore, the purpose AMCM mine-hunting missions is not to analyze a mine-like object in an attempt to identify mine-type. Rather AMCM mine-hunting missions are tasked to provide a quick surveillance of the area to confirm the presence and location (if possible) of mine-like objects. If mine-like objects are discovered, other assets may be employed in order to destroy or neutralize them. AMCM may also be redeployed to revisit the area with equipment specifically designed to:

- Cut the cable of a moored mine
- Use acoustic/magnetic influence devices to actuate an influence mine

The primary information that must be passed is an indication of whether or not mine-like objects are present and, if present, the location of these objects. Armed with this information the Commander can proceed to the next step: avoidance, destruction, or neutralization.

F. REAL REQUIREMENT

The real requirement is to deliver a sufficient amount of "critical information" in near-real time latency period (measured in tens of seconds) in order to provide a near-real time mine avoidance capability to the fleet. The system should not care not care whether the data format is text, video or single frame imagery, but only that the critical information is delivered in near-real time in a usable form to all levels where the necessary decisions must be made. In order to achieve this required objective, "critical information" must be explicitly defined and efforts must be made to minimize the amount of time that it takes to process, analyze and act upon this information.

1. Critical Information

Critical information consists of information that is crucial to success.

Information crucial to success in AMCM includes the following:

- a. Mine-like object position information. Crucial for prosecution by surface MCM and EOD assets and for avoidance of mine danger areas by shipping.
- b. AMCM and surface based MCM identification and asset positions. Crucial for deconfliction and safety of flight.

Essentially, either mine-like objects are confirmed in the operating area or are failed to be confirmed as they may not be detected or actuated due to variety of reasons including malfunctioning equipment, burial, navigation errors, etc. However, once detected, an accurate mine-like object position report must be made available as soon as possible.

2. Near-Real Time Transfer of Information

The only way to have a near-real time mine-avoidance capability is to have the information that makes mine-avoidance possible available in near-real time.

Therefore the objective is to minimize the amount of time required to process and transfer the information from the sensor to the decision maker. Numerous inter-related issues are involved in achieving this objective. These issues include, but are not limited to the following: range, throughput, processing, format, packaging, scalability, manpower, security, available technology, and cost.

These issues are discussed in following section as they are requirements that must be considered in conjunction with the near-real time capability issue.

G. ENGINEERING ISSUES

The following issues must be considered in conjunction with the near-real time capability requirement.

1. Range

Range is a crucial issue involved in the delivery of critical information to all levels where the necessary decisions must be made. If the MH-53E AMCM asset is out of range, no information will be delivered as connectivity cannot be established over the radio-based WAN. Ultra High Frequency (UHF) radios are limited to line-of-sight (LOS) communications. During AMCM operations, LOS range is typically 20 nautical miles. Unless satellite communications or High Frequency (HF) radios are used, information will not be available in near-real time in ranges beyond LOS. HF radio communications using surface waves typically provide over-the-horizon (OTH) ranges of 100 nautical miles. AMCM operations require OTH connectivity as operations are often performed in ranges beyond LOS.

2. Throughput

Throughput is a crucial issue as it directly impacts the speed in which information can be delivered over the radio-based WAN. Throughput is affected by numerous factors such as compression, modulation, bandwidth of the data channel, and the quality of the communications link itself. Typically, as any of

these factors increase, so does the data rate. Standard HF channels have a bandwidth of 3 KHz and support data rates of 2.4 Kbps (less than a typical home telephone modem). This rate may vary due to error correction, link quality, protocol performance etc., but the amount of information that HF can transfer in near-real time is extremely limited in comparison to UHF.

Standard UHF channels have a bandwidth of 25 KHz and support data rates of 16Kbps. However, UHF radios and modems are readily available that modify the standard UHF channel bandwidth to support near-real time data rates from Kbps to 2Mbps. Due to the higher throughput, UHF radio-based systems are able to support a wider range of multimedia applications such as audio, imagery and video.

Due to HF radio communications restricted throughput, HF usage should be limited to text based messages and small single frame images for supporting near-real time operations. Therefore imagery, not video, is the preferred method of transporting mine-like object images which are to be displayed, as HF communications will not support "video" throughput requirements.

3. Processing

The best way to minimize the amount of time required to process information, is to process as much as possible at the source. This reduces the amount of unprocessed information that must be transferred and processed upon arrival. Only pertinent information is transferred for further evaluation by the decision nodes. Less transfer time and/or throughput is required through bottleneck links because less data must be transferred.

There are several options available to increase the amount of processing at the source. The biggest impact would be through the use of computer-aided detection (CAD) algorithms on board the MH-53E. This will provide automated

on-site real-time sonar video processing in addition to the sonar operator's manual scanning process. The calculation of mine-like object position reports using information from the various sensors can also be processed on-board the MH-53E. This will further reduce the amount of sensor information which must be passed over the radio-based WAN.

4. Format

The critical information must be in the proper format so that the information can be directly analyzed by the decision maker. This can be accomplished in near-real time as long as:

- The information is properly defined
- The information is in a format that is usable upon delivery without requiring multiple conversions

The format of the data can be either text, imagery, audio or video depending on the ability of the communications channel to support delivery in near-real time. The format must be applicable to the path used for delivery. The critical information must be converted (i.e. from video to imagery or from imagery to text based position reports) if the channel cannot support near-real time delivery of the information in its original format.

5. Packaging

In order for the information to be available in near-real time, all relevant information must first be gathered and packaged together. Proper packaging includes the ability to contain and combine all relevant data independent of its format, i.e. video, audio, text or imagery. For example, a mine-like object's image, position, time, etc. must be contained within the same package. The

package must be addressable and secure to ensure near-real time delivery of information to decision makers.

6. Scalability

The system must be able to evolve as more assets are added to the overall network without reducing the near-real time performance capability desired. The open architecture ensures that the individual MH-53E assets are capable of performing as much of the processing efforts as possible so as not to overload the processing capabilities in the MOC. The use of open standards throughout each of the networks ensure that the system itself can easily evolve as individual components or software upgrades become available without causing cascading changes between modules.

7. Manpower

Additional manpower is not available in the MOC or MH-53E to assist in the near-real time processing or delivery of critical information. As numerous AMCM operations forward critical information to the MOC in near-real time, information overload is possible unless the data flows are minimized to contain only relevant information which is ready for use by decision makers upon arrival. No further action should be required to the critical information as such actions are potential bottlenecks to the information distribution process. Considerable life-cycle savings are possible as manning requirements may be reduced in the MOC due to automated processing and conversion of information. MH-53E helicopter manning will remain unchanged for this proposed architecture since the AMCM C⁴I Information system will run in the background with no additional manual effort required.

8. Security

Security must be transparent to the end user and not impact the speed at which information is transferred. Data rates up to 1.544 Mbps (T1 capacity) are possible using KG-84C compatible link-encryption devices over the radio-based WAN. The data should also be secure within the MOC LAN portion of the AMCM tactical network itself. This can easily be performed by using one of several secure e-mail programs available today to provide information confidentiality and authentication inside a physically secure LAN.

9. Available Technology

Commercial-off-the-shelf (COTS) and non-development-item (NDI) components are available today that support near-real time transmission of video, imagery and text over IP compatible LANs and radio-based WANs. However, modifications are required to the existing AN/AQS-14A sonar interface as the current system has no interface capable of transferring sonar video information to the MH-53E AMCM C⁴I network itself. Several interface options have been proposed by the manufacturer.

CAD can be made available for use on the aircraft if desired. An Ethernet interface card can be installed into an empty VME slot in the CAD Post-Mission Analysis (PMA) Workstation to interface with the network on the MH-53E LAN.

The PMA VME-bus-based cards would also need to be packaged for airborne use. Finally the Mission Planning Station can be attached to the MOC network simply by installing an Ethernet network interface card (NIC).

10. Cost

The marginal cost to achieve near-real time AMCM command and control is minimal, considering that most of the assets are already in place. LANs (optionally palletized) must be installed in the MOC and MH-53E helicopters.

However these systems can be built in phases as components evolve and are added to the network. Communications equipment may also be added incrementally as desired. The transmission of sonar video and the use of CAD on board the MH-53E are not stated requirements. If CAD is not used on the aircraft and video is not transferred over LOS using a UHF channel, the most significant costs in the palletizable system will be the Ethernet interface to the AN/AQS-14A and a HF radio/modem. Thus all component/software costs are minimal.

Where initial high component costs can potentially become involved is if CAD is used to process sonar video locally on the MH-53E, or if UHF equipment is used to transmit the sonar video in order for the video to be remotely processed by either manual operators or CAD in the MOC. These are options which can be added to enhance the processing of the sonar video information in near-real time.

In any case, the sonar video has always been "processed" in real time by the sonar operators on board the MH-53E. The sonar operators currently review the sonar tape in real time and "mark" mine-like contacts as they appear on the screen. The entire sonar video is also stored on magnetic tapes which may be reviewed by manual operators upon the helicopters return. With the addition of the tactical network, the system may be configured so that the operator may select mine-like contacts and forward position, imagery and even sonar video information over either a HF, UHF or even SATCOM channel; in otherwords, (because it's a true internet), over any and all of the above. For example, routers are capable of sending 3 packets of data to the HF queue, 8 packets to the UHF queue and 5 packets to the Satcom queue - all of which are part of the same e-mail message. The end system TCPs are perfectly capable of reassembling the packets back together to form the same original single e-mail message.

11. Options

Although near-real time video processing by any other method than the operator on board the helicopter is not required, the merits and deficiencies of the options available are worthy of further discussion.

There are three options available to process the sonar video in near-real time. The first option is to use CAD locally on the MH-53E. With CAD installed on the aircraft, the operational range in which information from CAD will be available is greatly improved as near-real time sonar video processing capability will no longer be limited to operations within LOS. The relevant mine-like contact information extracted from the processed video can be filtered into sizes acceptable for HF or Satcom transmissions world-wide. The only way to process the necessary information on the aircraft with the same level of "scan" as in the MOC is to embed CAD into the aircraft system. This way you still get one operator and one automated "look." This is possible as the Post-Mission Analysis Station computer-aided detection algorithm can be added to the LAN in the MH-53E by installing an Ethernet interface card in one of the empty VME slots in the PMA Station. Other options include installing the algorithm in a different processor either by using the existing VME cards or by porting the software to a separate host, such as a VME based TAC-4 processor. The sonar video tape will still be available for review upon aircraft return, or even while in transit as it is possible to send some information ahead.

The second option is to process the sonar video remotely in the MOC. To be able to process sonar video in near-real time in the MOC, additional UHF communications equipment is required on the helicopter and in the MOC, as the UHF transceiver that must be used to provide the data channel will be fully tasked and unavailable for voice communications. Therefore an existing voice radio

cannot be substituted or borrowed for the data channel communications. However use of UHF to transmit the sonar video so that CAD or manual operators located in the MOC can be used to process the sonar video in near-real time ultimately limits the real-time capability to LOS operations only. Additional problems arise when numerous mine-hunting operations are simultaneously trying to transfer sonar video information to the MOC. This requires additional hardware and personnel resources to manage the additional volume of information.

The third option is to continue doing what is being done now, with the exception that when spotted by sonar operator, the mine-like object's imagery and position location information can now be forwarded to the MOC via the tactical internet using standard HF communications equipment. As before, this option relies completely on the sonar operator on board the helicopter to manually pick out minelike image from the sonar video and send mine-like object images OTH using the HF path. CAD may still be used to process the entire sonar video tape upon return of the aircraft to the MOC. The end result of this option is that the tape will only be processed in real-time by the sonar operator, who will not be supported by CADs automatic detection algorithms.

H. SELECTION OF SONAR VIDEO PROCESSING METHOD

Of the three options, the eventual installation of CAD on board the MH-53E is the best choice for several reasons.

First it provides a consistent baseline for target detection. Operator training and experience varies widely in the fleet. This has previously led to a high level of false AN/AQS-14 contacts being reported. Over time, a lack of trust from the "marking" of too many false "mine-like" objects led to the development of standard operating procedures which required the tactics officer to review each mine-like object and approve its "quality" prior to release to the MIW community

as a mine-like contact. Policies such as these have added considerable delay to the system. A new CAD software version has recently been developed and released by the manufacturer which has a very high level of probability of detection. Therefore, CAD can be used as an onboard tool. It will assist the operator by highlighting potential targets as they appear on the sonar operator's screen. However, the operator still can have the final say on whether or not the contact is "marked."

Second, CAD on board the MH-53E provides the highest level of processing without requiring the addition of personnel or equipment to the MOC. In fact, the level of observation in the MH-53E with CAD on board may in some cases be better than in the MOC as the sonar operator in the aircraft is able to focus only on that one mission, while MOC sonar operators may be tasked with several missions simultaneously if multiple video signals are being received and if the CAD Post-Mission Analysis Workstation is already being used.

Thirdly, CAD in the aircraft helps to eliminate potential data-fusion problems due to information overload in the MOC, by eliminating the desire to send video at all. CAD in the aircraft will eventually diffuse the perceived video requirement once near-real time TARLOC position reports of mine-like objects marked and forwarded from the aircraft are shown to be accurate, without any assistance from the ground.

Fourthly, CAD in the aircraft reduces crew workload both in the aircraft and in the MOC as the data will be fully filtered and processed at the source. This can lead to less manning and considerable lifecycle savings in the MOC in both equipment and material. Although CAD doesn't directly provide longer range of operations, it helps reduce the data flows to levels which can be met by HF and UHF SATCOM throughputs. Therefore CAD processed information can be sent

over longer ranges that are only available using narrow bandwidths such as HF and SATCOM.

Finally, CAD costs may be significantly reduced as the Remote Mine-Hunting System (RMS) system contract has recently been awarded to Lockheed Martin. The RMS system will use the same AN/AQS-14A sonar (with an improved CAD system) as the AMCM community. It is possible to build the AMCM internetworked system now in the aircraft without CAD. CAD can be added later on, most likely with less cost. In the interim, the system will then be the same as that presented in option three, using only the operator to scan the sonar video. However, based on the author's experience as a squadron tactics officer, this is the best path since the real purpose of AMCM surveillance and fast reconnaissance mine-hunting missions is to provide a near-real time mine avoidance capability. The mission is to see if there are mine-like objects in the area; not to find every mine-like object in the area, and the AMCM sonar operator has consistently proven the capability to do that.

I. SUMMARY

The real requirement is to provide a near-real time mine avoidance capability to the fleet. This can effectively be done OTH by sending position mine-like object location and single frame sonar imagery information processed in near-real time on board the AMCM MH-53E assets.

VII. RELATED WORK

A. INTRODUCTION

This chapter discusses related work. Plans, publications, programs, scheduled future demonstrations, as well as results from the Gulf of Mexico Exercise '94 (GOMEX) prototype system, are presented to provide an overview of the current AMCM C⁴I situation.

B. PLANS AND PUBLICATIONS

The following publications officially address C⁴I for the Mine Warfare community:

- Mine Warfare (MIW) C⁴I Master Plan [Ref. 13:para 3.9.3]
- Mine Warfare (MIW) C⁴ISR Operational Architecture [Ref. 14]
- Mine Warfare (MIW) C⁴ISR Systems Architecture [Ref. 15]
- C⁴I Architecture Currently Supporting the Mine Warfare Community [Ref. 12:p. 2]
- MIW C⁴I Requirements Document (COMINEWARCOM, 1 June, 1995)

1. Mine Warfare (MIW) C⁴I Master Plan

The following is quoted from the Executive Summary of the MIW C⁴I Master Plan.

The MIW C⁴I Master Plan (MIWCMP) is one of a series of plans in development at the Space and Naval Warfare Systems Command (SPAWAR) designed to implement the Navy's portion of the JCS C⁴I for the Warrior concepts through the objectives and vision of

Copernicus...Forward... The bottom line is that the SPAWAR MIW C⁴I Master Plan is designed to assist CNO, SPAWAR, PEO MINEWAR, and other SYSCOMS to provide Mine Warfare with the C⁴I tools necessary to meet current and emerging challenges...

However, it must be understood throughout the MIW community that "Mine Warfare" in the SPAWAR context is principally focused on Mine Warfare Ships. AMCM requirements and systems integration aspects are presented, but they in no way drive the architecture, requirements or systems integration plans for the overall MIW community. The "MIW community" in SPAWARs MIW C⁴I Master Plan lacks integration and balance.

The SPAWAR MIWCMP is designed to document the strategies, plans and programs involving Command Control Communications Computer and Intelligence (C⁴I) capabilities for the Mine Warfare Ships currently under CNO and SPAWAR sponsorship.

This is evident as the MCS, MCM, and MHC are all strongly represented on the Systems Installation Planning Schedule, and no installations are planned between FY 97 and FY04, (the entire range of the chart) for all non-SMCM assets listed under MICFAC, MAST, EODC⁴I, SEAL C⁴I, and Airborne C⁴I in the Deployable Communications category.

The SPAWAR MIW C⁴I Master Plan is extensive and provides a great level of detail for the SMCM community. However, as it clearly states, its primary focus is on surface based MCM assets. The entire AMCM section from the MIW C⁴I Master Plan is included below:

All military aircraft are presently equipped with HF, UHF and/or VHF secure and/or non-secure voice systems. Present systems

should be used to fulfill all voice reporting requirements. No decision has been made to date on whether one of the existing Tactical Data Link circuits should be used to pass near-real time acoustical data, or if a new MIW unique system should be developed. As an interim measure a Link-11 type system (compatible with the MICFAC and MCS-12) could be deployed on the MH-53E AMCM aircraft. This interim system should be configured in such a way as to be deployed on a pallet until a permanent solution is identified.

AMCM is only specifically addressed in two other instances in the MIW C⁴I Master Plan. First, the SPAWAR MIW C⁴I Master Plan states that there is no AMCM plan.

Though a requirement exists for a Tactical Data Link to pass data from the MH-53 to the MCS, there has been no resolution as to whether one of the existing link architectures will be used, or if a new concept is to be developed for Mine Warfare.

Second, MAST is "selected" to support AMCM even though it's procurement and/or installation hasn't been planned. "MAST has been selected to provide deployable C⁴I for the AMCM commander." [Ref. 13:para 3.9.3]

2. Mine Warfare (MIW) Command Control Communication Computer and Intelligence Surveillance and Reconnaissance (C⁴ISR) Operational Architecture

The MIW C⁴ISR Operational Architecture is also part of the series of documents from Space and Naval Warfare Systems Command (SPAWAR). The MIW C⁴ISR Operational Architecture proclaims that is a

standards-based blueprint that will serve as the official source document containing the operational requirements, nodal

descriptions, operational activities (or tasks), and information exchange requirement (IER) information for MIW.

This document identifies an overall MIW operational hierarchy. It defines the scope of the C⁴I architectural problem in terms of operational command relationships, operational information exchange requirements and MIW nodal connectivity. The Mission Need Statement for Mine Warfare C⁴I System is provided in Appendix E. AMCM operational background information is provided in section 3.3.2.4. It is important to note that the Operational Information Exchange requirements listed in (Figure 7.1) C⁴ISR Operational Architecture) cannot be supported with the equipment listed for the MH-53E in MIW Node Connectivity - Communications Systems diagram as shown in Figure 7.2 C⁴ISR Systems Architecture).

3. Mine Warfare (MIW) C⁴ISR Systems Architecture

The MIW C⁴ISR Systems Architecture is also part of the series of documents from the Space and Naval Warfare Systems Command (SPAWAR). This document presents and provides the Mine Warfare MIW C⁴I Systems Architecture as a roadmap and a subset of the Naval Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C⁴ISR) Architecture which can support MIW, Joint, Allied, and Coalition forces, and support force interoperability and battlespace dominance. The MIW C⁴I Systems Architecture, when implemented will satisfy the operational activities, IERs, operational nodal connectivity identified in the MIW C⁴I Operational Architecture, and provide top-level performance boundaries. [Ref. 15]

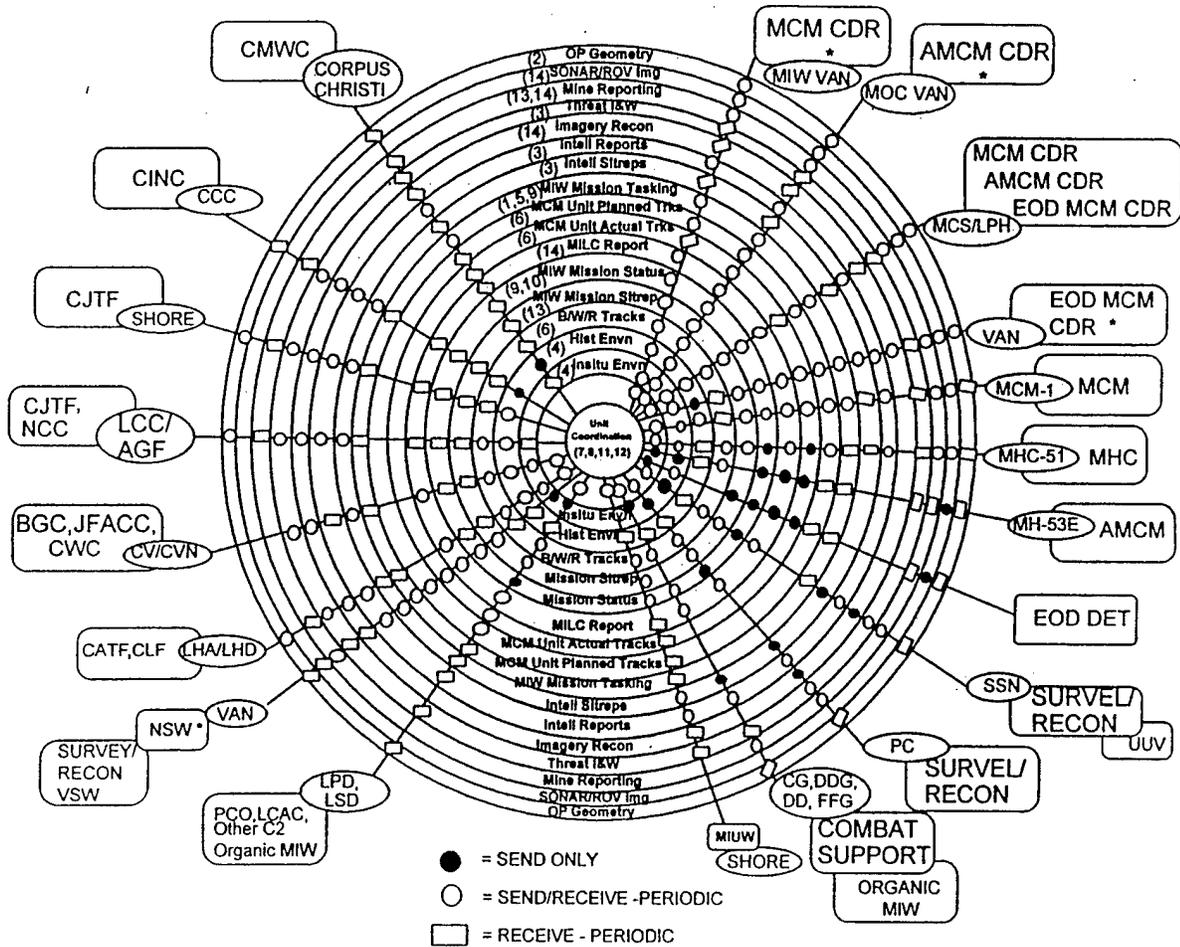


Figure 7.1. Operational Information Exchange

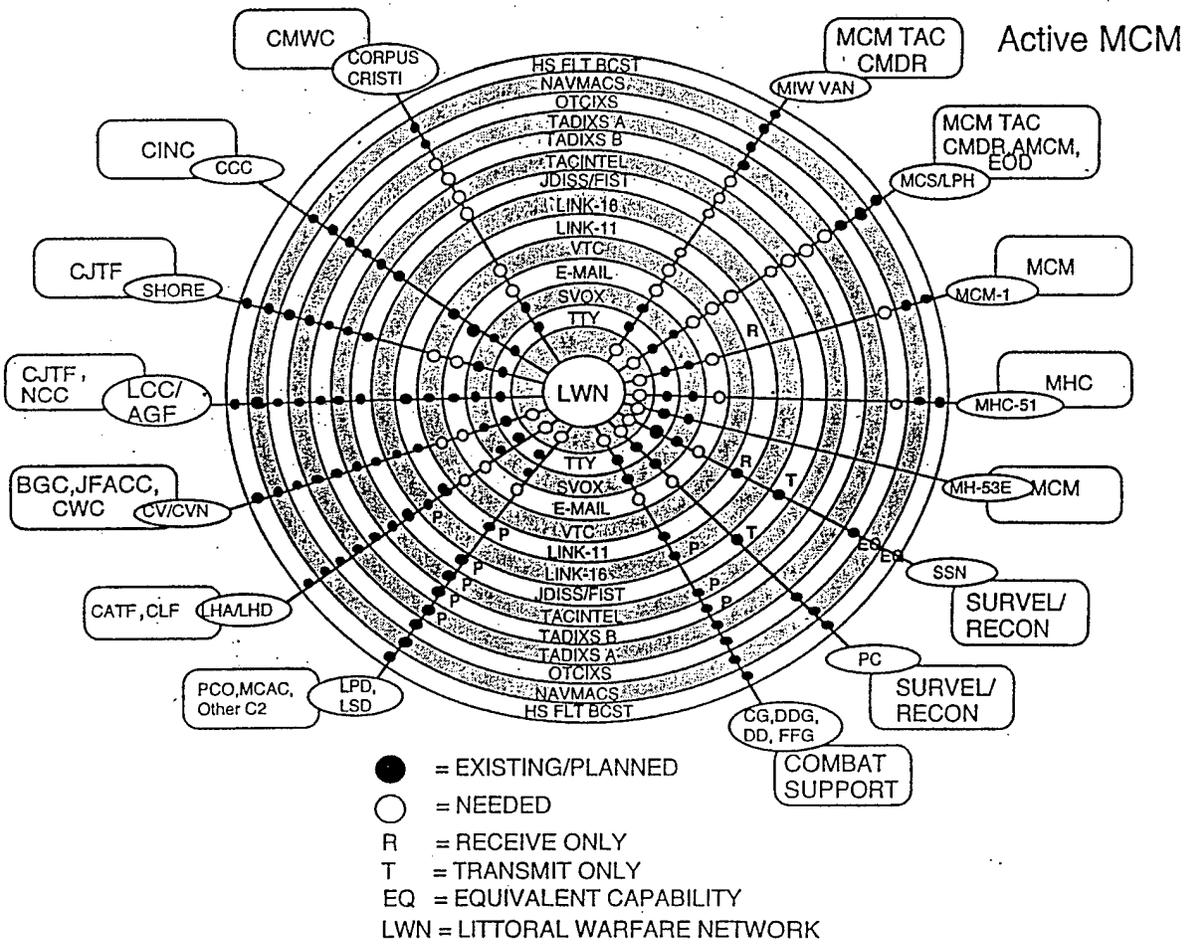


Figure 7.2. MIW Node Connectivity - Communications Systems

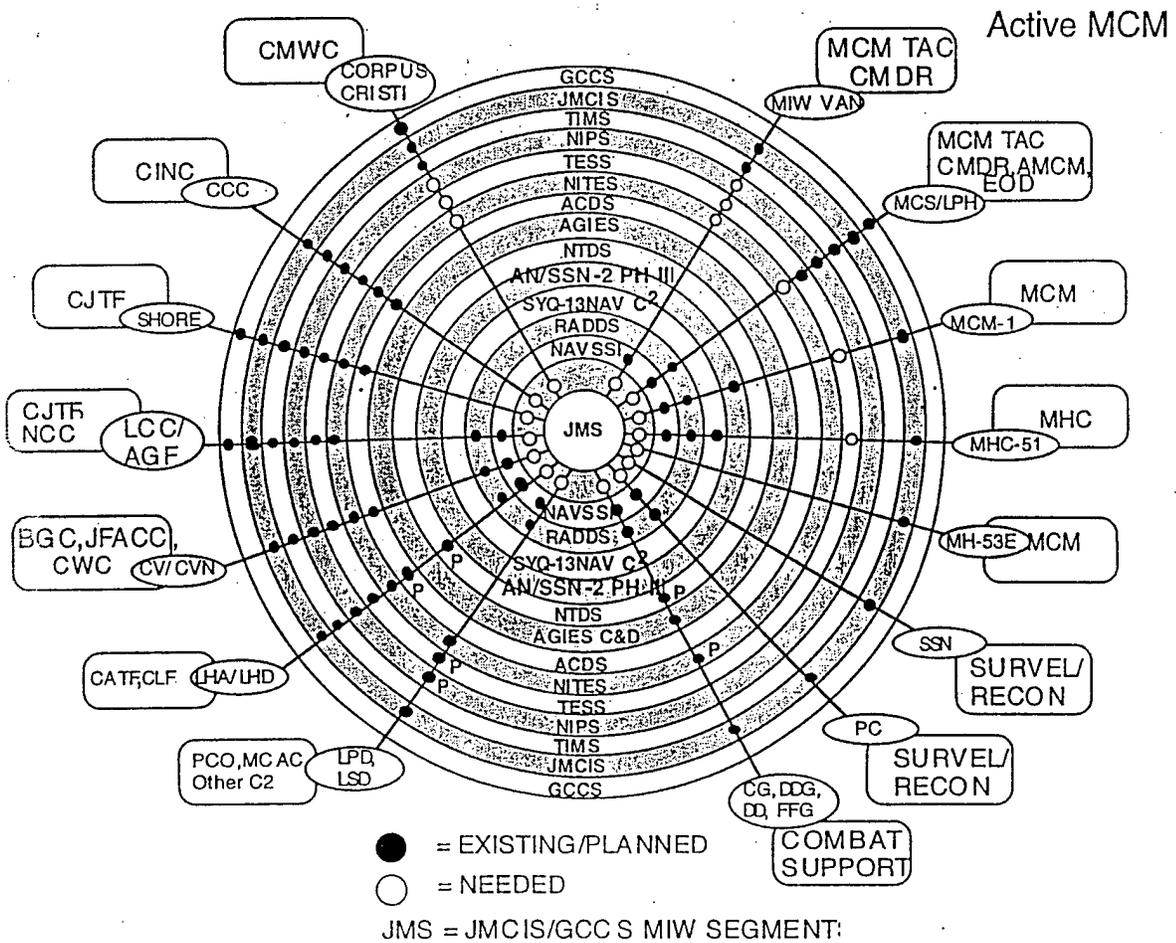


Figure 7.3. MIW Node Connectivity - Processing Systems

This document provides a high level overview of MIW C⁴I mission requirements and interoperability issues. Figures 7.2 through 7.3 provide insight to what is planned for AMCM. No specific AMCM System Architecture is provided. The MIW Node Connectivity - Communication Systems diagram, (Figure 7.2), reveals that terminal teletype (TTY) and secure voice (SVOX) are the only existing/planned AMCM communication system requirements needed to support the AMCM functions required in the conduct of MIW. Also, the document is not complete as the MOC Van, required when the AMCM unit is not on MCS-12, is not included in the MIW Node Connectivity - Communications Systems diagram (Figure 7.2).

4. C⁴I Architecture Currently Supporting the Mine Warfare Community [Ref. 16]

This was prepared by LANTFLT Systems Engineering in March '96 following a four-day review of the C⁴I architecture currently in use within the Mine Warfare community. "The objective was to determine the as-is C⁴I architecture and data flow requirements of units involved in Mine Warfare." [Ref. 16:p. 2] Shipboard and CMWC based hardware/software systems were examined as well as issues concerning upgrading MIW nodal capabilities. A list of C⁴I data requirements are also presented. The data requirements are broken down into continuously supplied data and periodic supplied data categories. The continuously supplied data can be further broken into intrinsic "raw" data and derived "calculated" data. This document provides no guidance on specific AMCM systems as they were not examined. Finally, the SPAWAR series of documents listed in the preceding paragraphs were based on the information contained in this document.

5. MIW C⁴I Requirements Document [Ref. 12]

COMINWARCOM's MIW C⁴I Requirements Document identifies the fundamental requirements for a "tactically effective MIW C⁴I system." It states that a "MIW C⁴I system is to be a segment within the Joint Maritime Command Information System (JMCIS) to provide interoperability with Navy, Joint, and Combined C⁴I systems and therefore will comply with USN Copernicus architecture requirements." Data transmission requirements listed include both beyond line of sight (BLOS) and within line of sight communications. Continual as well as periodic transmissions are also required. The document also states that "as a minimum, a data link will provide the following:"

1. MCM asset position
2. Parameters to compute trailback and offset of MCM gear.
3. MCM equipment settings/performance data, when sweeping.
4. Sensor video and/or digital sonar image data, when hunting (primarily for unmanned systems). [Ref. 12]

The data flow requirement descriptions contained within this document are extremely valuable in determining the required data flows between MIW assets.

C. PROGRAMS

1. The AN/AQS-20 Data Link

The AN/AQS-20 Data Link currently under development by Raytheon. It is a point-to-point, UHF line-of-sight data link with a throughput of 250 Kbps. The system is based on the 1553 data bus and the Navy Communications System (NCS) "glass cockpit upgrade." The system will add a third AN/ARC-210 UHF radio, a SSE DSM-102 Satellite Modem to the aircraft, and a DVME-739 serial

communications controller card to the AN/AQS-20 console processor module D. The simplex (send-only) system will supply unencrypted AN/AQS-20 sonar video only within LOS ranges to the MOC. Currently, only R&D has been funded for a prototype system. The AN/AQS-20 sonar and data link is scheduled to reach the fleet in 2003.

The AN/ARC-210 and the SSE DSM-102 were utilized in the AMCM C⁴I Information System proof-of-concept demonstration as part of the radio-based WAN. This was intentionally done to demonstrate how to convert this system to a secure, network-compatible system that can be used for all missions not just the AN/AQS-20 mine-hunting mission.

2. MAST

Mobile Ashore Support Terminal (MAST) is a self contained, transportable C⁴I system which can be rapidly deployed to meet any contingency. MAST provides an initial C⁴I capability for a naval detachment operating ashore. The MAST capabilities include a comprehensive communications suite: HF/UHF/VHF, SATCOM and associated crypto gear; a C2I capability: JMCIS/GCCS, GPS and an integrated briefing system. [Ref. 13:para 3.9.3] According to SPAWAR's MIW C⁴I Master Plan, MAST has been selected to provide deployable C⁴I for the AMCM Commander. However, it is unknown whether it has been funded or if funded, when it will be made available to the AMCM squadron. MAST currently costs \$1.25 Million and is expected to require 1 year to deliver. MAST does not integrate the current AMCM C⁴I assets into a coherent system or improve connectivity with the MH-53E.

3. Remote Minehunting System (RMS)

Lockheed Martin was awarded the Remote Minehunting System (RMS) contract in August '96. The RMS consists of a semi-submersible diesel submarine

that tows the AN/AQS-14A side-scan sonar. The submarine is unmanned and the RMS will be controlled using a LOS UHF data link. The LOS data link will also provide sonar video data and target location information. The RMS sonar system is to be based on a VME bus with Ethernet ports to the sensor and to the data link. Computer-aided detection (CAD) will be added to the system as a future upgrade using 8 additional VME cards. Two MVME-167 VME cards will provide Ethernet interface to connect the Ethernet-based sensors and data link to VME bus. One MVME-167 card will act as a sonar data interface and perform sonar data routing functions. The other MVME-167 card will act as the image compression interface and control and perform message collection functions. A UHF radio will be used to transmit the data to the command and control platform.

The sonar to be used in the initial RMS version (AN/AQS-14A) is also employed by the MH-53E. The AN/AQS-14A sonar used in AMCM requires an upgrade in order to gain Ethernet access. However AN/AQS-14A upgrades being made for the semi-submersible RMS system can also be used with AMCM's AN/AQS-14A. Common software engineering, research and development, and logistics costs can be drastically reduced if these components are used for the AMCM upgrades to the AN/AQS-14A. It is essential that common definitions and interfaces be identified early on in order to be interoperable and to take advantage of this parallel effort.

4. Link-11

Link-11 is a two-way secure, netted link that exchanges information in the TADIL-A message format. Link-11 functions as a primary data link for surveillance, combat weapons coordination and battle management. Link-11 configurations vary as it may be used over both HF and UHF radios. Link-11 maximum throughput is 6 Kbps, which will not support video. Link-11 is not currently

programmed for MCMs, MHCs or AMCM MH-53E. MCS-12 received Link-11 during the conversion process. The MOC has Link-11 installed.

5. Link-16

"Link-16 is not currently programmed for MCMs or-- MHCs or MCS-12. It should be a future requirement for MCS-12, MCMs, MHCs, MICFAC, MAST and the COMINEWARCOM (CMWC) Command Center." [Ref. 13:para 3.4.2.2]

Though Link-16 is to be the primary data link for the USN, it is restricted to LOS. In full ECCM mode, it supplies only 28.8 Kbps and lacks the throughput to support video. Since it is based on Time Division Multiple Access (TDMA), less time is available to each user as more users are added. As a result, because each user has less time to transmit/receive data, the throughput will degrade as the number of users on each net is increased. It will be expensive and will not solve all the problems that expectations will place before it.

6. Link-22

NATO Improved Link Eleven (NILE)/Link-22 is an improved version of Link-11. Through TDMA, it will be capable of multinetting with a gapless coverage over 300 NM range by combining HF with UHF line of sight nodes. The link will be based on TADIL- J series data elements and messages. Link-22 is not currently programmed for MCMs, MHCs or MCS-12. [Ref. 13:para 3.9.3]

MIW needs a "force coordination" networked communications system. The tactical-communications-based e-mail and IP network proposed in this thesis will meet this need. What MIW does not need is a "weapons coordination" communications system like Link-16, Link-11 and Link-22. These "weapons coordination" systems are very expensive and pose gigantic systems integration problems.

D. PREVIOUS DEMONSTRATIONS

A previous AMCM data link system includes EDOs TLTS prototype data link that was used during the U.S. Navy Gulf of Mexico (GOMEX) Exercise in 1994. This effort demonstrated the real-time capability to report aircraft, towed body, and mine-like object position information. The data link was also used to transmit single frame sonar imagery over a HF radio system. Approximately seven minutes were required to transfer the uncompressed single frame mine-like sonar images during the demonstration. The system successfully demonstrated AN/AQS-14 minelike contact analysis capability in the MOC as well as transmission of data from the MOC to COMINEWARCOM via Link-11.

E. FUTURE DEMONSTRATIONS

Future demonstration efforts include the Joint Countermine Advanced Concept Technology Demonstration (JCM ACTD) 97-2 which includes a proposal for a MH-53E data link. This system is outlined in the Joint Countermine (JCM) Advanced Concept Technical Demonstration (ACTD) Command, Control, Communications, and Intelligence (C⁴I) Component [Ref. 17]. The JCM ACTD Data Link proposes to provide preformatted position, contact and status reports (compatible with the display and database features of JMCIS) from the MH-53E helicopter to the AMCM control node and the MCM Tactical Commander. The software on the DOS-based INC includes communications channel access protocols and a modified TCP/IP protocol for use over radio networks. This software will be used on all MIW platforms in the exercise. A RS-232 serial connection will be used to attach the TAC-4 to the INC. The INC is attached to the SINGARS radio via a data interface device or to a KG-84C cryptological device from which it is connected to a HF modem and existing AN/ARC-174 HF radio. The bandwidth provided by both systems will not support video. The maximum

throughput of the line-of-sight SINCGARS system is < 9600bps. The throughput of the HF system will be unpredictable as the unit does not support ALE and uses an mechanical coupler. Finally, the detailed interfaces with existing MH-53E systems remain to be determined according to the May '96 Configurations and Interface Description Document.

F. SUMMARY

Although many MIW C⁴I plans, publications, programs, and proposed systems exist today, no plan or system currently satisfies the overall requirements of the AMCM community. None of these plans, publications, programs or proposals integrate existing AMCM squadron C⁴I assets including JMCIS/Mine Warfare Environmental Decision Aids Library (MEDAL), Mission Planning Station, Post-Mission Analysis Station, and the MH-53 E mine countermeasures helicopter into a cohesive C⁴I system. [Ref. 18] The three-part series from Space and Naval Warfare Systems Command (SPAWAR) is based on shipboard MCM requirements. AMCMs own requirements are not weighted equally in the determination of the overall technical architecture.

Finally, although the plans and programs mentioned in this chapter do not provide specific guidance for fully integrating AMCM C⁴I assets into a cohesive AMCM C⁴I Information System, these plans and programs do provide a invaluable target baseline which the AMCM C⁴I system can reference to ensure compatibility with other MIW C⁴I (systems including MCS, MCM, MHC). This reference baseline includes protocols, standards, message formats, which shall be compatible with the AMCM C⁴I Information System. System requirements can be deduced from these documents but no coherent implementation plan exists to meet these requirements. The architecture proposed in this thesis provides a contender solution which can solve this critical shortfall.

VIII. RECOMMENDATIONS FOR FUTURE WORK

A. INTRODUCTION

The AMCM C⁴I Information System can be built today using a tactical internet to provide connectivity between all AMCM C⁴I assets. This system will provide a significant step forward in command and control for the AMCM community. Future work is required to ensure all the necessary projects currently under development can be migrated onto the tactical internet as desired.

B. RECOMMENDATIONS

Numerous products are already on-line to appear in the AMCM community.

1. Sensors

The AN/AQS-20 sonar will be available in the year 2003. It is not based on a internetworked design, however the console has a VME serial port communications card which can be used for AMCM LAN access. However the other interface definitions such as the data definitions must also be met as well to provide interoperability within the tactical network. The present data definitions are not designed for JMCIS or MEDAL interoperability.

The RMS semi-submersible mine-hunting system and the AMCM AN/AQS-14A programs must cooperate to provide as many commonalities as possible. This will reduce costs and improve logistics.

This is an illustration how procurements coming out of two different program management offices can duplicate results in incompatible ways. Nothing in the acquisition system encourages them to work together.

2. Decision Support

AMCM's Mission Planning System and the JMCIS mine warfare segment MEDAL must become interoperable. The MH-53E "glass cockpit" Navy Communications System (NCS) is currently being introduced to the fleet and will

provide the MH-53E with a 1553B data bus. The bus can be interfaced to the tactical network on the MH-53E using a 1553 based PCMCIA card. However, the MPS data module that is loaded into the overhead in the cockpit (which preloads and then stores all mission information trapped from the 1553 bus) is incompatible with MEDAL/JMCIS. Position reports, minelike contact messages etc. cannot be passed between the two systems without manual conversion. In effect, the potential exists for two entirely separate, non-interoperable, tactical decision aids (TDA) to reside on the same networked platforms. MEDAL will be MIW's primary TDA. However, both can be put onto the network and be interoperable once the message format and data definition issues are resolved.

The era of stovepipe TDA's like MPS has passed. Modern TDA's must be LAN based, host network management platforms and use compatible data definitions and common operating environments like those based on the Naval Warfare Tactical Data Base and JMCIS/MEDAL etc.

3. Radio-Based WAN

Efforts to install incorrect incompatible solutions must be abandoned. Link-11, Link-22 and Link-16 will cost far more and be far less useful and effective in meeting MIW needs than a proven, widely-compatible, networkable yet inexpensive COTS solution like Battle Force E-mail.² Open solutions which are secure, easy to clone, integrate, adopt and understand can be implemented with little cost or risk today. The AN/AQS-20 data link program must become more than a one-way, point-to-point, unsecure (unencrypted), UHF radio-based LOS stovepipe. The AN/ARC-210 UHF radio used by this system can be used to provide a secure, network compatible, high data rate UHF/SATCOM channel (as shown in the proof-of-concept demonstrations by this thesis).

²B.F. e-mail uses Qualcomm's Eudora IC based E-mail application. [Ref. 19]

4. Proposals

Proposals must be made early on before it is too costly and too late to make meaningful changes to projects currently under development. Planning Documents, Mission Need Statements, Engineering Change Proposals all will be required to make meaningful progress on the internetworked C⁴I front.

There are numerous programs that must be integrated. Doing so will ensure connectivity between the necessary C⁴I systems. Failing to do so will ensure AMCM remains standing alone and in the dark. This is evident as our existing baseline consists of stand-alone decision aids with no connectivity to pass critical information. The problem is chronic as little or no effort has been made to provide interoperability between AMCM C⁴I assets. By insisting on the proper architecture early on in the requirements part of the procurement phase, it will be virtually impossible for the contractor to develop anything but the proper solution.

Finally, the move from AX.25 point-to-point connections to a reliable multicast transport protocol should be made as soon as possible. Like AX.25, NRAD's Battle Force E-Mail system is only the first step. Use it to get a basic internetworked working system as soon as possible, but consider other alternatives that meet the networked architecture at each opportunity.

C. SUMMARY

The AMCM community needs to implement the C⁴I Information System based on the architecture outlined throughout this thesis. With the appropriate networked architecture, the network can be expanded as the need arises. Without the appropriate architecture, the community will be locked into another closed stovepipe system tied to individual systems and components.

IX. DEMONSTRATION RESULTS

A. INTRODUCTION

Two laboratory proof-of-concept demonstrations were successfully conducted. The first demonstration was presented to Captain Arnold (AMCM PEO) on 16 September 1996 and the second demonstration was presented to Admiral Williams (PEO MIW) on 8 October 1996.

B. DEMONSTRATION GOALS

The demonstration goal was to provide a working proof-of-concept prototype using standard COTS/NDI equipment, NRaD's Battle Force HF E-mail System, multicast backbone (MBone) video tools within an open architecture using standard protocols available today. [Ref. 17] The demonstration was also intended to provide an overview of the capabilities inherent in the system's architectural design. These capabilities include:

- Near-real time video and message reports over LOS using UHF equipment
- Single frame imagery and message reports OTH using HF equipment
- Adjustable throughput, frame rate, and resolution of the multicast backbone video tools
- Internet Protocol (IP) routing and internet compatible HF e-mail
- Flexible, scalable, reliable, open network architecture

The demonstration was an opportunity to provide a working systems-based solution to AMCM's C⁴I problem.

C. DEMONSTRATION SETUP

The demonstration was arranged using two LANs on two separate tables to simulate the MOC and a mobile MH-53E helicopter respectively as shown in Figure 9.1. Connectivity between the two LANs was only possible through UHF, HF and a microwave bridge RF based links. The "MOC" LAN was also connected via a standard 10Base2 Ethernet cable to the Naval Postgraduate School's network backbone to demonstrate connectivity to the Internet. AN/AQS-14 sonar input was simulated using an actual sonar playback videotape provided by the Helicopter Mine Countermeasures Squadron Fifteen.

D. DEMONSTRATION RESULTS

AN/AQS-14 sonar video was successfully converted from standard VHS video cassette format into IP datagrams and forwarded over a "MH-53E" LAN to the radio-based wireless WAN. It was then transmitted via the radio based WAN to the "MOC" LAN and forwarded to a processor where it was displayed on a monitor as a real-time sonar video stream.

Single frame mine-like object images were captured using a "frame grabber" from the sonar video data stream and forwarded over the RF network to the MOC LAN where they automatically appeared on the screen as clear single frame mine-like object images.

NRaD's Battle Force HF E-Mail was installed but a "clear to send modem error" precluded fully successful e-mail operations. The error was internal to the modem itself and was not a result of any architectural or system design flaws. NRaD's Battle Force Electronic mail HF e-mail system has been proven to work and has successfully been demonstrated in shipboard environments.

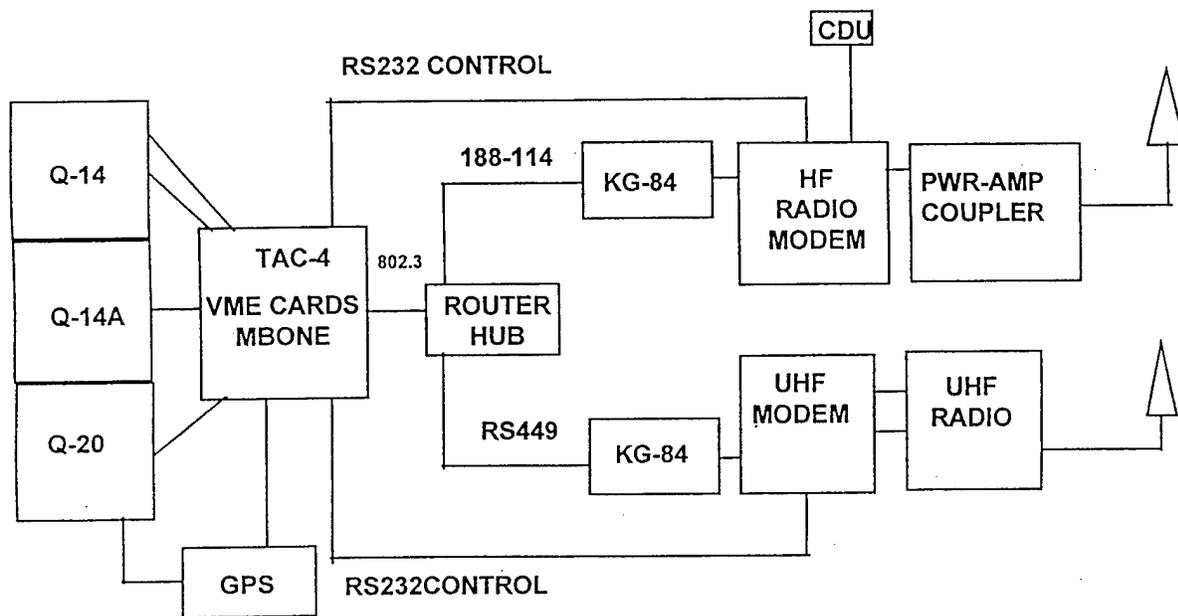


Figure 9.1. MH-53E Aircraft

UHF throughput was demonstrated at 250 Kbps and at 380Kbps to show the frame rate that can be expected using UHF based WAN communications channels for video transmissions.

Messages were transferred over the HF radio's internal data link channel to demonstrate HF connectivity.

The sonar video used in the lab demonstration was not integrated with aircraft skew, heading, altitude, time etc. as the sensors that provide these inputs were not available. Figure 9.2 shows the lab testbed component diagram.

E. SUMMARY

The demonstration design objectives were met as sonar video and single frame imagery information were successfully transferred in near-real time over the radio based WAN. Nearly any communications component, regardless of frequency (VHF, UHF, HF etc.) can be connected to a router, controlled, and be used to pass information over the radio-based WAN. This system was ready to be tested at sea. Planned testing was unexpectedly terminated when the author's orders were changed just prior to graduation.

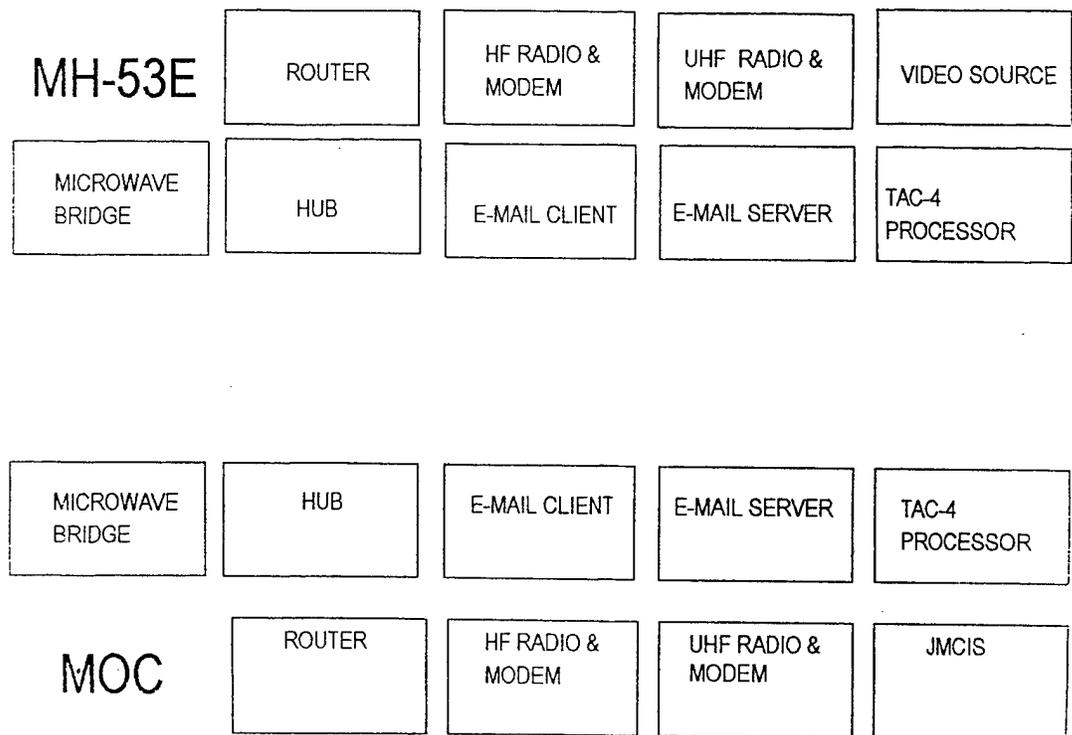


Figure 9.2. Lab Testbed Component Diagram

X. LESSONS LEARNED AND CONCLUSIONS

A. INTRODUCTION

This thesis was rapidly written after building the prototype system. As a result of building the prototype, numerous lessons have been learned first hand that would not have been as deeply gleaned from a purely academic endeavor.

B. LESSONS LEARNED

Proper network interfaces are essential. The system must be network-centric with common LAN interfaces. Serial connections between components severely limits flexibility and interoperability. If the components have common network interfaces, they can be attached to a network and information can be routed or shared between the components.

Ethernet (IEEE802.3) and Internet Protocol (IP) compatible products are widespread. If a system component doesn't provide the interface, chances are an internal or external adapter or card can be purchased COTS that will provide the appropriate interface. For example, Ethernet and FDDI cards are available for VME bus based systems.

Use what is available and proven to work before attempting exotic capabilities. AX.25 and NRaD's Battle Force HF E-Mail system is a good start. After successfully integrating this system, begin to add basic capabilities such as secure e-mail encryption tools and image compression.

Battle Force TCP must be modified for use in wireless environments. Numerous modification schemes are available. The problem is well understood, having been solved both by the amateur radio community and by other parts of the Navy such as NRaD. NRaD's Battle Force HF E-Mail system uses the JNOS

Implementation of TCP/IP over the AX.25 packet radio data link layer. Adequate performance is possible today nevertheless.

Data packaging is a very important issue. The e-mail enveloping definition is the same independent of the contents inside. MIME is recommended as it has less overhead, is readily available, poses less development risk than X.400, and is the most compatible.

Information systems architecture as outlined in Chapters II, III and IV needs to be corporately established throughout the MW community. This is not a programmatic function. Information systems architecture is not a platform issue, but rather a cross-platform one. A cadre of individuals must understand the information systems architecture in order to guide multiple programs in a coherent direction.

Systems engineering is no longer a "do it once at program inception" affair. It must be viewed as life-cycle activity from the overall systems perspective. Such an approach was previously lacking for AMCM. This thesis provides the foundation for an overall system that can be planned on a life-cycle basis.

C. CONCLUSIONS

The transmission of sonar video itself is not a necessary requirement. The use of CAD on the MH-53E LAN will provide a near-real time over-the-horizon video processing capability, as the TARLOC position information and single frame mine-like contact imagery can be supported within HF transmission parameters.

Common data definitions are essential. Common data definitions save processing time by eliminating conversions and provide data interoperability between end systems which directly support rapid near-real time information exchanges between the sensor and the decision maker.

A good inherent design goal is to get information put into Internet Protocol (IP). Once information is converted into IP datagrams, it can be transported over networks virtually everywhere.

D. SUMMARY

Numerous lessons were learned during the building of the prototype. Most importantly, a network-centric, systems based, open architectural approach provides the highest levels of interoperability, availability and scalability. Other stovepipe proprietary solutions will continue to fail.

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