UHF MILSATCOM Systems with Emphasis on Changes Made By the Recent Introduction of Automatic Control (AC) Mode Demand Assigned Multiple Access (DAMA)

(June 1999)

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ABSTRACT

Ultra high frequency (UHF) military satellite communication (MILSATCOM) has been providing service to mobile users for more than twenty years, and has become the common denominator for Allied communications. Prior to 1992 there were no formal interoperability standards governing the use of the UHF satellite system. To increase the efficiency of use of UHF satellite communication resources and to improve interoperability, a series of UHF satellite communication standards were developed. The publishing of the standards, along with a Joint Staff mandate requiring use of terminals certified to the new standards, has resulted in a tremendous surge of interest in UHF satellite communication. As many as twenty thousand new terminals, certified to these standards, will be built over the next few years. This paper begins by describing the previous and current UHF satellite constellations and summarizes how UHF satellite communications are being used. The history and capabilities of the three main UHF satellite communication standards are described along with problems that have delayed the move to demand assigned multiple access (DAMA). The paper also describes the initial development and future plans for a decentralized communications planning and management tool that will assist with creating, approving, allocating and maintaining networks of certified terminals. The paper concludes by describing work being performed to increase channel control reliability, improve the quality of secure voice, increase data rates, and enhance the ability to accommodate variable rate data protocols, including internet protocols.

BACKGROUND

The UHF spectrum allocated for US Military satellite communications is located at the boundary between the Very High Frequency (VHF) and UHF frequency bands. Uplink frequencies are located at the lower end of the UHF band (292 to 317 MHz) while downlink frequencies are located at the upper end of the VHF band (243 to 270 MHz). A pair of UHF Follow-On (UFO) satellites in geostationary orbits operates over each of four overlapping satellite coverage areas providing around-the-world coverage. Limited polar coverage is provided by two Package D satellites in Molniya polar orbits and a twenty year old Lincoln Experimental Satellite that has drifted into a highly inclined geosynchronous orbit.

Military UHF satellites contain a mixture of 5-kHz and 25-kHz bandwidth channels, each using an independent transponder. The transponders are unprocessed (they do not demodulate the data), simply filtering, frequency translating and amplifying the received signal. The use of unprocessed transponders has allowed UHF SATCOM users to take advantage of improved modulation techniques that have been developed since the original UHF satellites were launched. While twenty years ago a 25-kHz bandwidth transponder was often used at only 2400 bps, today they can be used at rates as high as 56,000 bps. The transponders hard limit received signals, providing maximum gain for weak signals, but also preventing the use of bandwidth-efficient modulation techniques that depend on amplitude modulation. Hard limiting makes it difficult for simultaneous signals to share a channel. UHF DAMA waveforms use Time Division Multiple Access (TDMA) to share channels since this technique doesn't require simultaneous access.

The UHF frequency spectrum has many characteristics that make it very suitable for mobile communications. The relatively low frequencies and data rates allow use of small, inexpensive terminals. Many current terminals actually began as 10-watt line-of-sight UHF radios. Non-directional antennas can be used since no other satellites share the frequency allocation. Directional antennas are required only when extra gain is needed to improve link margins. Because the satellite transponders are hard limiting, only minimum transmit power

Paper presented at the RTO IST Symposium on "Tactical Mobile Communications", held in Lillehammer, Norway, 14-16 June 1999, and published in RTO MP-26.

control is required. The signal must be just strong enough to overcome channel noise while not so strong that out-of-band emissions interfere with other satellite channels. UHF frequencies operate through weather and under foliage much more reliably than SHF and EHF frequencies do.

The main problem with UHF SATCOM is that there just isn't enough of it. There are many more potential users of UHF SATCOM than there are available channels, and channel capacity is primarily limited by the UHF spectrum allocated for military use, not by an inability to build and launch satellites. The combination of earth coverage and non-processed transponders results in no anti-jam capability, and UHF is subject to ionospheric scintillation, multipath, and unintentional interference. By international agreements, satellite communication is the secondary user for the allocated UHF spectrum. The US has no legal recourse when interference is caused by other country's legitimate use of the frequencies.

UHF SATELLITE CONSTELLATIONS

The UFO satellites are 23,500 miles high in slightly elliptical geostationary orbits (e=.005), and begin life inclined 6 degrees off the equator. The four coverage areas are centered over the continental United States, the Atlantic Ocean, the Indian Ocean, and the Pacific Ocean. The UFOs are the fifth generation of UHF satellites.

Lincoln Experimental Satellites (LES)	1965Operational
MARISAT (Gapfiller)	1976
Fleet Satellite (FLTSAT)	1978Operational
Leasat Satellite (LEASAT)	1984
UHF Follow-on (UFO)	1994Operational

Other U.S. satellites, including Package D, DSCS and MILSTAR, carry UHF transponders, as do satellites owned or leased by our allies.

LES-3 was launched in 1965 on a Titan 3C launch vehicle. The purpose of this 35-pound satellite was to characterize the UHF band for military operations. LES-8&9 were launched together in 1976. These 1000-pound satellites were three-axis stabilized using momentum wheels, used pulsed plasma thrusters for station keeping, and were powered by a radio isotropic 238 Plutonium power generator. Both satellites are still operational. LES-8 is used to help locate interfering signals while LES-9 is providing polar communication services.

Three MARISAT satellites were launched in 1976 on Delta 2914 launch vehicles to provide interim operational capability while waiting for FLTSAT availability. Each satellite carried three transponders: two 25-kHz transponders and one 500-kHz transponder. The 500-kHz transponder was designed to accommodate a jam-resistant frequency-hop communication service. Designed for a service life of five years, the satellites were deactivated in 1996 after over 19 years of service.

Beginning in 1978, eight FLTSAT satellites were launched on Atlas Centaurs, but only six achieved proper orbits. Each satellite carried twenty-four transponders: twelve 5-kHz transponders, ten 25-kHz transponders, one 500-kHz transponder, and a 25-kHz transponder using an SHF uplink and a UHF downlink. Seven of the 5-kHz transponders contained onboard processing to accommodate a jam-resistant frequency-hop communication service used by the Air Force. The transponder with the SHF uplink was designed for use by the Navy Fleet Broadcasting service and contains onboard processing for a jam-resistant spread-spectrum uplink. FLTSATs 7 and 8 carry Fleet EHF Packages (FEPs). FLTSATs 1, 4, 7, and 8 are still in use providing operational communication services.

For a short time Congress mandated the use of leased rather than purchased satellites. While the Navy continued to work on a new generation of tactical/strategic tri-service satellites, five LEASAT satellites were launched using the Space Shuttle. One satellite failed early and one had to be repaired by a Shuttle crew while still in its initial parking orbit. These satellites provided a minimum capability for extending the service life of the FLTSAT constellation. Each satellite carried thirteen transponders: five 5-kHz transponders, six 25-kHz transponders, one 500-kHz transponder, and one 25-kHz transponder using an SHF uplink and a UHF downlink.

The newest constellation consists of a pair of UHF Follow-On satellites operating over each of the four satellite coverage areas. UFO-1 was launched in 1993 on the first commercially built Atlas but was placed into an improper orbit. The following eight launches were successful, providing a complete constellation. UFO-10 is scheduled for launch in 1999 to provide a spare satellite. Each satellite pair operating together provides seventy-eight transponders: forty-two 5-kHz transponders, thirty-four 25-kHz transponders, and two 25-kHz transponders using an SHF or EHF uplink and a UHF downlink. The portion of the frequency spectrum that was formally allocated to the 500-kHz transponders is now allocated to additional 5-kHz and 25-kHz transponders. UFOs 4-6 also carry Low Data Rate (LDR) EHF packages while UFOs 7-10 carry an enhanced EHF package. UFOs 8-10 carry a Ka-Band Global Broadcast System (GBS) broadcast package.

UHF MILSATCOM USERS

There is still considerable use of low rate message services (mostly 75 bps teletype networks), but secure voice, messaging networks, and information exchange networks operating at 2400 bps are the major users of UHF resources. UHF MILSATCOM is often used by early entry forces then replaced by large SHF and EHF communication systems as soon as possible. Early UHF satellites had special processed transponders to provide jam-resistant communications for a few critical communication systems but these functions are being moved to other satellites. The SHF uplink jam-resistant channel is still used for the Navy Fleet Broadcast. With thousands of new terminals becoming available, all services are expected to become large users of UHF MILSATCOM.

EVOLUTION OF DAMA

The first and still most prevalent use of UHF MILSATCOM channels is in dedicated access mode where the entire channel bandwidth is dedicated to a single communications requirement, regardless of the actual bandwidth required. There is a simple one-to-one correspondence between the number of UHF SATCOM channels available and the number of communications requirements that can be supported at any given time. The U.S. Navy developed an early version of DAMA to make more efficient use of the limited UHF SATCOM resources by providing multiple access to a UHF channel through the use of time-division multiple access (TDMA), increasing circuit availability and reducing radio requirements.

DAMA was introduced by the U.S. Navy more than 15 years ago with the development and fielding of the TD-1271 DAMA terminal. These terminals operated on a limited set of 25-kHz UHF satellite channels in DAMA Distributed Control (DC) mode, whereby users were provided access to predefined DAMA networks assigned to 25-kHz DAMA time slots on a relatively permanent basis.

The demand for UHF SATCOM resources to support the communications requirements of all the services has continued to increased at a rate that far outpaces the availability of these resources. As a result, the Joint Chiefs of Staff (JCS) mandated all UHF MILSATCOM users to transition to DAMA operation.

In 1996-1997 the Navy and the Air Force each fielded systems to provide Automatic Control (AC) mode access to DAMA channels. The Navy's DAMA Semi-Automatic Controller (SAC) provides user access to 25-kHz DAMA channels and the Air Force-developed Network Control System (NCS) supports user requirements on 5-kHz DAMA channels (with 25-kHz channel control functionality being added). These access modes are described in more detail in the following paragraph.

THE SWITCH TO AC MODE DAMA

Motorola, under contract to the Navy, developed the first Fleet Satellite Communication System (FSCS) UHF DAMA specification and the TD-1271 terminal. Although the FSCS DAMA specification was originally developed for operation on both 5-kHz and 25-kHz satellite channels, only the 25-kHz mode has been used. The FSCS standard defined two DAMA modes, Distributed Control (DC) mode and Automatic Control (AC) mode. DC mode operates as a distributed time division multiplexer, allowing multiple circuits to share a satellite channel in the same way that a multiplexer is used to combine circuits for transmission over a terrestrial link. AC mode added the capability for user terminals to control the setup of the multiplexer by requesting a circuit when needed and giving up the circuit when no longer needed. Both DC and AC modes require one terminal to act as a centralized channel controller. The main requirement for the DC mode channel controller is to establish frame timing. All TD-1271s are capable of serving as DC mode channel controllers. Under the direction of a controlling system, TD-1271s are also capable of serving as AC mode channel controllers. Motorola developed a Semi-Automatic Controller (SAC) to control TD-1271s in the AC mode. The Motorola SAC was developed when microprocessors were just emerging. Rather than use software to make the communication resource allocation decisions, SAC required a dedicated operator 24 hours a day to look at and respond to every request received from user terminals. Early in the life cycle of the SAC, this was determined to be not operationally feasible and all energy was directed toward DC mode. The Navy used DC mode exclusively until 1996.

In 1988 the Navy decided to take another look at AC mode operation. A small research and development project was funded to build a new SAC that could operate without a dedicated operator. Originally this project was intended to be nothing more than a demonstration of a capability. However, several events occurred during the development of the DAMA SAC that resulted in major changes and a major increase in scope for the project. The new UFO satellite constellation was being readied for launch and UHF MILSATCOM would now be available to all services. With the promise of more channel availability the Air Force started development of the UHF Satellite Terminal System (USTS), a DAMA system for operation over 5-kHz satellite channels. Also at this time the services were attempting to work closer together and found that most of their communication systems would not interoperate. To ensure that any new terminals developed to operate over the new UFO satellite constellation would be able to interoperate, the Defense Information Systems Agency (DISA) Joint Interoperability and Engineering Office (JIEO) Center for Standards developed a set of DAMA terminal waveform standards to provide terminal interoperability and efficient use of both 5-kHz and 25-kHz UHF satellite channels. The original DAMA mandate has been updated to require all UHF terminals being fielded to be certified to operate in accordance with MIL-STD-188-182[1] when operating on a 5-kHz DAMA channel and in accordance with MIL-STD-188-183[2] when operating on a 25-kHz DAMA channel. See Table I for a list of the MIL-STD-188 series.

Table I. UHF MILSATCOM STANDARDS

MIL-STD-188-181B Interoperability Standard for Dedicated 5-kHz and 25-kHz UHF Satellite Communications Channels.
MIL-STD-188-182A Interoperability Standard for 5-kHz UHF DAMA Terminal Waveform.
MIL-STD-188-183A Interoperability Standard for 25-kHz UHF TDMA/DAMA Terminal Waveform Communications Channels.
MIL-STD-188-184 Interoperability and Performance Standard for the Data Control Waveform.
MIL-STD-188-185 Interoperability Interface Standard for 5-kHz and 25-kHz UHF SATCOM DAMA Control System.

MIL-STD-188-181[3] provides interoperability for non-DAMA users of UHF MILSATCOM. The standard is meant to minimize interference between users and to ensure that interoperability exists for all users. Only a few of the operating modes specified in the standard are mandatory. These include 2400 and 16,000 bps digital voice and 1200, 2400, and 16,000 bps data. MIL-STD-188-181A added convolutional error correction coding and Quaternary Phase Shift Keying (QPSK) modulation to the waveform. MIL-STD-188-181B, released in May 1999, added multi-h Continuous Phase Modulation (CPM), increasing the maximum data rate supported to 9.6 kbps operation over 5-kHz channels and 56 kbps operation over 25-kHz channels.

The two current DAMA standards that define operation over UHF satellite channels are MIL-STD-188-182A for operation on 5-kHz channels and MIL-STD-188-183A for operation on both 5-kHz and 25-kHz channels.

MIL-STD-188-182 protocols were originally developed to support an Air Force requirement for around-the-world messaging among Military Airlift Command (MAC) aircraft. MIL-STD-188-182 can support user data rates as high as 2400 bps and provides a messaging capability.

MIL-STD-188-183 protocols were based on the FSCS waveform introduced by the Navy with the fielding of the TD-1271. MIL-STD-188-183 can support user data rates as high as 16 kbps, but generally is used in a mode where the maximum data rate available is 2400 bps.

During the development of MIL-STD-188-182 it became apparent that the 5-kHz DAMA standard was not going to meet emerging user voice requirements. While the waveform was never intended to provide voice service, a voice capability was included. Because the waveform used an 8.96-second frame, circuit setup required 18-27 seconds and round trip voice delay was around 18 seconds, which was considered unacceptable by the user community. To reduce 5-kHz DAMA voice delays, and to address several other issues, DISA JIEO developed "A" revisions to both standards. MIL-STD-188-182A now allows a data transmission to begin before a full frame of data has been buffered. This can decrease the round trip voice delay to an average of around 5 seconds. MIL-STD-188-183A adds the ability to operate on 5-kHz time slots while being controlled by a 25-kHz channel controller. This decreases the round trip voice delay on a

5-kHz time slot to less than 2 seconds, reduces circuit setup to 4 seconds, and provides interoperability between users of 5-kHz and 25-kHz channels.

MIL-STD-188-184[4] defines an interoperable waveform allowing the error-free transmission of very long messages over 5-kHz and 25-kHz non-DAMA channels. Data compression, adaptive error-correction, and packet communications techniques are used to reliably control the flow of data over noisy communications channels at high-throughput rates.

MIL-STD-188-185[5] establishes mandatory requirements for equipment that control access to DAMA and demand assigned single access (DASA) UHF 5-kHz and 25-kHz channels. Since there will only be one manufacturer of UHF DAMA channel control equipments, this standard will no longer be maintained. Instead, the channel control requirements will be captured in system specification documentation.

DAMA TERMINALS

Towards the end of the development of the standards, the Army began a competitive development and procurement of a new man pack terminal certified to the new UHF standards. This contract was awarded to Magnavox (now Raytheon) with ViaSat, as a subcontractor to Magnavox, providing the DAMA modems. More than 5000 AN/PSC-5 "Spitfire" terminals are being built and all services have purchased substantial quantities. In 1989, prior to the development of the standards, the Navy contracted to Titan for the development of the Mini-DAMA, a FSCS-compliant terminal destined for aircraft and submarines. Mini-DAMA was started as a 25-kHz FSCS terminal, but during development, the DAMA mandate required all new terminals to be certified to all of the new DAMA standards or risk being denied satellite access. Mini-DAMA terminal fielding was delayed to allow implementation of and certification to the DAMA terminal waveform standards.

Many other companies have developed terminals using their own funds plus funding from various Government programs. Table II lists the terminals that have been submitted to the Joint Interoperability Test Command (JITC) for certification to the standards.

Table II. DAMA Terminal Certification

Nomenclature	Manufacturer	Current Certification
AN/PRC-117F Transceiver	Harris Corp.	181
AN/PSC-5 Spitfire	Raytheon Systems	181, 182, 183
AN/USC-54 VICS	E-Systems (now Raytheon)	181, 183
LST-5D Transceiver	Motorola Corp.	181, 182, 183
MD-1324 Modem	ViaSat Corp.	181, 182, 183
MD-1333/A (LSM-1000) Modem	Titan-Linkabit	181, 182, 183
MD-1293 USC-42 Mini-DAMA	Titan-Linkabit	181, 182, 183
MST ICOM/DAMA Radio (MIDR)	Cincinnati Electronic (now NOVA)	181
MXF-440 (Skyfire-440)	Raytheon Systems	181, 182, 183
MXF-460 (Skyfire-460)	Raytheon Systems	181, 182, 183
RT-1797/ARC-210A(V) Terminal	Rockwell	181, 182, 183

Currently there are three major terminal development programs, though there are many smaller programs building small lots of radios for specific platforms. The lead program is the Joint Tactical Radio System (JTRS) with a mission to develop a family of affordable, high-capacity tactical radios to provide both line-of-sight and satellite communications. This family of radios is planned to cover an operating spectrum from 2 to 2000 MHz, and be capable of transmitting voice, video and data. By building upon a common open architecture, JTRS's objective is to improve interoperability by providing the ability to share waveform software between radios.

The Air Force Airborne Integrated Terminal Group (AITG) program is under contract with Raytheon to develop an open system architecture, reprogrammable terminal. The terminal will be based on the Raytheon Multiple Output SATCOM Terminal (MOST) and will include Line-of-Sight (LOS) and satellite communications, Air Traffic Control protocols, digital secure voice, and communication security (COMSEC) for airborne applications.

The Navy Digital Modular Radio (DMR) program is under contract with both Motorola and Raytheon to develop an open system architecture, reprogrammable terminal. While similar to the AITG, the DMR will be designed for a shipboard environment, providing 8 data ports when operating on 25-kHz DAMA and include HAVEQUICK II and SINGARS capabilities. The Navy contract requires sample radios from both Motorola and Raytheon to be used to evaluate and select a single supplier of the DMR.

DAMA CHANNEL CONTROL

During the development of the DAMA standards the Navy accepted the responsibility for developing the 25-kHz DAMA channel control system required by the introduction of the new DAMA standards and the change over to AC mode operation. The Navy was already performing DC mode control for their own channels and was in the process of developing the DAMA SAC AC mode control system, although at the time DAMA SAC was being designed to control terminals designed to the FSCS specification, not the new DAMA standards. The Navy's DAMA SAC uses TD-1271 modems and WSC-5 radios installed at the three Naval Computer and Telecommunications Area Master Stations (NCTAMS) and the Naval Computer and Telecommunications Stations (NCTS) at Guam and Stockton. These control stations are all located in the overlap of two adjacent satellite coverage areas. Each control station can control satellite channels in two satellite coverage areas, providing redundant control capability for each coverage area. Equipments at these sites also control many of the baseband systems operating over the satellites and can provide data relay between adjacent satellite areas.

The DAMA SAC, which began only as a tool to demonstrate AC mode operation for FSCS terminals, was redefined to become the joint services 25-kHz DAMA control system, providing communications resources for FSCS and MIL-STD-188-183 terminals. DAMA SAC began operational service in 1996 and has performed very reliably. Just last month, the United Kingdom installed a DAMA SAC system to provide AC mode control of UK satellite resources.

The 5-kHz DAMA specification the Air Force developed as part of the USTS program was modified late in the program to implement the MIL-STD-188-182 waveform requirements. Since MIL-STD-188-182 has no DC mode equivalent, the original development contract included a 5-kHz DAMA control system. Late in 1994 the Air Force contracted with ViaSat to design, build, install, and test a 5-kHz DAMA control system, the NCS. The NCS was co-located with the DAMA SAC at the three NCTAMS and NCTS Guam (the fifth DAMA SAC site at NCTS Stockton is no longer active). In 1996 Air Force again contracted with ViaSat to add MIL-STD-188-183 AC mode channel control capability to the NCS. This will be completed in 1999.

Although developed and fielded by the individual services, the DAMA SAC and the NCS are both capable of supporting communication requirements for users operating terminals in accordance with MIL-STD-188-183. The NCS also supports 5-kHz DAMA services in accordance with MIL-STD-188-182 (and by the end of this year, MIL-STD-188-182A). These two DAMA control systems each provide user access to a separate set of satellite channels and the behavior of each control system, from the terminal user's perspective, is slightly different. From the control system operator's point of view, the operation of each of the two systems is completely different. The need for a single, integrated system became clear.

As these DAMA channel control systems were being developed, it also became evident that the ability to support more user communications requirements would significantly increase the complexity of communications planning and management. A UHF DAMA Concept of Operation (CONOP) and Operational Requirements Document (ORD) were developed and accepted by the joint services to define the requirements for the joint integrated DAMA channel control system. This system is under development and is known as the Joint (UHF) MILSATCOM Network Integrated (JMINI) Control System.

The JMINI Control System project is being led by the U.S. Navy (Space and Naval Warfare Systems Command), but is a joint-interest program and will support all U.S. and allied forces.

The JMINI Control System is the integrated 5-kHz/25-kHz DAMA and non-DAMA controller for all non-processed UHF MILSATCOM channels. The JMINI Control System consists of three main components, the Resource Controller (RC), the Channel Controller (CC), and the Network Management Subsystem (NMS). The RC does the real time processing of the DAMA orderwire, the CC consists of the modem, radio, power amplifier, and antenna system, and the NMS contains the database of UHF satellite, terminal, and network characteristics, and provides the user interface for communications planning and management.

Because of its already-fielded 5-kHz capability and its recent upgrades for MIL-STD-188-183 and MI-STD-188-182A operation, the Air Force-developed NCS was selected as the starting point for the JMINI RC subsystem. The CC requirement is to be able to operate every UHF channel in a DAMA mode, which adds up to over 300 channels globally. For the remainder of the CC requirement, the Navy will be procuring a next generation radio, the Digital Modular Radio (DMR). There was no direct product available to leverage the NMS; therefore a new product is being developed to provide the software tools to allow decentralized communications planning and management.

COMMUNICATION PLANNING

The UHF constellation has historically operated with only one network per channel. Some channels do have two networks, using frequency division to share a channel, and there are a few DAMA channels in each satellite coverage area. The process of planning which users get service, allocating networks to channels, and handling conflicts is done via manual coordination and manually with some rudimentary tools. For clarity, a *network* is defined as two or more user terminals communicating together with the same data type (voice, message, etc.) and encryption technique. As more and more channels transition to DAMA, and as the user population increases ten-fold, the process of planning and management will become overwhelming. In addition, the DAMA CONOP requires the management process itself to be distributed into the battlefield to provide necessary information required for re-planning in response to the real-time operational environment. These factors contribute to the need for automated communications planning and management tools to be provided by the JMINI Control System's NMS.

As stated above, whereas the RC subsystem is an enhancement to the existing NCS, and the CC subsystem will be provided through the DMR program, there was no product available that could be modified to become the NMS. A product that provides planning and management tools used for EHF MILSATCOM does exist, however. This system, known as the Automated Communications Management System (ACMS), did allow for some design and code reuse to begin the development of the NMS.

The starting point for the NMS was to understand the manual processes its tools will replace, leading to the development of a planning/management Concept of Operations (the NMS CONOP). As documented in this CONOP, it was highly desirable to utilize existing computer systems where possible since many facilities are space-constrained. It was also important to implement a familiar operator interface to simplify training since military departments are manpower constrained[f].

The NMS will enable decentralized communications planning and management by providing software tools to:

- Access and maintain databases of user terminal descriptions, capabilities, and configurations, network service definitions and membership, satellite ephemeris data, and MILSATCOM channel descriptions (e.g.. frequency codes, channel numbers, channel names, uplink and downlink frequencies, translation offsets, access mode);
- Apportion satellite resources among CINCs, services components and supporting echelons, and other agencies tasked to support operational missions and exercises;
- Allow these organizations and agencies to define and establish the relative priorities (ranking) of their own communications service requirements (CSRs);
- Determine best-fit communications service allocations and preassign and schedule resources for the most critical communications requirements;
- Monitor system performance to compare actual against planned operations, assisting the communications manager in finding ways to optimize the use of the limited UHF MILSATCOM resources; and
- Automate some of the planner's manual tasks.

[f] The Defense Information Infrastructure (DII) Common Operating Environment (COE) establishes a standardized set of applications, hardware, and User Interfaces to promote uniformity across DoD systems.

It was also understood that flexibility and modularity in software design would be extremely important since the requirements were not completely firm and the software would be developed incrementally. The software design objectives included reuse of existing modules from ACMS, portability, and to be able to add new functions simply. Therefore, the NMS is being developed using a true object oriented approach that uses a functional architecture as shown in Figure 1.

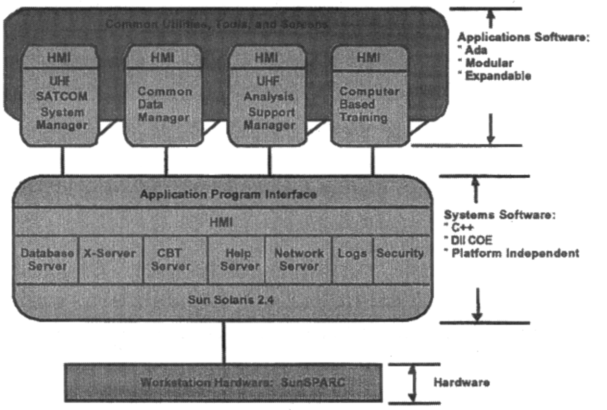

Figure 1. NMS Layered Architecture

This architecture will be fielded for IOC and is designed to be located at four main ground control points worldwide. This configuration will serve as the basis of a more elaborate distributed computing architecture for FOC. For IOC there are three main functional layers: the hardware – which is a Sun SPARC workstation, the system software – consisting of the Solaris operating system, database and other segments as an integrated portion of the DII COE, and the application software – customized modules designed for growth.

The NMS objective is to have a planning and management capability at many different levels, corresponding to "resource owners". A resource owner is typically an organizational entity that has authority to operate their network(s) over specific channels or DAMA time slots. The establishment of resource owners follows a well-documented process outlined in a Chairman of the Joint Chiefs of Staff Instruction. In accordance with NMS objectives, all users outside the four main ground control points (the JMINI Control Stations at the NCTAMS and NCTS Guam) will connect to these systems via a secure network using *any* existing computer that has access to the secure network and a Web browser. With modern client/server systems this method is very practical. The IOC configuration has been designed to allow for this expansion by using an object oriented design together with the Common Object Request Broker Architecture (CORBA). CORBA provides the "middleware" for distributed processing capabilities, promotes the maximum degree of machine and language independence and includes an interface to Java, thereby allowing easy scalability of capabilities through time. Objects representing satellites, terminals, or networks, for example, can be located anywhere within the distributed architecture and exchanged between processes using the Internet InterOrb Protocol (IIOP). This allows the Graphical User Interface (GUI) that runs on a Sun Workstation to be ported to other computers and still interface with the database for access and updates. Figure 2 illustrates the machine and language independence of CORBA.

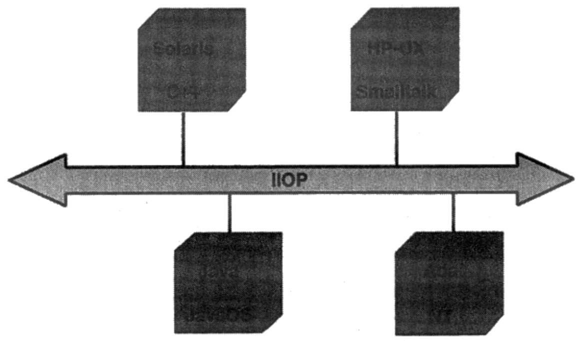

Figure 2. Machine and Language Independence

By FOC, there will be perhaps dozens of NMS users, most of which will be remote from the four control stations. They will use Web browsers to access and populate the database for the real-time resource controller. These NMS users will be able to handle the access requests, apportionment, allocation, and other processes electronically and rapidly, as well as perform their day-to-day mission even with as much as a ten-fold increase in DAMA users.

PROBLEMS WITH DAMA

While multiple access and demand assignment can greatly expand the number of users that UHF MILSATCOM can serve, nothing comes free. When a 25-kHz channel is used for a single "non-DAMA" voice network, the effective modulation rate over the satellite channel is equal to the baseband rate of the voice service. When DAMA is used, the modulation rate over the satellite channel has to exceed the sum of the data rates of all users. For example, when five users all operating at 2400 bps share a 25-kHz channel, each user is allocated 1/5 of the channel time and must operate at five times the normal modulation rate. The increased modulation rate, along with the requirement to break the signal into small bursts, requires a higher quality signal than required for single user operation. A channel that can provide good service for a single user communications requirement may operate poorly when DAMA-tized.

None of the DAMA terminals has been designed to provide the ease of use expected of a commercial cellular phone system. While the DAMA standards fully define how a terminal must communicate to the satellite, terminal communication to the user is not well defined or well understood. The requirement that the DAMA control orderwire be encrypted adds another level of complexity.

In DC mode the assignment of each time slot was fixed and the DAMA orderwire was not encrypted. A voice network was given a Circuit Identification Number (CIN) to identify the time slot it was allocated to and the user terminal operator only needed to acquire the orderwire and enter the CIN to join the network. With the introduction of AC mode, after acquiring the encrypted orderwire, the terminal operator must successfully transmit a return orderwire message to log in, transmit another return orderwire message to request to join a network, then wait for an orderwire message to direct connection to a network. If the operator has improperly set the terminal's address, port configuration code, or network address, the connection will be refused and an error message will be returned by the control system. The increased complexity of AC mode operation as well as limited user knowledge of the benefits and tradeoffs inherent in both 5-kHz and 25-kHz DAMA operation are two factors contributing to the hesitancy to move to DAMA.

The Navy was the first UHF MILSATCOM user to make the transition to AC mode. The transition was made in two steps. First, orderwire encryption was added to the existing DC mode controllers. Encryption of the DC mode orderwire allowed the Navy to identify and correct problems with orderwire encryption before attempting the switch to AC mode. AC mode operation requires orderwire encryption since orderwire requests can identify users and provide some indication of mission activity. The switch to AC mode was not problem-free. A few networks immediately experienced communication problems and AC mode was initially blamed and shut down. After extensive re-testing it was determined that the problems were not the fault of AC mode operation. Today there are 17 25-kHz channels operating in AC mode worldwide.

While technically we are operating these 17 channels in AC mode, there is currently little or no demand assignment being used. DAMA time slots are still being preassigned to each communication network. Many time slots are assigned to Navy messaging systems that require communications 24 hour a day, 7 days a week. Other time slots need to be preassigned because the baseband equipments being used are not capable of generating a DAMA request or responding to an incoming call. For example, voice networks are normally routed to a speaker. Hearing a voice from the speaker is the only indication that a "call" is coming in. Another major limitation to the use of demand assignment is Navy's use of single radios to operate in multiple networks. A single DAMA radio is used to connect to as many as eight separate networks. To operate on eight networks requires that no two time slots overlap in time. Since every platform must operate on a different set of networks, careful planning is required when assigning networks to time slots.

The transition to DAMA has progressed very slowly. In addition to the increased complexity that DAMA adds, and baseband equipment limitations mentioned above, other contributing factors are lack of terminals in the field and limited user training. Of these two problems, user training is probably the more serious. Despite the efforts of the DAMA Education team and service unique training programs, understanding of the most basic DAMA concepts seems to be lacking. For example, many users are not aware of the differences between the service quality on 5-kHz and 25-kHz DAMA channels and are, therefore, not anxious to move their secure voice requirements to DAMA channels.

Another problem that has kept many voice networks from transitioning to DAMA is user reluctance to accept the lower voice quality provided by 2400 bps LPC-10 narrowband vocoders. Some users currently use CVSD vocoders operating at 16 kbps on dedicated 25-kHz channels. This data rate is too high to be used efficiently on a DAMA channel. CVSD provides voice recognition and works well in the high background noise environment found in a helicopter and in the battlefield. LPC-10 works very poorly in a high background noise environment. MELP, a newly developed 2400 bps vocoder algorithm, solves both of these deficiencies but will not be generally available for several more years.

Users accustomed to operating over a dedicated channel are hesitant to accept the extra setup time required to operate over a DAMA channel. Users want guaranteed and immediate service when operating under battlefield conditions.

There are many UHF MILSATCOM systems using protocols that are incompatible with DAMA operation. The Navy has redesigned some of its systems to allow operation over DAMA, but many systems have requirements or funding problems that make it impossible to move them to DAMA channels.

Terminal fielding has also slowed the transition to DAMA operation. Terminals are being fielded by organization, not by network, however every member of a network must have a DAMA terminal before a network can be transitioned to DAMA operation. This problem will be resolved over time, if not by changes to fielding plans, then by the fielding of sufficient terminals. However, even if we solve the equipment and training problems, the severe interference problems we are experiencing on UHF MILSATCOM channels may become the limiting factor controlling the number of channels that can be switched to DAMA operation. As many as half of the channels currently have interference levels that are too high to allow DAMA operation.

NEW SATELLITES

The current UHF constellation will be complete after the launch of UFO-10 later this year. To prepare for the possible loss of one or more satellites during the planned lifetime of the UFO constellation, the Navy is in the process of procuring a single gapfiller satellite. UFO-11 will help ensure that adequate UHF communication resources will be retained until the next generation of satellites becomes available. While all previous UHF satellites have used analog filters and transponders, UFO-11 will use an all-digital design. Although this will make it possible to adjust the bandwidth and center frequencies of transponders after launch, the digital design may also reduce the dynamic range of the transponders. The Joint UHF MILSATCOM Technical Working Group (TWG) is investigating both the possible advantages and disadvantages of the new digital design.

The Mobile User Objective System (MUOS) is intended to be the next generation of satellites to provide narrowband communication services to mobile users. The MUOS requirements are performance-based and allow alternatives such as Low-Earth-Orbit (LEO) constellations to be considered. A key system objective is seamless operation with existing UHF systems and terminals, so the next generation of satellites is expected to provide services similar to those provided by the UFO constellation. The major MUOS goals are to greatly increase circuit capacity, increase the maximum data rate to 64-kbps, and to greatly improve the ability to communicate with very portable terminals having negative-gain antennas and very low transmit power. The most promising approach is the use of a mixture of earth coverage and spot beams. Spot beams allow frequency reuse within a satellite footprint while at the same time providing greatly increased link margins.

INTEGRATED WAVEFORM

The Joint UHF MILSATCOM TWG is working on a single integrated waveform standard that will provide a significant improvement over the two current DAMA waveforms now required for operation over 5-kHz and 25-kHz UHF military satellite channels. While the two current standards may have been sufficient for their intended purpose, they are not interoperable with each other and are not capable of satisfying all current and developing user requirements. This has contributed to the low user acceptance of DAMA, greatly slowing the transition of UHF MILSATCOM users from dedicated access to DAMA operation.

The TWG is presently developing a new layered protocol to be incorporated in revisions to the existing standards. The first revised standard will define the interoperable modulation, error-correction coding and multiple access protocols required to access the satellite channels. The second revised standard will define higher layer protocols, including demand assignment, required for full voice and data interoperability. MILSATCOM user systems not requiring interoperable voice and data would be required to implement only the lower layer protocols of the first standard. The integrated waveform standard will accommodate backward compatibility with the present standards.

The lower level multiple access protocol will operate much like 25-kHz DAMA DC mode, broadcasting stable channel and time slots assignments for all UHF SATCOM users. Setup and maintenance of these assignments will be performed by the NMS. At this protocol level terminals will have no ability to directly affect time slot assignments. A Forward Orderwire

Message (FOW) burst located within a time slot on a legacy 25-kHz controlled channel will be used to broadcast the assignment information for all channels. Navy messaging systems that require communications 24 hour a day, 7 days a week would operate on a stable time slot defined solely by this multiple access protocol, as would many voice networks that cannot tolerate the setup delays imposed by the higher layer demand assigned protocols. It is anticipated that many systems that cannot use DAMA today will be able to operate on top of this simplified multiple access protocol.

The higher layer protocols for voice and data interoperability will ride on top of the multiple access protocol layer, providing voice and data services similar to what is provided by commercial telephone systems. This protocol layer will use its own addressing plan, independent from any DAMA addressing plan, making it possible to interface to other secure voice systems.

The existing DAMA standards provide for fixed-rate "circuit" services, and fixed-length "message" services. Newer data protocols are generally designed to move data asynchronously, i.e. at variable data rates. Protocols that support the efficient handling of Internet Protocol (IP) datagrams will be developed to operate over the lower level multiple access protocols. A paper[6] presented last year at MILCOM'98 describes a proposed packet transfer mechanism, called the Variable Rate Data Packet (VRDP) transfer protocol, which could be used for this purpose.

CONCLUSION

In is anticipated that the increased circuit capacity, higher data rates, and improved quality of service that will become available with the launch of the next generation of satellites, along with the introduction of the integrated DAMA waveforms, will improve user acceptance of DAMA. The layered protocol design of the integrated DAMA waveform will allow the use of Commercial communication protocols over UHF satellite channels, providing simplified terminal operation and improved communication services similar to those provided by cellular phone systems.

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