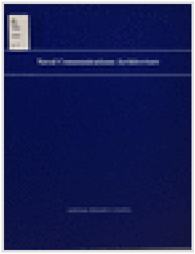

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NAVAL COMMUNICATIONS ARCHITECTURE

Task Group 2
Navy Space Panel
Naval Studies Board
Commission on Physical Sciences,
Mathematics, and Applications
National Research Council

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Executive Summary

Major changes in recently announced naval missions and strategy emphasize the need for comprehensive command, control, and communications (C^3) capabilities to support naval forces that are deployed globally and that are ready to project power ashore as part of a joint U.S. military force. Under this new doctrine, the Naval Force Commander requires these new capabilities either to command a joint task force or to host a joint task force commander, as well as to conduct assigned missions as part of that task force.

The Space Panel of the Naval Studies Board was asked by the Chief of Naval Operations to examine two areas relating to this new strategy. The first concerned the use of space and airborne systems in the surveillance, detection, identification, targeting, and battle damage assessment of a generic target set (including critical mobile targets) expected in regional conflicts. The second concerned the definition of a new space-based communications architecture to support a wide variety of naval tactical operations anticipated in a regional conflict environment. This report describes the panel's work to define a space-based naval communications architecture.

The effort involved a review of existing naval communications requirements as well as the definition of new requirements based on several postulated tactical situations involving precision strike operations. These requirements were characterized at the global, theater, regional, and tactical levels in terms of coverage, type of service, threat protection level (or robustness), timeliness to initiate the service, and capacity.

The results show that global coverage will continue to be needed well into the foreseeable future and that the need is particularly significant in the mid-latitudes. A wide range of communications services are required, depending on the specific level of command. These services are required for both fixed and mobile users and include voice, data, facsimile, video, and image transmission, with data rates extending from less than 10 kilobits per second (kbps) to upward of several hundred megabits per second (Mbps), again depending on the specific user and purpose. The degree of protection afforded these links ranged from "hard core" (high levels of antijam, intercept, and scintillation protection), through "soft core" (moderate levels of antijam and intercept protection), to "general purpose" (minimal protection). The panel concludes that naval communications have to be interoperable with joint service, allied, and selected coalition force systems and observes that this could be achieved most effectively through the use of waveform, frequency assignment, and communications protocol standards in most cases, and with common equipment in selected cases. The panel recommends that these requirements be incorporated into future Navy satellite communications requirements documentation.

The study reviewed current and planned military, civil, and commercial satellite communications capabilities, and the panel concludes that selected combinations of these systems (using existing technology) could meet most identified requirements. Current Navy communications is highly structured, with little flexibility to dynamically shift or reconfigure resources. Also, the current systems have limited throughput capacity and are vulnerable to unintentional, as well as intentional, interference, and jamming. The panel observes, however, that the Navy has strong programs in the ultra-high frequency (UHF) and extremely high frequency (EHF) bands, in terms of on-orbit and planned satellites and terminal development efforts. Also, recent efforts have been made to improve throughput capacity by making greater use of super-high frequency (SHF) systems on its principal command (Tomahawk-capable) ships.

The Navy currently makes only limited use of commercial satellite communications service. Large-scale use of this service by the Navy requires careful consideration of several factors, including (1) *coverage*—commercial systems provide only limited oceanic coverage and are driven more by the market potential over landmasses, (2) *frequency* assignments and compatibility with existing Navy terminals, (3) *shipboard electromagnetic interference* from local high-power transmitters, (4) *throughput* capacity available to military users, (5) *cost of service*, and (6) *treaty restrictions* on military use.

In defining a "goal" naval communications architecture, the panel concludes that this architecture, designated NAVSATCOM-21, should consist of a multilayered hierarchical structure of interconnecting networks that are geographically dispersed and employ differing topographies (i.e., mesh and hub-spoke) that allow point-to-point and broadcast services to network users. The architecture should include a global, high-capacity backbone network using optical fiber technology to achieve data throughput greater than 1 gigabit per second (Gbps), with both fixed and mobile gateways to selected task force elements and tactical units. High-capacity (several Mbps) tactical networks should provide connectivity among selected platforms and command nodes utilizing satellite communications relay, as appropriate, and these should interface directly to shipboard local area networks. The architecture should permit dynamic network management and control, and rapid configuration.

For those connectivities of the architecture requiring high throughput capacity (>2.4 kbps) to some fixed, but predominately mobile, users at over-the-horizon distances, the links should be implemented using integrated UHF, EHF, and SHF military satellite communications capabilities, heavily augmented by commercial systems where practicable. Figure ES.1 provides an overview of the principal elements of NAVSATCOM-21.

The panel recommends that the Navy maintain and reinforce continued investment in EHF as the principal *hard-core* and *soft-core* satellite communications resource and utilize UHF and commercial to support *general-purpose* requirements. Also, the Navy should consider adding a medium-data-rate (MDR) capability to existing low-data-rate (LDR) EHF terminals and investigate the feasibility (in terms of cost, schedule, and technical risk) of an MDR engineering change to the UHF Follow-On satellites. The Navy should continue its efforts at SHF as an interim soft-core capability (particularly the demand assign multiple access (DAMA) program) to increase the use of available SHF channel capacity—especially on the Defense Satellite Communications System (DSCS).

Also recommended is Navy investment in development of a low-cost multifrequency (C-, X-, and Ku-bands) shipboard terminal for increased access to services at SHF. Particularly important to this multifrequency terminal is a suitable antenna system. The panel endorses Navy efforts to develop a multimission, multi-user broadband antenna (MMBA) to achieve a more robust SHF capability with minimal space and weight requirements.

The panel acknowledges the Navy's expansive use of UHF as a general-purpose service and recommends that the throughput capacity of these systems be increased tenfold through the use of more efficient modems and modern modulation techniques, such as constant envelope, multiphase, trellis-coded approaches.

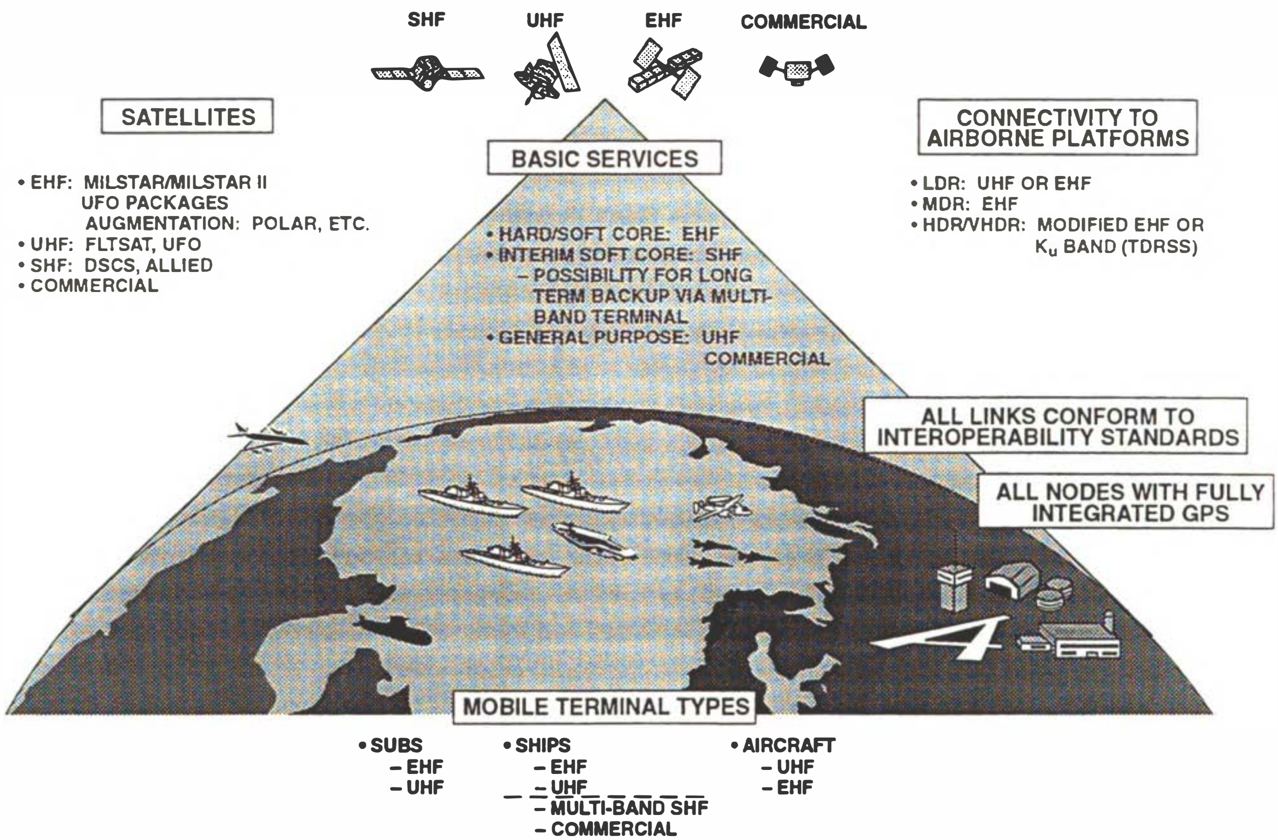

FIGURE ES.1 NAVSATCOM-21 overview.

The panel concludes that expanded use of the Global Positioning System (GPS) in all communications nodes is a straightforward way to improve control and operation of all Navy satellite communications in terms of more accurate positional knowledge (especially for mobile users) and timing synchronization, and recommends its full integration into these nodes as soon as possible.

Finally, the panel concludes that a robust satellite communications capability, as highlighted by the NAVSATCOM-21 architecture, could have a significant impact on the effectiveness of all expanded Naval Expeditionary Force missions, especially precision strike operations. Figure ES.2 summarizes the key features of NAVSATCOM-21 and relates the capabilities to conduct these operations today to those that would be enabled if the architecture were to be fully developed. The panel recommends that NAVSATCOM-21 be implemented in a time-phased manner in conjunction with ongoing Department of Defense (DOD) and commercial satellite communications development efforts, and through existing and planned Navy communications programs, including the Copernicus architecture effort, Communications Support System (CSS) effort, and advanced multifrequency terminal and antenna development efforts.

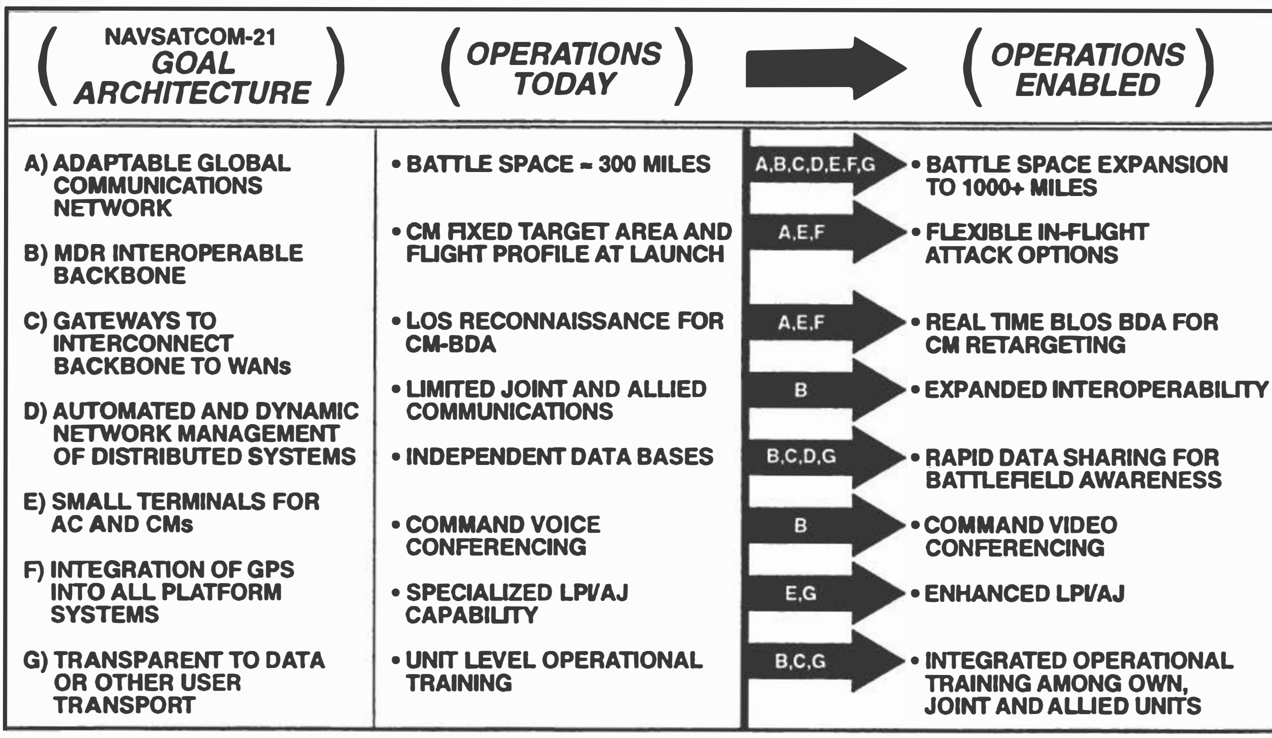

FIGURE ES.2 NAVSATCOM-21 key features summary and their impact on future naval operations. (The letters in the arrows identify the specific architectural feature(s) that affect the operations capability.)

1
Introduction and Background

1.1 CHANGING WORLD ORDER AND NATIONAL MILITARY STRATEGY

The United States has planned its military capability and posture since the end of World War II to contain the spread of communism and deter aggression by the Soviet Union and associated communist states.

Significant changes in the world order, most notably the collapse of communism in the Soviet Union and other Eastern European countries, the dissolution of the Warsaw Pact military alliance, the establishment of the Commonwealth of Independent States (CIS) (from the former Soviet Union), the reunification of Germany, and the emergence of independent and democratic governments around the globe, have prompted a significant change in this traditional defense approach. In August 1990, in an address in Aspen, Colorado, President Bush announced a new, regionally oriented national defense strategy that embodied four key elements: strategic deterrence and defense, forward presence, crisis response, and reconstitution. The disposition of nuclear weapons and delivery systems within the CIS and the proliferation of this technology to Third World countries remain uncertain and have prompted the need to maintain strong nuclear deterrent and defensive capabilities, including warning systems. The presence of U.S. forces throughout the world over the years has been effective in averting crises, preventing war, and demonstrating U.S. commitment to regional stability and prosperity. When forward presence has failed, however, U.S. forces have responded to regional crises on very short notice and have fought unilaterally or as part of a coalition. The United States, to continue responding in similar crises, must be capable of reconstituting a credible force—forming, training, and fielding new fighting units, activating the industrial base on a large scale, and maintaining a high level of technological advantage to oppose any potential adversary.

Early in 1992, the Chairman of the Joint Chiefs of Staff provided strategic direction for the Armed Forces that reflected this new national defense strategy. He issued the 1992 National Military Strategy,[1] which employed a set of strategic principles that encompassed a broad range of military areas, including readiness, collective security, arms control, maritime and aerospace superiority, strategic agility, power projection, technological superiority, and decisive force. He provided guidance on the planning and deployment of U.S. forces in responding to regional versus global threats and directed that operational planning be decentralized to the theater commanders-in-chief to the maximum extent possible, including the determination of force composition and recommended military strategies. A base force composed of four conceptual force packages—Strategic, Atlantic, Pacific, and U.S.-based Contingency Forces—was part of the strategy. These forces were supported by four key capabilities—space systems for warning, weather, surveillance, navigation, and communications; transportation systems to permit rapid deployment from U.S. bases to any region; reconstitution and mobilization capabilities on a large scale; and significant research and development capabilities to ensure technological superiority.

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[1]*The National Military Strategy*, Chairman of the Joint Chiefs of Staff document, 1992 (unclassified).

In September 1992, the Navy and Marine Corps, in support of the new National Military Strategy, issued a new directive for the naval service, entitled *From the Sea,*[2] to provide naval expeditionary forces operating forward from the sea in joint service operations. The directive represented a fundamental shift from open-ocean warfighting to regional conflicts involving littoral operations. The document focused on naval forces operating globally in a forward presence posture with the capability to project power ashore as part of a joint U.S. military force in crisis response situations.

Navy and Marine Corps command, control, and communications (C^3) capabilities were identified as a key element of this new direction. The Naval Force Commander would require new capabilities either to command a joint task force or to host a Joint Task Force Commander.

To achieve battlespace dominance in the sea, air, and land environments, this Commander, more than ever before, would have to rely on a highly capable C^3 system that used U.S. and coalition space-based assets to support his tactical needs.

1.2 CHARGE TO THE SPACE PANEL

Early in 1992, the Space Panel of the Naval Studies Board was asked by the Chief of Naval Operations (CNO) to conduct two concurrent studies that would suggest improvements in C^3 capabilities and define new naval systems required to conduct future global power projection missions.

The first task focused on surveillance, detection, identification, targeting, and battle damage assessment for targets expected in missions involving Third World or regional tactical conflicts. The results of this task are available in a separate report, entitled *Space Support to Naval Tactical Operations,*[3] and provide specific recommendations for intelligence systems, weapon support, and coordination for precision strike against critical moving and stationary targets; and surveillance, target identification, and battle damage assessment from airborne and space platforms.

The second task given to the Space Panel focused on naval communications. It was recognized that global power projection by naval forces would rely heavily on a communications capability to support voice and data traffic, surveillance and reconnaissance data exchange, strike targeting information, and intelligence data needed for mission planning and precision targeting.

The specific terms of reference given to the Space Panel for this second task are as follows:

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[2]*From the Sea*, Navy and Marine Corps strategy document, Secretary of the Navy, September 28, 1992 (unclassified).

[3]*Space Support to Naval Tactical Operations* (U), classified report by the Space Panel's Task Group 1 (National Academy Press, Washington, D.C., 1993).

Task 2—Naval Communications Architecture

Reliable, flexible, and affordable communications will be critical to support future naval operations. This study will evaluate current Navy space communications, including ultra-high frequency (UHF), super-high frequency (SHF), and extremely high frequency (EHF) systems. The ability of the current and planned communications architecture to support global naval operations will be assessed. The future capability provided by MILSTAR and UHFFO systems will be evaluated, as well as the potential of future LIGHTSAT communications packages and the expanded use of civil and commercial systems. The unique communications needs of the Navy in polar regions and the ability of the current systems to support expanded strike operations in tactical, global conflicts will be evaluated. The study will attempt to define a future space communications architecture for the Navy that will allow the successful execution of global conflicts. The study will include the use of commercial systems and recognize that tactical and administrative communications traffic will use common systems for many future naval operations. The need for satellite to satellite crosslinks versus the use of ground relay sites to tie this architecture together will be addressed.

Essentially, six specific areas were identified for investigation: (1) evaluate current Navy space communications systems, (2) evaluate planned military, civil, and commercial systems, (3) define a future global space communications architecture, (4) assess crosslink feasibility versus ground relay approaches, (5) evaluate current systems in expanded strike operations, and (6) assess current and planned Navy communications architectures. This report contains the results of the Task 2 study team effort that addressed these specific subjects.

1.3 APPROACH

1.3.1 Naval Communications and Scope of the Study

Naval communications capabilities have evolved over the past several decades to use selected frequency bands over a wide portion of the electromagnetic spectrum, from extremely low frequencies (ELF) at tens of hertz (Hz) to extremely high frequencies (EHF) at tens of gigahertz (GHz). Radio frequency propagation characteristics, information bandwidth, and operational posture are the key parameters for selecting the frequency band of operation for a particular application. For example, communications to submarines use the lower frequency bands (ELF, VLF, and LF) to achieve seawater penetration of the signal to floating wire or towed buoy antennas at long distances (thousands of miles) when the platform is submerged. The information bandwidth at these frequencies, however, permits only low data rates, generally from a few bits per minute to roughly 50 bits per second (bps). Operation in the high frequency (HF) band allows increased data rates (up to a few kbps) at beyond line-of-sight distances using both ionospheric and ground wave propagation modes. One must move to the ultra-high frequency (UHF), super-high frequency (SHF), and extremely high frequency (EHF) bands to realize high information throughput (tens to thousands of kbps). However, in doing so the operator must be willing to deal with line-of-sight distances and atmospheric attenuation principally by water vapor, particularly at EHF frequencies.

As indicated by the task, this study focused on naval space communications systems that operate in the UHF, SHF, and EHF frequency bands because of their capacity for high information throughput and global coverage by relays. The study considered the space, ground, and control elements of these systems. Because this work was conducted concurrent with Task 1, it was necessary to consider airborne relay platforms, especially when addressing the tactical situations involving deep strike missions.

1.3.2 Study Methodology

The approach employed in this study is illustrated by Figure 1.1. To achieve a reasonable understanding of naval communications requirements, an effort was made to review naval missions and doctrine in light of the new strategies previously discussed. This effort also reviewed the results of the Task 1 study to incorporate any additional requirements that might emerge from the precision strike scenarios being considered. These requirements were then compared to the current and planned satellite communications capabilities of the Department of Defense (DOD), other government agencies, allied countries, and commercial sources to identify critical shortfalls and specific performance, technical, programmatic, organizational, or legal issues that exist with respect to the requirements identified earlier.

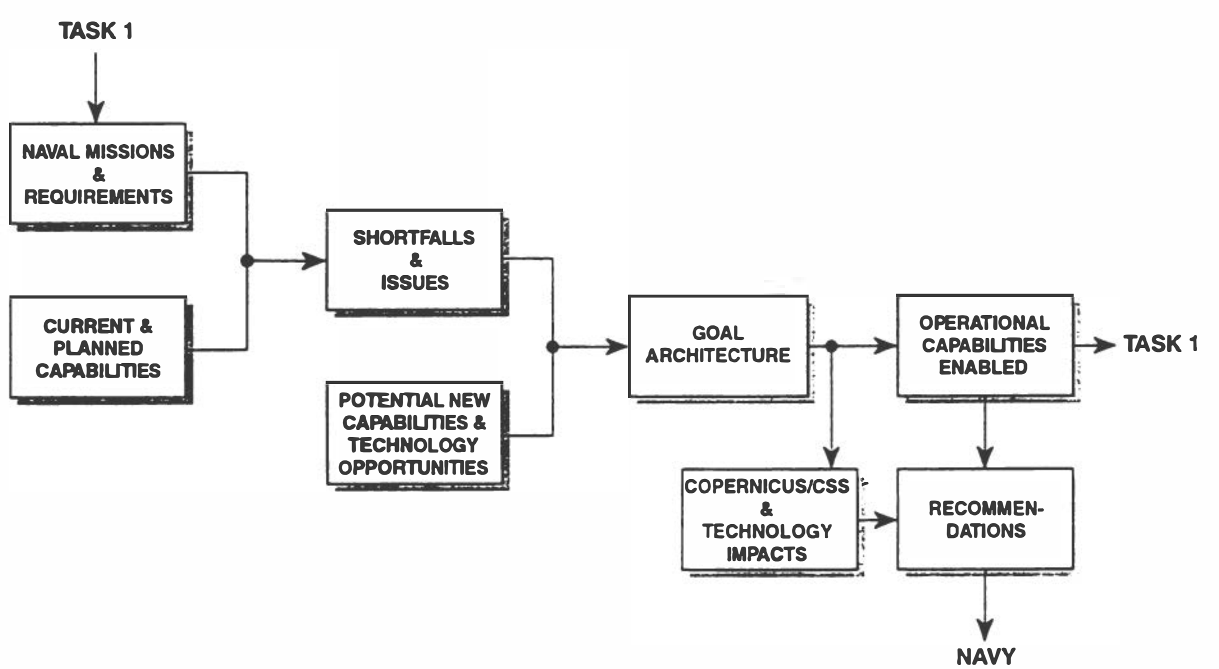
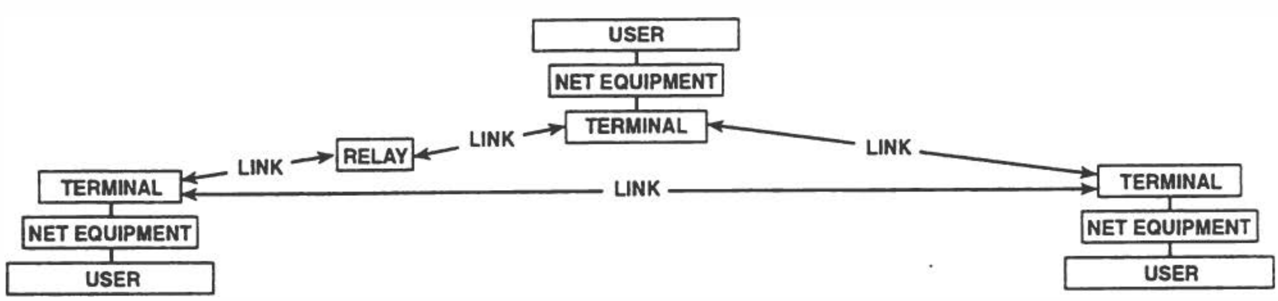


FIGURE 1.1 Study methodology to develop a goal naval communications architecture.

A review of new satellite communications capabilities, particularly in the commercial sector, was conducted to ensure that all possible opportunities were considered in developing a goal naval communications architecture. This goal architecture was then identified based on consideration of current and planned military, civil, and commercial systems and the availability of new technology. The resulting goal architecture was then compared with operational requirements to determine what new tactical capabilities could be achieved if this architecture were implemented. This information was fed back to the Task 1 team so that new communications approaches would be incorporated into precision strike planning. It was also compared with the current Navy communications architecture, known as Copernicus, and the ongoing Communications Support System (CSS) project to identify similarities and/or differences for possible Navy consideration. These comparisons led to a series of specific recommendations to the Navy for consideration in developing satellite communications systems for the global power projection mission.

1.3.3 Glossary of Terms

In the course of this study, it was necessary to develop a satellite communications systems taxonomy to ensure uniform use of terms among all study participants. Figure 1.2 provides a glossary of terms used in the study and an illustration of the key components of a multi-user satellite communications network. The terms are used extensively throughout this document and are provided here for the convenience of the reader. A more extensive list of acronyms and abbreviations is provided in the appendix.



- Communications: Information exchange among users (one-many, one-one, many-many)
- Connectivity: A measure of the number of users that can exchange information
- Network: A set of users organized for information exchange
- Links: Means used to connect two or more users for communications
  - Can carry information (voice, video, facsimile, imagery, data)
  - At one or more frequencies (VHF, UHF, SHF, EHF)
  - Earth-to-space/air, space/air-to-earth, space/air-space/air
- Circuits: Characterize links as one-way or two-way
- Relays: Retransmit information and data received from one link on another
- Terminals: Equipment employed by users to provide one or more links
- Net Equipment: Equipment employed by users to constitute a network

FIGURE 1.2 Naval communications architecture glossary of terms and network illustration.

2
Naval Communications Requirements

Naval satellite communications requirements are driven by the missions that naval forces are called upon to execute and by the operational doctrine developed to fulfill these missions. The mission determines what needs to be done, and the doctrine determines the equipment, personnel, and communications required to execute the mission.

2.1 MISSION AND DOCTRINE

The post-Soviet world, as discussed in the previous chapter is a substantially different and more complex military environment. As a result, both doctrine and mission are changing. The doctrine of an apocalyptic battle with the Soviets has been replaced with numerous small actions against regional military threats. These conflicts may have limited scope and objectives. Also, whereas earlier some U.S. losses were acceptable, now such losses are unacceptable. This change in attitude, and the simultaneous requirement to minimize even enemy civilian casualties, greatly increases information requirements. For example, stopping and boarding a particular ship require more information (and less ordnance) than preventing all shipping from transiting a choke point. The information flow has to be two ways: the operating forces need access to databases and rules of engagement; the National Command Authority (NCA) needs near-real-time information on the precise situation as it occurs to determine an appropriate plan of action.

The doctrine is evolving to keep pace with the changes. The Commander-in-Chief (CINC), U.S. Pacific Forces (USCINCPAC), has developed a two-tier concept in which a Joint Task Force Commander (CJTF) is designated to deal with a particular situation, reporting directly to USCINCPAC; the component commanders (in this case, Pacific ground, air, and fleet commanders) are out of the operational chain of command but provide administrative and logistical support. Although this change simplifies the decision-making process, it places the decision maker away from much of his supporting infrastructure, such as intelligence and communications facilities. This separation imposes additional communications requirements of its own.

The requirements discussed are taken in part from the Navy's input to the Joint Staff Integrated Satellite Communications Requirement Document on Doctrine Based Requirements.[1] The Navy's input reflected the requirements for global operations but did not incorporate the requirements of expanded strike operations discussed by Task Group 1. Those expanded requirements are added to the global operations requirements in this report.

[1]Joint Staff Integrated Satellite Communications Requirement Document on Doctrine Based Requirements (SECRET), April 1992.

2.2 REQUIREMENTS HIERARCHY FOR GLOBAL OPERATIONS

Communications requirements can be segmented into four tiers consistent with the command structure. At the highest level are the connections between the National Command Authority (NCA), national agencies, and the CINC. This is the global level, since similar connections must be available to support all CINCs. At the second level are the connections between the CINC and the CJTF, referred to as the theater level. The third level involves the connections between the CJTF and JTF elements and is referred to as the regional level. The fourth level involves the connections between JTF elements and individual ships and aircraft. The requirements at this level are tactical communications requirements to support the operating forces and are referred to as tactical-level requirements.

Each requirement can be satisfied by one or more communications links. These links may differ in the protection of the C^3 function they provide. Generally, there is a tradeoff between communications rate and vulnerability level. Higher integrity levels are obtained at the expense of reduced communications rates. At the highest level of integrity, called hard core, links are protected against nuclear scintillation effects, high levels of jamming, and interception by hostile forces. Hard-core links are required where message delivery must be assured. If delivery of a message can be delayed until the jamming threat decreases, then soft-core or even general-purpose links may be all that is necessary.

Soft-core links provide moderate antijam capability. General-purpose links provide the highest capacity but give no protection against jamming or intercept and detection. One requirement that all links share is the need for communications security; that is, the data elements that pass over the link must not be exploitable by hostile listeners.

Each link may be described in terms of the type of service it provides, the data rate passed over it, the length of time to establish the link, and the degree of protection required. Table 2.1 shows the definition of the terms for low, medium, and high data rates. It also shows the definition of the terms used to describe how rapidly a circuit should be established—near real time, moderate, slow, and very slow. Finally, it reiterates the terms for link integrity.

For each of the levels, the types of services required were examined and translated into a bit rate. The conversion values used are contained in Table 2.2. The nature of the links required and their number were examined to estimate the aggregate bit transfer rate required and the degree of protection required.

TABLE 2.1 Requirements and Key to Terms

DATA RATE	LDR	Low data rate	Data rate ≤ 9.6 kbps
	MDR	Medium data rate	9.6 kbps < data rate ≤ 1.54 Mbps
	HDR	High data rate	1.54 Mbps < data rate ≤ 44 Mbps
	VHDR	Very high data rate	44 Mbps < data rate ≤ 274 Mbps
TIMELINESS	NRT	Near real time	Delay ≤ 1 second
	MOD	Moderate	5- to 10-second delay
	S	Slow	1- to 5-minute delay
	VS	Very slow	30- to 60-minute delay
THREAT ENVIRONMENT[a] (LPI AND AJ)	GP	General purpose	LPI $R_c/R_i < 2$; AJ $R_c/R_j < 2$
	SC	Soft core	LPI R_c/R_i 2 to 10; AJ R_c/R_j 2 to 10
	HC	Hard core	LPI $R_c/R_i > 10$; AJ $R_c/R_j > 10$; Nuclear Scintillation

[a]The ratios of communications range to interceptor range (R_c/R_i) and communications range to jammer range (R_c/R_j) are typically used to illustrate the degree of threat protection associated with specific communications links. For example, $R_c/R_i = 2$ means that the range from the communicator to the intended receiver is equal to twice the range from the communicator to the interceptor, and thus the low probability of intercept (LPI) capability of such a link would be *low*. If the ratio $R_c/R_i > 10$, then the LPI capability is *high*, and similarly for the ratio of communications range to jammer range (R_c/R_j). The antijam (AJ) margin is *low* if $R_c/R_j < 2$ and *high* if $R_c/R_j > 10$.

TABLE 2.2 Requirements and User Services

VOICE	LDR, MDR (2.4 to 64 kbps)
DATA	LDR, MDR (75 to 300 bps; 1.2 to 56 kbps)
FAX	LDR, MDR (2.4 to 64 kbps)
IMAGERY	LDR, MDR, HDR, VHDR (2.4 to 56 kbps; 5 to 274 Mbps)
VIDEO	MDR, HDR, VHDR (64 kbps; 1.5 to 274 Mbps)

Data rates are derived from Navy and commercial usage.

2.2.1 Global Level

At the global level, communications are required to exchange information between the NCA, CINCs, and national agencies. The services required to support a CINC staff include voice, facsimile, data, imagery, and video. Much of this support can be satisfied by commercial terrestrial and satellite communications. The required connectivity changes very slowly, so links are established and disconnected infrequently. An overall information throughput in excess of 100 Mbps is required at the global level.

CINCs are located near the mid-latitudes; only a limited requirement exists for polar coverage. Some of the communications, such as threat-warning conferences, strategic coordination and planning meetings, and dissemination of emergency action and report-back messages, requires integrity protection at the hard-core level. Other tactical information, such as operational plans, requires protection at the soft-core level. The remainder of the links may operate at the unprotected or general-purpose level.

Links at the global level may be characterized as high capacity between a limited number of fixed users.

2.2.2 Theater Level

Communications links between the CINC and his CJTFs and among the CJTFs, including allied field commands, represent the theater-level network. The aggregate data transfer rates required are high (in excess of 1.5 Mbps) but significantly less than required at the global level. The same overall services are required as at the global level (i.e., voice, data, facsimile, imagery, and video), but the connectivity changes more often as task forces are formed and disestablished. No more than three CJTFs are expected in a theater at any one time.

This level of operations introduces new requirements: polar coverage in addition to mid-latitude coverage and beyond-line-of-sight (BLOS) connectivity to mobile users. Since the CJTFs may be afloat or mobile, and at considerable distance from the CINC and each other, their support requires high-volume BLOS links.

2.2.3 Regional Level

Links at the regional level are links between the CJTF and his JTF element commanders. Operational messages, such as the air-tasking order (ATO) would be passed at this level. This level is characterized by a number of medium data rate links, none of which is large individually. Similar services are required at this level as at the higher levels (i.e., voice, data, facsimile, and imagery), but video teleconferencing is not required.

The connectivity requirements, including polar region coverage, may change rapidly, as smaller task forces are formed and disestablished. No more than 10 task forces per CJTF at any one time are expected.

Because of the generally smaller scale of operations within a region, many of the links will require line-of-sight (LOS) connectivity. The communications requirements may be satisfied by a combination of LOS and BLOS links.

2.2.4 Tactical Level

At the tactical level, communications are required between JTF element commanders, ships, aircraft, and ground units that carry out the operations. Under some proposed concepts, cruise missiles may transmit and receive information while in flight. Data rates are generally modest—approximately 64 kbps between mobile users. Services required will include voice, data, imagery, and facsimile transmission.

Connectivity is very dynamic at this level, as individual units enter and exit various networks. A large number of platforms are involved, possibly more than 100 at any one time. Fortunately, many of the communications requirements may be satisfied by line-of-sight links.

Communications at this level require the greatest degree of threat protection. Most tactical operations require timely exchange of information at close proximity to the enemy. The hard-core requirement is still low, approximately 10 percent, but the soft-core requirement rises to 60 percent. It is estimated that only a moderate requirement exists for general-purpose communications.

2.2.5 Global Operations Summary Requirements

Table 2.3 summarizes the services, data rates, link establishment times, and protection required for each of the four levels. The data rates shown are for individual data links. The number of data links depends on factors such as the size and composition of the JTF. As can be seen from the table, slow or very slow link establishment times are acceptable for all cases. The degree of threat protection required increases as one moves from the global to the tactical level. The services required stay remarkably stable, except for video, which drops out at the regional level. The data rates required over an individual link decrease from the global to tactical levels, and the number of links between entities decreases rapidly.

TABLE 2.3 Requirements: Global Operations Summary

	Global Level			Theater Level			Regional Level			Tactical Level		
Voice	LDR MDR	S	HC SC GP	LDR	S	HC SC GP	LDR	S	HC SC GP	LDR	S	HC SC GP
Data	LDR MDR	S	SC	LDR MDR	S	SC	LDR MDR	S	SC	LDR MDR	S	SC GP
Fax	LDR	S	GP	LDR	S	GP	LDR	S	GP	LDR	S	SC
Imagery	MDR HDR	VS	GP	MDR	S	SC	MDR	VS	SC	MDR HDR VHDR	VS	SC
Video	MDR HDR	VS	GP	MDR	VS	GP	None			None		

Legend:	Data Rate	Timeliness	Threat Protection
	Low data rate	Near real time	Hard core
	Medium data rate	Moderate	Soft core
	High data rate	Slow	General purpose
	Very high data rate	Very slow	

2.3 ENHANCED STRIKE OPERATIONS

As mentioned in Chapter 1, the Space Panel also conducted a parallel study, entitled *Space Support to Naval Tactical Operations*, in which a number of enhanced strike options or constructs were examined. Each of these constructs would likely impose additional communications requirements at the regional and tactical levels. They are treated in this section to develop a more complete set of communications requirements.

Construct 1, called *Deep Strike*, addresses the requirement to suppress critical stationary targets at long range. It uses cruise missiles and stealthy long-range strike aircraft. A possible development within this construct is a cruise missile that provides sensor data and/or battle damage assessment (BDA) on its way to the target. The missile may also be redirected in flight. Figure 2.1 illustrates the *Deep Strike* concept.

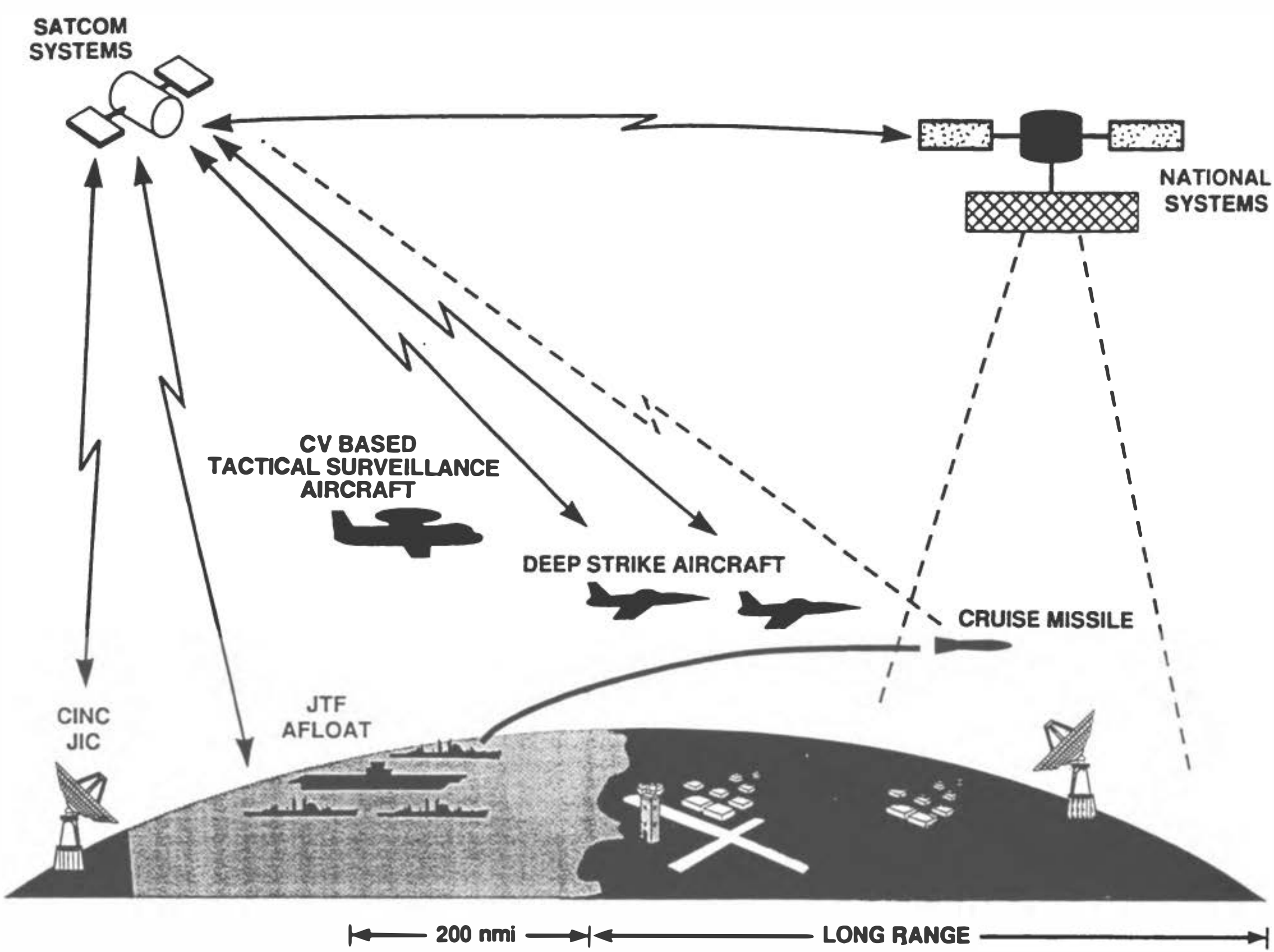


FIGURE 2.1 Construct 1—deep strike.

Construct 2, called *Control of the Coastal Zone*, is designed to provide continuous defense suppression and close air support to 250 nautical miles inshore. It uses a mix of stealthy and conventional strike aircraft and relies on an aircraft carrier (CV)-based tactical surveillance aircraft. This aircraft may also provide a communications relay to strike aircraft prosecuting targets. Figure 2.2 illustrates the *Coastal Zone* concept.

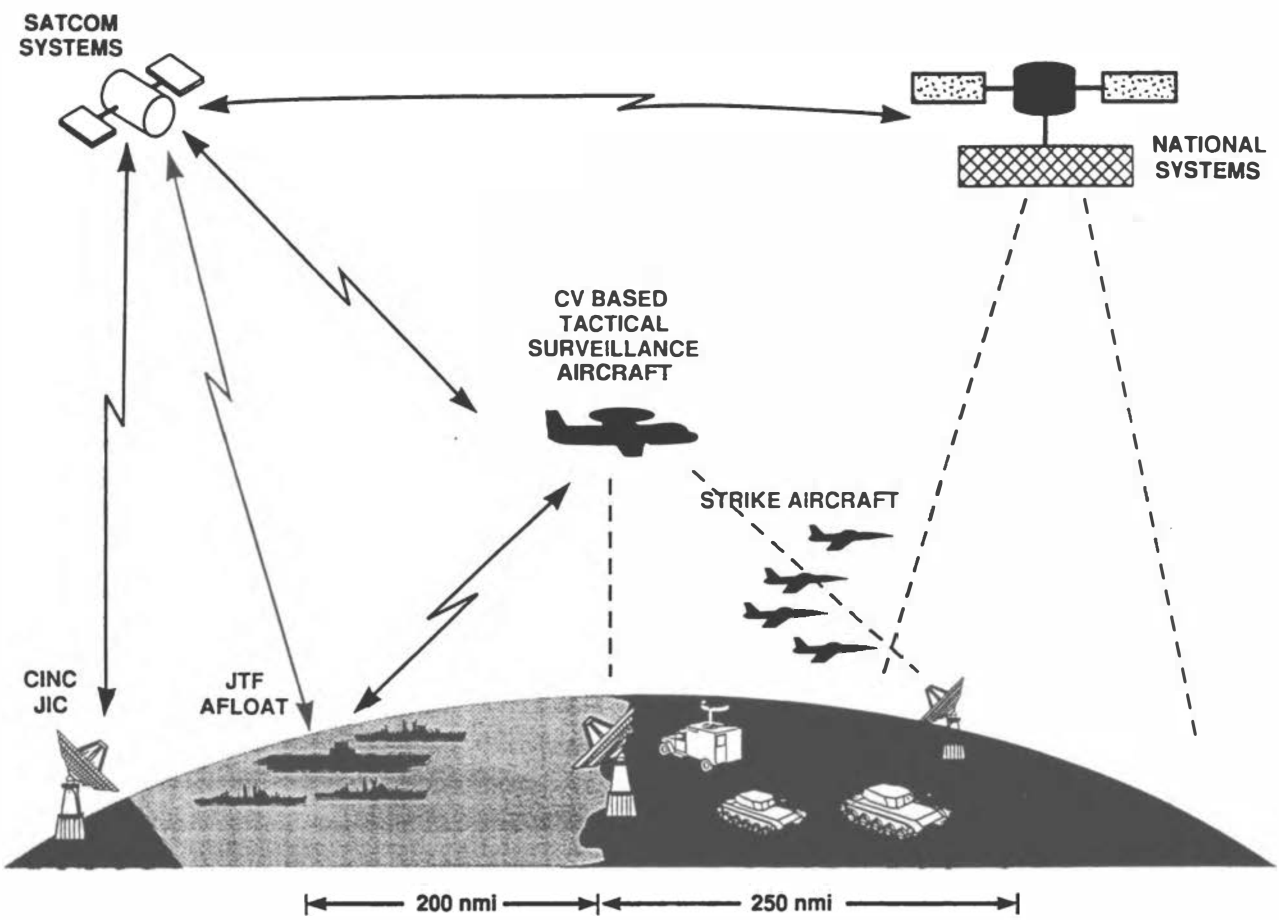


FIGURE 2.2 Construct 2—control of the coastal zone.

Construct 3, called *Control of the Extended Coastal Zone*, is designed to expand the Construct 2 concept to 800 nautical miles from the coast for strikes against targets far inland. This concept introduces long-endurance aircraft as sensor platforms and as communications relays. Figure 2.3 illustrates the *Extended Coastal Zone* concept.

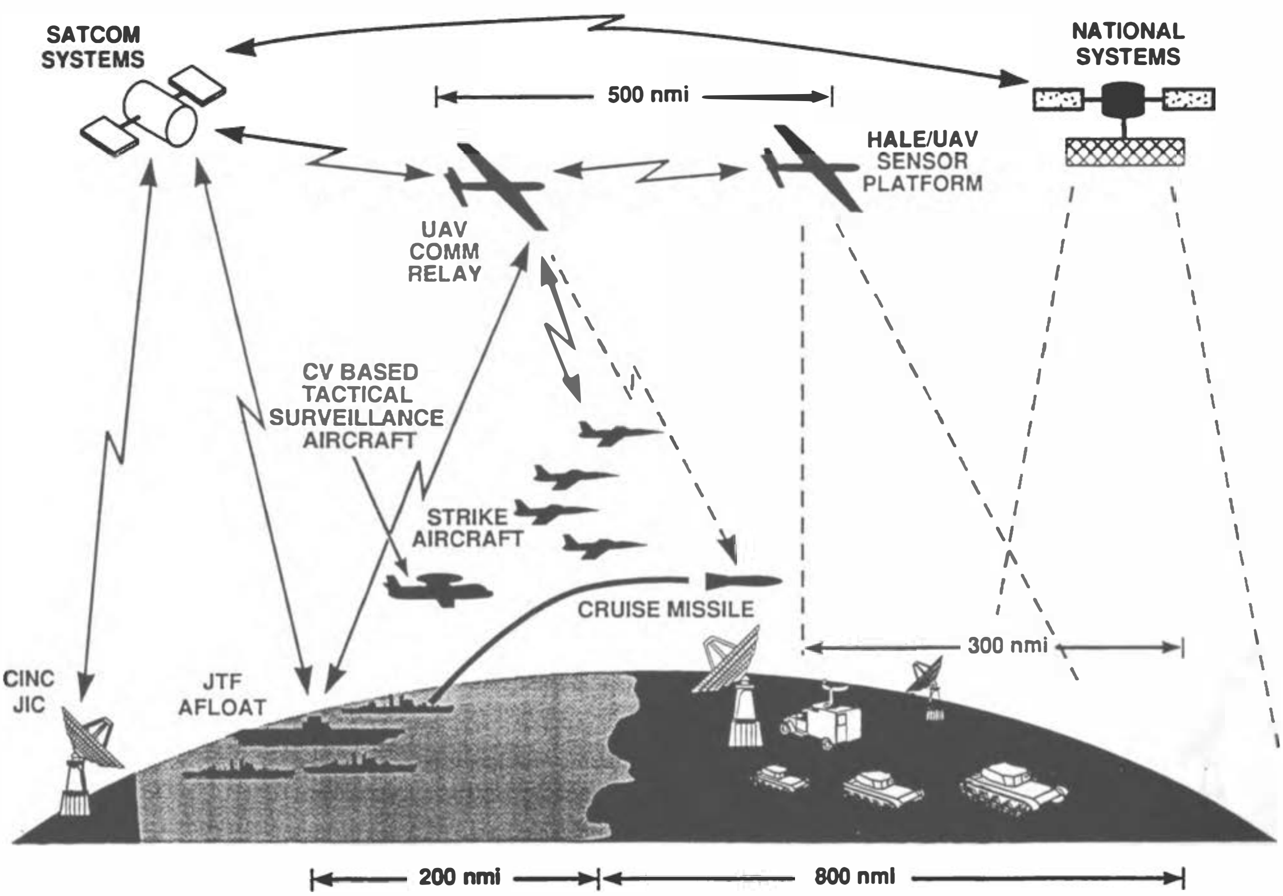


FIGURE 2.3 Construct 3—control of the extended coastal zone.

Construct 4, called *Control of the Extended Coastal Zone with Added Space Capability*, adds improved space sensors and extends the penetration range beyond 800 nautical miles. Figure 2.4 illustrates this *Added Space Capability* concept.

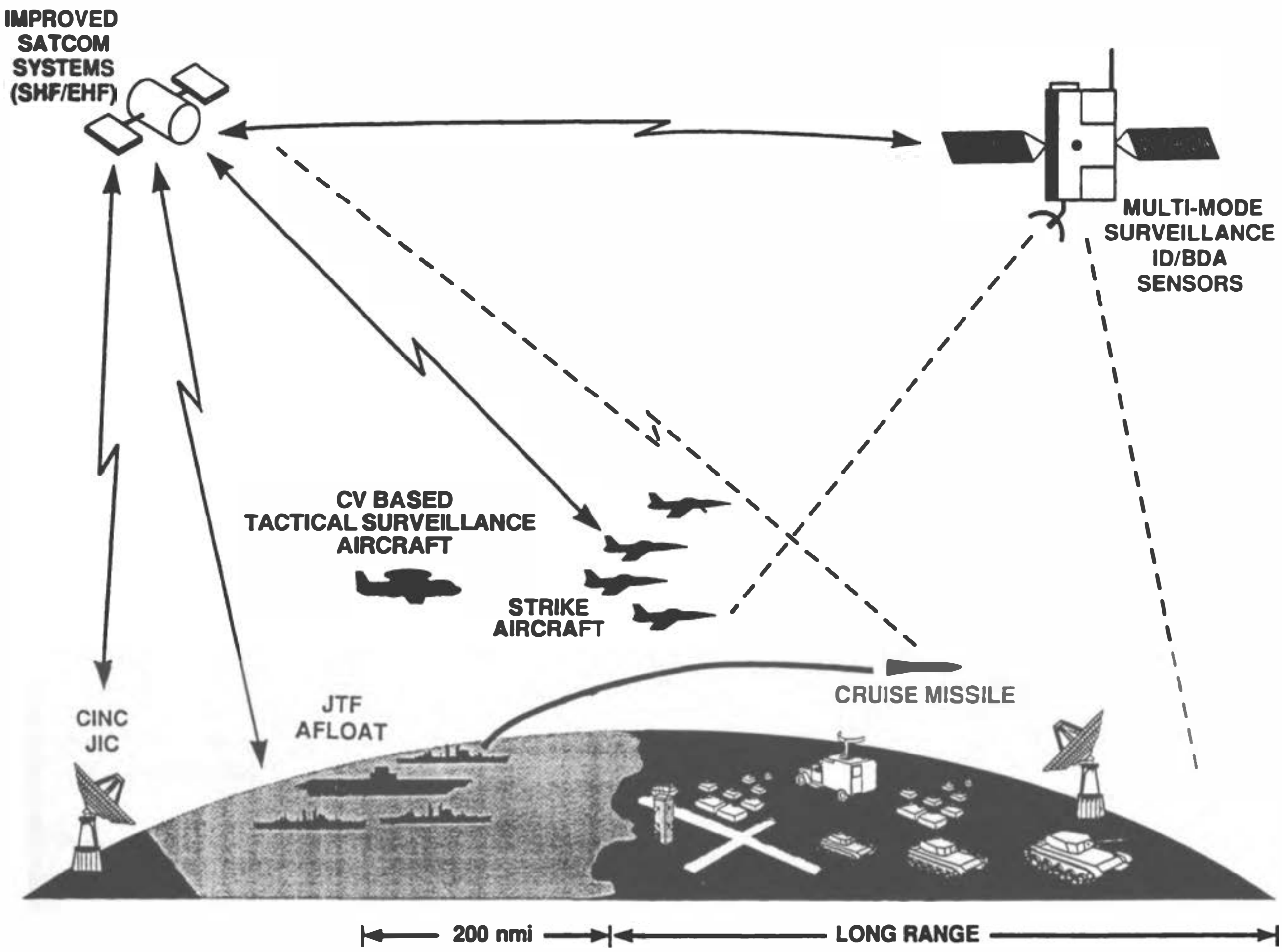


FIGURE 2.4 Construct 4—control of the extended coastal zone with added space capability.

The communications requirements imposed by these enhanced capabilities are summarized in Table 2.4. For each construct, there are four phased functions. The first phase, which is essentially *peacetime planning and training*, is characterized in Constructs 1 and 4 by modest voice, data, and imagery links. Constructs 2 and 3 introduce airborne sensor platforms that require high data rate video links. All these communications need to be beyond the line of sight to mobile users.

TABLE 2.4 Requirements for Expanded Strike Operations (Regional/Tactical Level)

Construct / Phased Functions	1 Deep Strike (1,000 M)	2 Ground Targets Suppression (250 M)	Alt. to (2) 3 Ground Targets Suppression (800 M)	4 Space-Based Targeting (1,000 M)
Day-to-Day Training and Exercises and Mission Planning	Voice, LDR,VS, GP Data LDR/MDR, VS, GP Imagery, LDR/MDR, VS, GP	Voice, LDR, M, GP Data MDR/HDR/VHDR, M, GP Imagery, MDR/HDR/VHDR, M, GP Video, MDR/HDR/VHDR, M, GP	Voice, LDR, M, GP Data MDR/HDR/VHDR, M, GP Imagery, MDR/HDR/VHDR, M, GP Video, MDR/HDR/VHDR, M, GP	Voice, LDR, VS, GP Data LDR/MDR, VS, GP Imagery, LDR/MDR, VS, GP
Rapid Retargeting	Data, LDR/MDR, VS SC Imagery, MDR, VS, SC	Data, MDR/HDR/VHDR, NRT, GP Imagery, MDR/HDR/VHDR, NRT, GP Video, MDR/HDR/VHDR, NRT, GP	Data, MDR/HDR/VHDR, NRT, GP Imagery, MDR/HDR/VHDR, NRT, GP Video, MDR/HDR/VHDR, NRT, GP	Data, MDR/HDR, M, SC Imagery, MDR/HDR, M, SC
Execution	Voice, LDR, S, SC	Voice, LDR, M, SC Data, LDR, M, SC	Voice, LDR, M, SC Data, LDR, M, SC	Voice, LDR, M, SC
BDA *Cruise Missile*	Data, LDR/MDR, VS, SC Imagery, MDR, VS, SC *Data, LDR/MDR, NRT, SC*	Data, MDR/HDR/VHDR, NRT, GP Imagery, MDR/HDR/VHDR, NRT, GP Video, MDR/HDR/VHDR, NRT, GP	Data, MDR/HDR/VHDR, NRT, GP Imagery, MDR/HDR/VHDR, NRT, GP Video, MDR/HDR/VHDR, NRT, GP	Data, LDR/MDR, M, SC Imagery, MDR/HDR, M, SC

Legend:

BLOS (shaded) LOS (unshaded)

In the next phased function, *rapid retargeting*, strike assets may be diverted on their way to the target. Again, Constructs 1 and 4 require modest BLOS data and imagery links. Construct 4 requires more because of the increased data collection volume of improved satellite systems. Constructs 2 and 3 require rapidly established, high-data-rate, unprotected LOS links for data, imagery, and video. In these constructs the airborne communication relay relieves the BLOS requirement.

For the *execution* phase, Constructs 1 and 4 require protected beyond-line-of-sight voice links. Constructs 2 and 3 require soft-core line-of-sight voice and data.

For the *battle damage assessment* phase, Constructs 2 and 3 require the same capabilities as the rapid retargeting phase. Constructs 1 and 4 also require the same capabilities as the rapid retargeting phase, except that in the case of the advanced cruise missile, a low or medium data rate link is required to pass BDA and way-point data to and from the missile. This link must be protected at the soft-core level.

2.4 OBSERVATIONS

Several observations concerning the naval communications requirements follow:

- The capacity requirements change from a few high-capacity users at the global and theater levels to many low-capacity users at the tactical level.
- Most users at theater level and below are mobile, require links beyond line of sight, and must be able to establish and disestablish links rapidly.
- The requirement for antijam and LPI communications increases from the global to the tactical level and is especially important at the regional and tactical levels.
- Interoperability among U.S. forces and with allied forces is required at all levels of command.
- Expanded strike operations increase the need for imagery at the tactical level. The introduction of new sensor systems will increase the data rates required to take advantage of new capabilities.
- Some of these sensors may integrate their own line-of-sight links, but many strike assets will require high-capacity beyond-line-of-sight connectivity.

3
Current and Programmed Satellite Communications Capabilities

This chapter describes the panel's efforts to investigate current and planned satellite communications capabilities of the DOD, other agencies of the government, and allied countries and commercial organizations; determine if there are shortfalls in current and planned Navy capabilities; develop issues as a result of the shortfall investigations; evaluate potential new capabilities and technologies, particularly those in the commercial sector; and recommend promising technologies and programs to the Navy to support the power projection mission. The results of these investigations were viewed as input to the development of a naval communications architecture.

This effort was chartered to look at a broad range of programs, capabilities, and technologies, and, therefore, the results extend beyond the boundaries of a goal architecture, which is necessarily constrained by resources and available technology. The effort, however, did not attempt to identify systems and technologies that were clearly unaffordable or that would not lead to reasonably high payoffs. Therefore, the panel concentrated its efforts on affordable, high-leverage, solution-oriented systems and enabling technologies that offer real and significant benefit to the Navy. The panel emphasized activities that offer improved capacity, capacity on demand, antijam, and/or low probability of exploitation communications when required by mission analyses.

While the effort was fundamentally satellite-communications oriented, that panel has not neglected other approaches for LOS, extended-line-of-sight (ELOS), or BLOS communications.

3.1 BATTLE GROUP COMMUNICATIONS SYSTEMS

A typical battle group communications scenario is depicted in Figure 3.1. An attempt has been made to illustrate the various communications links that can exist in support of a battle group. These communications must be able to support voice, record, data, and imagery, both intrabattle group and interbattle group, as well as long-haul communications to land-based or remote facilities. The communications are carried over low-, medium-, or high-data-rate channels. The range of rates is defined by the requirements imposed by the missions to be supported. For example, a data link supporting radar imagery transmission can require data rates as high as 274 Mbps, whereas command and control links may require much lower data rates (i.e., <9.6 kbps). These rates may have to be sustained under peacetime, crisis, and conflict.

It is the panel's opinion that Navy programs such as the ARC-210, Joint Tactical Information Distribution System (JTIDS), and the Common High Bandwidth Datalink (CHBDL) provide comprehensive capabilities for many intrabattle group line-of-sight or extended-line-of-sight communications. (Extended line of sight could require active relay platforms.) If sensor platforms are used, such as unmanned airborne vehicles (UAV), high-altitude long-endurance (HALE) unmanned and manned aircraft, it follows that these assets are also candidates for communications relay platforms that not only support the sensor data but can also be used for area communications defined by the altitude of the platform. The antiaircraft warfare (AAW) weapon support Data Distribution System being developed for the Aegis Cooperative Engagement Concept mission provides a robust and survivable data link for intrabattle group communications. It should be considered, along with other programs, as a means for providing high-capacity, protected communications for the battle group.

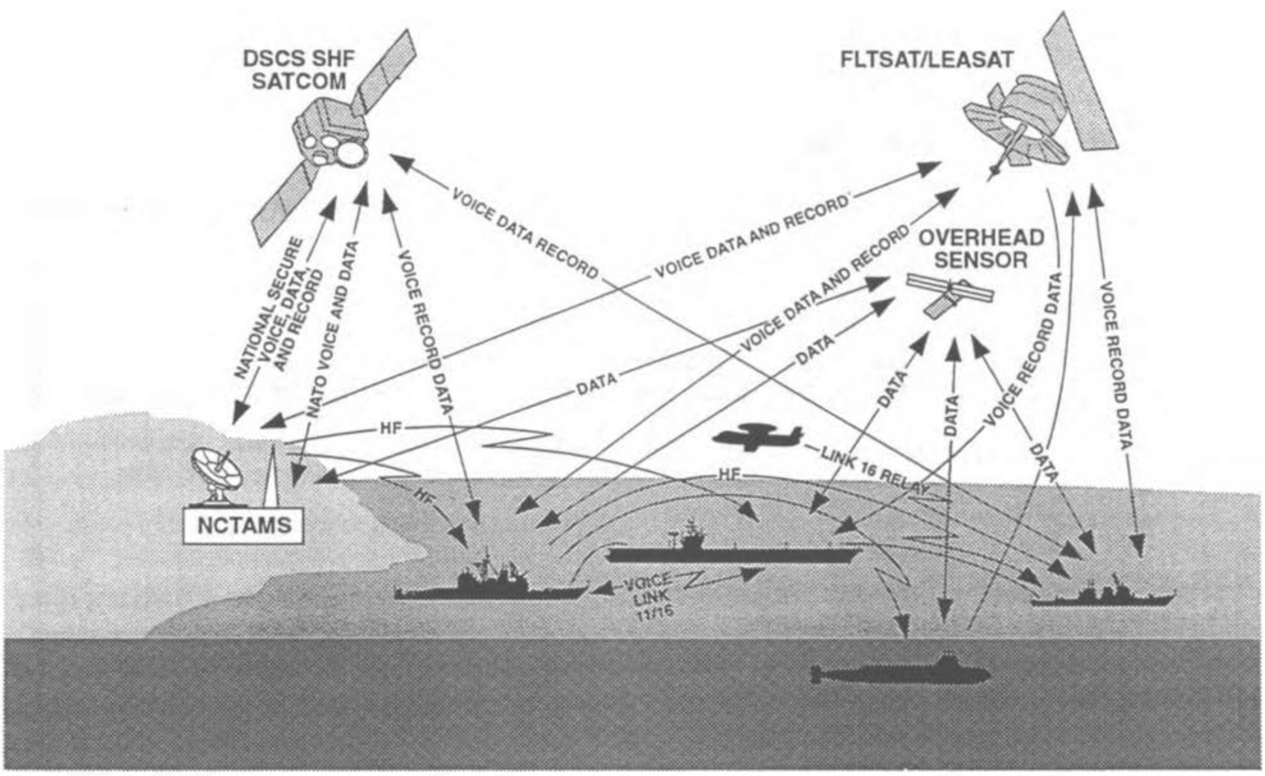


FIGURE 3.1 Battle group communications.

There are several tactical communications research and development programs ongoing, particularly within the JTIDS program, that could lead to smaller, lighter, lower cost JTIDS implementations with significant capacity improvements. The U.S. Air Force is sponsoring these JTIDS activities. The panel reviewed selected ongoing Navy activities under Project Croesus and endorses the efforts of the Croesus study group[1] with respect to tactical data link development.

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[1]CNO, Director, Space and Electronic Warfare, "Tactical Data Link Assessment" briefing, June 15, 1992.

3.2 SATELLITE COMMUNICATIONS SYSTEMS

The panel investigated a wide variety of satellite systems to determine their applicability to Navy missions, particularly those missions involving precision strike, deep strike, and amphibious operations. The panel considered current and proposed satellite systems from the commercial, civil, and military sectors, as well as foreign and domestic systems. Satellite systems that employ low earth, geostationary, and highly elliptic orbits as well as high earth circular orbits were considered. The satellite systems considered by the panel are summarized in Table 3.1.

TABLE 3.1 Satellite Communications Systems Considered

- UHF (FLTSAT, UFO)
- L-Band (INMARSAT, IRIDIUM, Global Star, Odyssey)
- C-Band (Commercial, INTELSAT, PANAMSAT)
- X-Band (U.S. and allied satellites)
- Ku-Band (Commercial, Orion, DBS, INTELSAT, TDRSS, TDRSS II)
- Ka-Band (ACTS, MILSTAR, EHF Payloads, Low cost EHF SATS, TDRSS II, IRIDIUM, Japan SAT, ITALSAT)
- Crosslinked satellites (MILSTAR, TDRSS II, FEWS, IRIDIUM, SYRACUSE II)
- New-generation LEO satellites/shuttle launched communications payloads
- Store and forward satellites

ACTS - Advanced Communications Technology Satellite (NASA)
DBS - Direct Broadcast Satellites

The frequency range for these candidate systems is predominately UHF through EHF. For reference purposes, the current frequency band allocations used by satellite communications systems are provided in Figure 3.2.

The effort did not treat laser communications via satellites, although it recognized that laser communications for satellite crosslinks is a viable option for future communication satellites, and the Advanced Research Projects Agency (ARPA) currently sponsors a low-cost, light-weight, crosslink laser program.

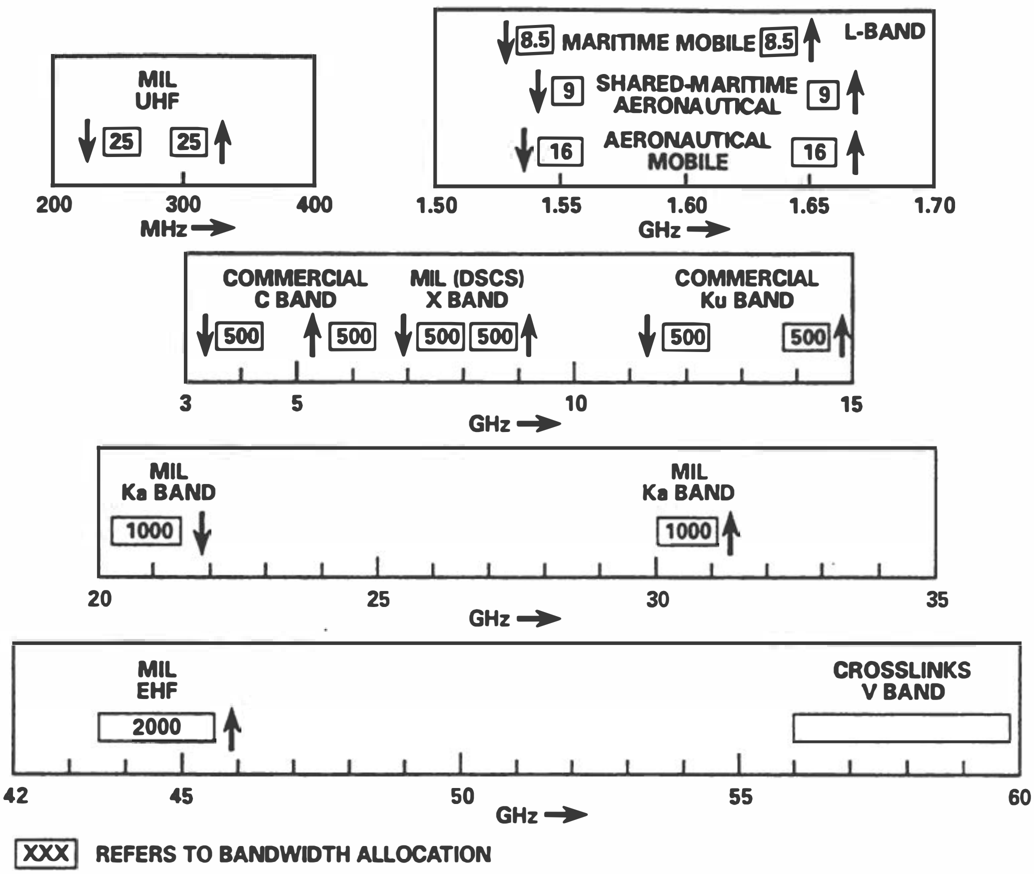

FIGURE 3.2 Current satellite communications frequency allocations.

3.2.1 Ultra-High-Frequency Systems

The panel considered the existing UHF Fleet Satellite Communications System (FLTSATCOM) and its follow-on, the UHF Follow-On (UFO). FLTSATCOM has served the Navy well for many years in a wide range of tactical applications.

The system provides connectivity between designated mobile users (ships, submarines, aircraft) and shore sites. The system provides global coverage between ± 70 degrees latitude using geosynchronous satellites and supports a range of point-to-point as well as broadcast services. The FLTSAT EHF Package (FEP) is attached to two UHF FLTSATs to provide an early-on EHF communications capability to the operating forces and a test environment for the development of MILSTAR terminals.

Each FLTSATCOM satellite provides relay communications on 23 separate UHF channels (ten 25-kHz channels, twelve 5-kHz channels, and one 500-kHz channel). The FEPs are compatible with selected MILSTAR EHF functions and have two antenna beams (5 degree spot beam and an Earth Coverage beam), providing a total of ten EHF low-data-rate (2.4 kbps each) channels.[2]

The UFO system will continue the Navy's UHF capability beginning in 1993 and will gradually introduce the added features of low-data-rate EHF channels and protected telemetry, tracking, and command (TT&C).

The UFO UHF communications suite will also consist of 5- and 25-kHz channels, and on the fourth and subsequent spacecraft will include ten EHF channels for broadcast and communications purposes that are also MILSTAR compatible.

The panel concluded that improvements can be made to Navy UHF communications systems by using more modern modems to increase frequency channel efficiency. The use of adaptive, nonlinear signal processing at ground stations should be evaluated as a means of providing a modest amount of electronic countercounter measures (ECCM) against a range of jammers or other types of interference. The panel highly recommends Improved Demand Assign Multiple Access (DAMA) techniques for the existing and proposed UHF satellites, and the consideration of retrofitting future UFOs to include medium-data-rate EHF channels. The panel also encourages the Navy to investigate the use of smart multiplexer terminals that allow for the more efficient use of available channel capacity on such links as FLTSATCOM and INMARSAT. These terminals are capable of combining data, voice, and low-rate video transmissions.

3.2.2 L-, C-, X-, and Ku-Band Systems

The Navy currently has a vigorous program to install L-band terminals on selected ships that operate with the worldwide INMARSAT system. This program is applauded, and the panel encourages the Navy to continue the deployment of these terminals on surface ships as required. Like FLTSATCOM, the L-band INMARSAT channels can be improved in terms of capacity through the use of modern modulation techniques such as constant envelope, 8-phase, trellis-coded modulation. A simple test is in order to demonstrate this enhancement. The Navy has supported development work for such a modem that should be transparent to the WSC-3 UHF terminal. The panel encourages the continuation of this effort. The potential payoff would have significant impact on overall channel efficiency.

Commercial geostationary satellites that offer services at C-band and Ku-band frequencies should be available to the Navy if commercial shipboard terminals are employed by the Navy. Commercial shipboard terminals exist with stabilization and can be readily demonstrated. Some work needs to be done to ensure full stabilization under the worst sea-state conditions. The panel anticipates that the size of these terminals can range from 1.2 meters (m) to 3.5 m for shipboard installation with stabilized platforms. Transmit power levels range from 30-W solid-state power amplifiers to 1- to 2-kW traveling wave tubes (TWTs) for C- and Ku-band applications. Typical high-reliability medium-power amplifiers using TWT technology are

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[2] "Navy UHF Satellite Communications System, Description of," Naval Command, Control, and Ocean Surveillance Center, Research, Development Test and Evaluation Division Report FSCS-200-83-1, December 31, 1991.

available at 50 to 250 W. A single TWT amplifier can now operate over the range from 6 GHz to 18 GHz at medium power levels.

A typical listing of C-band and Ku-band satellites is shown in Tables 3.2 and 3.3. Because of the extensive geostationary orbit capabilities presented by these commercial satellites, the panel recommends that the Navy consider the acquisition of commercial satellite terminals that could be used in these frequency bands. The terminals could be bought or leased. The C-band commercial assets provide much better worldwide coverage than currently provided at Ku-band. However, Ku-band is steadily increasing in terms of on-orbit assets, and Ku-band satellites can be used for communications several hundred miles from the shoreline in many locations around the world.

Of particular interest to the panel was the possibility of large amounts of on-orbit capacity at X-band, represented principally by the Defense Satellite Communications System (DSCS) II/III satellites, as well as selected future allied X-band satellites.

DSCS provides the primary transmission path for much of DOD's highest priority communications. DSCS is designed to satisfy Worldwide Military Command and Control System (WMCCS) requirements and provides high availability service between the National Command Authority, the Joint Staff, unified and specified commands, service component commands, and organic combat forces, and among early warning sensor sites and command centers. Services provided include clear- and secure-voice, high-capacity digital data at an overall maximum throughput of 3 Mbps, and jam-protected circuits. The spacecraft uses six transponders with 10- or 40-W power output and employs multielement (61 and 19) receive and transmit arrays, respectively. Figure 3.3 summarizes DSCS capability and illustrates the channel and antenna configurations employed by various user communities. Table 3.4 summarizes strategic and tactical DSCS terminals available for military application.

The panel anticipates that there will be a large X-band capacity on orbit in the 1995 to 2005 time frame that could provide worldwide access to suitably equipped Navy platforms. U.S. industry is now able to demonstrate a shipboard X-band commercial terminal with a stabilized antenna in the 1.2- to 3.5-m aperture range and power levels that are consistent with C-band and Ku-band terminals. A summary of X-band satellites available from the United States and its allies is shown in Table 3.5. DSCS III can be considered the most capable of these X-band assets, with SYRACUSE and ITALSAT, NATO IV, and SKY NET representing lesser capabilities, and BRAZIL SAT, AUSSAT, and HISPA SAT representing satellites with only two X-band transponders for each satellite. The aggregate X-band capacity created by DSCS III and these allied satellites is significant.

Also of interest is the Universal Antijam Modem (UAJM) under development by the Army's Communications and Electronics Command (CECOM) for all U.S. services. The UAJM has been released to our NATO allies. This frequency-hopped modem can be used to provide antijam/antiscintillation and interoperable channels over a wide variety of X-band satellites. It is recommended that the Navy consider X-band shipboard terminals equipped with the UAJM, or a low-cost equivalent available from industry, as a method for providing X-band service between U.S. and allied ships and Marine Corps terminals via a variety of X-band satellites. UAJM can also be used with C-band and Ku-band translating satellite transponders with prior access arrangements.

TABLE 3.2 Typical On-Orbit Satellite Performance Capabilities

SATELLITE	MANUF	CUSTOMER	ORBIT SLOT	DESIGN LIFE	ANTENNA COVERAGE	EIRP. dBW	TRANSPONDERS @ BANDWIDTHS
C-Band							
PALAPA B2R	Hughes	Perumtel	113°E	1998	Indonesian and neighboring Asian countries	36	24 @ 36 MHz
GALAXY V	Hughes	HCI	125°W	2004	CONUS, Alaska, Hawaii, Puerto Rico	36-37	24 @ 36 MHz
SALCOM C1	GE	RCA Americom	137°W	2000	CONUS, Alaska, Hawaii	28-36	24 @ 36 MHz
ASIASAT-1	Hughes	ASIASAT	105.5°E	2000	North Beam: China, Mongolia, Korea, Japan, Taiwan South Beam: Turkey through India and Phillipines	34-37	24 @ 36 MHz
Ku-Band							
SBS 6	Hughes	HCI	99°W	2000	CONUS, Alaska, Hawaii	44-50	19 @ 43 MHz
ASTRA 1B	GE	SES	19.2°E	2001	Luxembourg and neighboring countries	45-52	16 @ 26 MHz
ECS II F3	Aerospatiale	Eutelsat	16°E	2000	Wide beam all around Europe	39-44	9 @ 36 MHz
					Narrow beam around western Europe	47-52	7 @ 72 MHz
TELE-X	Aerospatiale	Swedish Space	5°E	1997	Scandinavian countries	59-65	3 @ 27 MHz
GSTAR 4	GE	GTE	125°W	2000	CONUS, Alaska, Hawaii	40	1 @ 40 MHz 1 @ 86 MHz 16 @ 54 MHz
					East CONUS and west CONUS spot beams	42-45	
SALCOM Ku-1	GE	GE American	85°W	1996	CONUS or east CONUS and west CONUS	39-48 37-43	16 @ 54 MHz
AUSSAT A3	Hughes	AUSSAT	164°E	1997	National Australia	34-38	15 @ 45 MHz
					Papua, New Guinea spot	41-45	
					SW Pacific Ocean region	29-34	
					Four Australia spot beams (W,C,NE,SE)	38-42	
MARCOPOLO-1	Hughes	BSB	31.3°W	1999	United Kingdom	59	5 @ 27 MHz
JCSAT2	Hughes	JCSAT	154°E	1999	Mainland Japan	49-51	32 @ 27 MHz
Multiple Frequency							
INTELSAT VI F4	Hughes	INTELSAT	27.5°W	2004	C-band: Hemi, zonal and global beams	26.5-31	26 @ 72 MHz 12 @ 36 MHz 2 @ 41 MHz
					Ku-band: Steerable spot beams	51.7-54.7	6 @ 72 MHz 2 @ 77 MHz 2 @ 150 MHz 25 @ 33 MHz
ARABSAT 1C	Aerospatiale	ARABSAT	31°E	1999	C-band: Arab States	31	25 @ 33 MHz
					S-band	41	1 @ 33 MHz

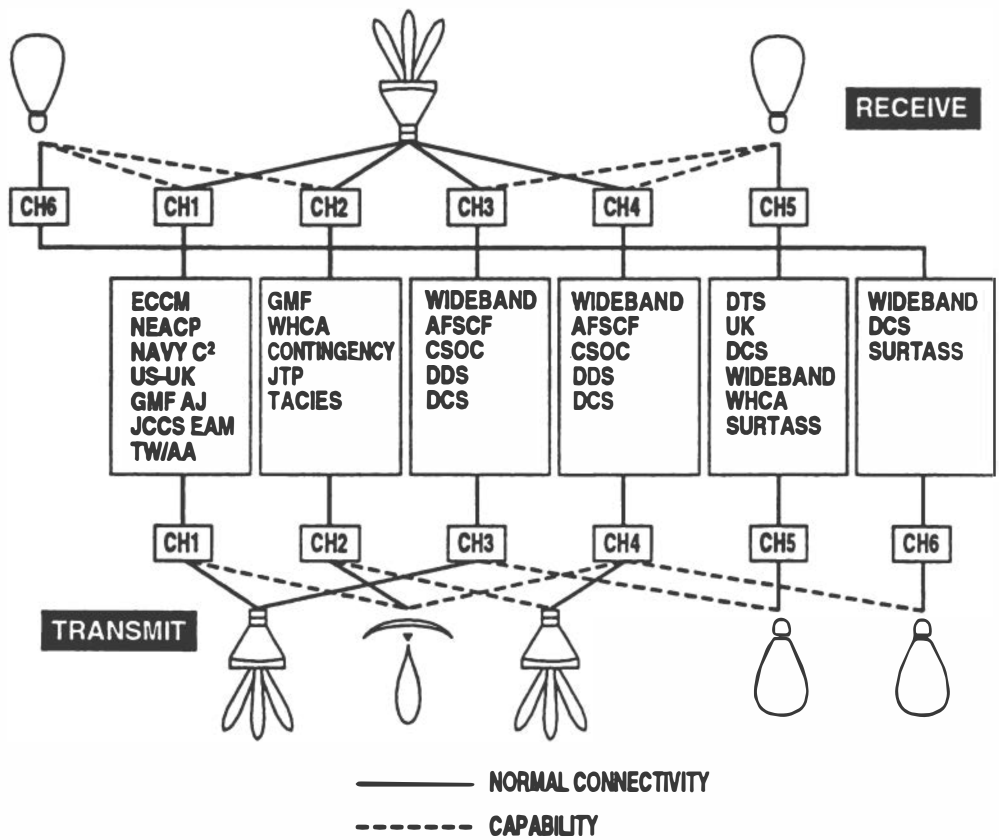
TABLE 3.2 Continued

SATELLITE	MANUF	CUSTOMER	ORBIT SLOT	DESIGN LIFE	ANTENNA COVERAGE	EIRP. dBW	TRANSPONDERS @ BANDWIDTHS
INMARSAT II F3	British Aerospace	INMARSAT	178°E	2001	C/L-band: Atlantic Ocean Region	24	1 @ 16 MHz
					L/C-band: Atlantic Ocean Region	39	2 @ 4.5 MHz 1 @ 7.3 MHz 1 @ 3.2 MHz
SUPERBIRD B1	Loral	SCC	162°E	2002	Ku-band: Mainland Japan	49-53	19 @ 36 MHz
					Ka-band: Mainland Japan	50-54	7 @ 100 MHz
					Ka-band: Tokyo spot beam	58-60	3 @ 100 MHz
INSAT 1D	Loral	India Space Research Org.	83°E	2000	C-band: India and neighboring countries	32	12 @ 36 MHz
					S-band: India and neighboring countries	42	2 @ 36 MHz
SPACENET 4	GE	ASC/GTE	101°W	2001	C-band: CONUS, Alaska, Hawaii	25-34	12 @ 36 MHz 6 @ 72 MHz
					Ku-band: CONUS	41	6 @ 72 MHz
PANAMSAT 1	GE	PANAMSAT	45°W	1998	C-band: Latin and South America	34-42	12 @ 36 MHz 6 @ 72 MHz
					Ku-band: Western and eastern Europe, CONUS except for Pacific time zone	44-48	6 @ 72 MHz
TELECOM II F1	Matra	France Telecomm	8°W	2001	C-band: Semi-global beams and Antilles, Guyana, St. Pierre, Reunion spot beam	34-42	6 @ 50 MHz 4 @ 92 MHz
					Ku-band: Mainland France	50-52.5	11 @ 36 MHz
					X-band: Global, center Europe, steerable spot	28-43	3 @ 40 MHz 1 @ 60 MHz 1 @ 80 MHz
CS-3B	Loral	NASDA	136°E	1995	C-band: Mainland Japan, outlying islands	31	2 @ 180 MHz
					Ka-band: Mainland Japan	38	10 @ 100 MHz
ITALSAT	Selenia	ITALSAT	13.2°E	1993	Ka-band: Six spot beams over Italy	57	6 @ 147 MBPS demod/remod channels
					Ka-band: One spot beam over Italy	46	3 @ 36 MHz
					3 Beacons: Western Europe spot beam-18.7, 39.6, 49.5 GHz	23-27	
DFS KOPERNIKUS	MBB	Deutsche Bundespot	28.5°E	2000	Ku-band: Germany coverage	49	7 @ 44 MHz 3 @ 90 MHz
					Ka-band	48	1 @ 90 MHz
ANIK E2	GE	TELESAT Canada	107.3°E	2003	C-band: Canada, northern half of CONUS, Alaska	35-37	24 @ 36 MHz
					Ku-band: East and west Canada spot, Canada National, cross border beams	43-52	16 @ 54 MHz

TABLE 3.3 Commercial Satellites to be Launched by 1994

SATELLITE	MANUF	CUSTOMER	ORBIT SLOT	LAUNCH DATE	FREQ	ANTENNA COVERAGE	EIRP. dBW	TRANSPONDERS @ BANDWIDTHS
TURKSAT 1B	Aerospatiale	Turkey's PSA	31°E	1993	Ku-band	Turkey, Central Europe	48-51	10 @ 36 MHz 6 @ 72 MHz
INTELSAT VII	F2 Loral	INTELSAT	177°E	1993	C-band	One steerable, one global, two hemi, and four switchable zone beams	26-33	16 @ 72 MHz 8 @ 36 MHz 2 @ 41 MHz
					Ku-band	Three steerable spot beams	43-48	6 @ 72 MHz 4 @ 112 MHz
INTELSAT-K	GE	INTELSAT	21.5°W	1992	Ku-band	Western Europe, Latin and North America	50	16 @ 54 MHz
TELSTAR 4A	GE	ATT	97°W	1993	C-band	CONUS, Alaska, Hawaii, Puerto Rico, Virgin Islands	33-38	24 @ 36 MHz
	Aerospace				Ku-band	CONUS, Alaska, Hawaii, Puerto Rico, Virgin Islands	40-47	16 @ 54 MHz cross-straps avail.
THAICOM 1	Hughes	Shinawaira	101°E	1993	C-band	Taiwan, Pacific rim region	34	12 @ 36 MHz
					Ku-band	Taiwan	50	3 @ 54 MHz
USDBS 1	Hughes	HCI	101°W	1993	Ku-band	CONUS	48-54	16 @ 24 MHz or 8 @ 24 MHz
GALAXY VII	Hughes	HCI	91°W	1992	C-band	CONUS, Alaska, Hawaii, Puerto Rico, Virgin Islands	38	24 @ 36 MHz
					Ku-band	CONUS, switchable offshore coverage	45	16 @ 27 MHz or 8 @ 54 MHz
SOLIDARIDAD I	Hughes	Mexico Telecomm	109.2°W	1993	C-band	Mexico, South America, Caribbean	40	12 @ 36 MHz 6 @ 72 MHz
					Ku-band	Mexico, U.S. spot beams	47	16 @ 54 MHz cross-strap with L-band
					L-band	Mexico, surrounding waters	45	4 @ 2 MHz subbands, cross-strap w/Ku-band
AUSSAT B1	Hughes	AUSSAT	160°E	1992	Ku-band	National Australia, five spot beams	44-51	15 @ 54 MHz cross-strap avail.
			85°W	1996	L-band	National Australia	46-48	1 @ 14 MHz cross-strap avail.
					Ka-band	National Australia		One beacon
ASTRA 1C	Hughes	SES	19.2°E	1993	Ku-band	Luxembourg and neighboring countries	52	18 @ 26 MHz
INSAT 2B	ISRO	India Space Dept	93.5°E	1993	C-band	India	32	Unknown
					S-band		42	Unknown
HISPASAL 1	Matra	Spain	31°W	1992	Ku-band	Spain, Canary Islands, Americas	41-52	10 @ 36 MHz 4 @ 54 MHz 4 @ 72 MHz
					X-band		Unk	1 @ 40 MHz

DSCS III CHANNEL AND ANTENNA CONFIGURATION



- All-service capability
  - WMMCCS/GMF
  - Wideband
  - Service to isolated areas
- Operational flexibility
  - Operates with large/small terminals
  - Groups users by operational needs
  - Allocates transmitter power for maximum efficiency
- Six independent transponders (two 40-W channels, four 10-W channels)
- 61 element receive MBA
- Two 19 element transmit MBAs

FIGURE 3.3 Defense Satellite Communications Systems summary.

TABLE 3.4 Defense Satellite Communications Systems Terminal Population

NOMENCLATURE	CAPABILITIES	TYPE	G/T (dB)	EIRP (dBW)	CAPACITY (CARRIERS)	ANTENNA SIZE (FT.DIA)
Strategic						
AN/FSC-9		Heavy Terminal (1)	39	103	4TX/9RX	60
AN/FSC-78	CW, TDMA, SS	Heavy Terminal	39	97/94	9TX/15RX	60
AN/MSC-46		Medium Terminal (1)	34	93/87	4TX/9RX	40
AN/GSC-39		Medium Terminal	34			38
AN/GSC-52		Medium Terminal	33			38
AN/TSC-54	Voice, Teletype	Light Terminal	26	87	2TX/3RX	Cloverleaf 18 equiv
AN/TSC-86		Light Terminal (1)	18/26	-74/82		8/20
AN/GSC-49	Jam-resitant Secure Comm	Light Terminal			SCT	8/20
AN/FSC-79	Upgraded (78) Navy	Heavy Terminal to FLTSATCOM	No rcvr	-90		60
AN/MSC-61		Heavy Terminal	34	93	3TX/RX	38
Tactical (Ground Mobile Forces)						
AN/TSC-85A	Voice, PCM Digital Data	Army Nodal Terminal	18/26	71	4CR-96 Channel	8/20
AN/TSC-93A	TAC Trunking	Army Spoke Terminal	18	71	6/12/24 Voice	8
AN/TSC-94A	Similar to 93	AF Net Terminal			6/12 Voice Channel	8
AN/TSC-100A		AF Nodal Terminal			6-60 Channels	8/20
AN/MSC-114A	CTLS < 50 E/T	Network Control Terminal				20
AN/WSC-2		Navy Shipborne	12/18	67/76		4/8
AN/WSC-6		Navy Ships to DSCS	12	76		8
AN/ASC-24		SHF Airborne E-4B	7	70		3.3
AN/ASC-18		Airborne	7	71	1/1	2.75
PTS	In development for ESD	Portable/Light	6	39		
Other						
LST-8000	Developed for classified customer	Portable/Light	19	68	Support up to 16 channels simultaneously	7

TABLE 3.5 SHF Satellite Communications Summary (X-Band Capabilities)

- There will be a large SHF satellite capability on orbit in 1995 to 2005
  - DSCS II
  - DSCS III
  - DSCS III Upgrade
  - SKYNET
  - SYRACUSE
  - ITALSAT
  - BRAZIL SAT
  - AUSSAT
  - JAPAN SAT
  - HISPA SAT
  - NATO IV
- Terminals of all kinds available
- Wide variety of modems available
  - Universal AJ modems available for nuclear-protected channels
- Allies will have abundance of SHF satellite capacity on orbit in 1995 to 2005

3.2.3 Ka-Band Systems

The panel also reviewed satellite developments under way or projected in the Ka-band (EHF) frequency regime. MILSTAR is the preeminent military satellite communications development effort under way by the United States in this band, with low-data-rate channels available on the first three deployed MILSTAR satellites, followed by future MILSTARs with low and medium data rate capabilities.

MILSTAR will provide a hard-core warfighting satellite communications capability with onboard processing to allow maximum flexibility by the user community, crosslinks for worldwide relay and control, and a variety of antenna configurations (spot, agile, and earth-coverage beams) to obtain maximum security and user flexibility and highly jam-resistant waveforms. The system is designed to provide full interoperability among service organizations. Figure 3.4 illustrates the planned MILSTAR configuration. Recent DOD reviews have modified the eventual constellation to include only low-inclined orbits. Figure 3.5 lists the EHF terminal procurements planned by each of the services. A significant number of terminals will be available to the services in the mid- to late nineties.

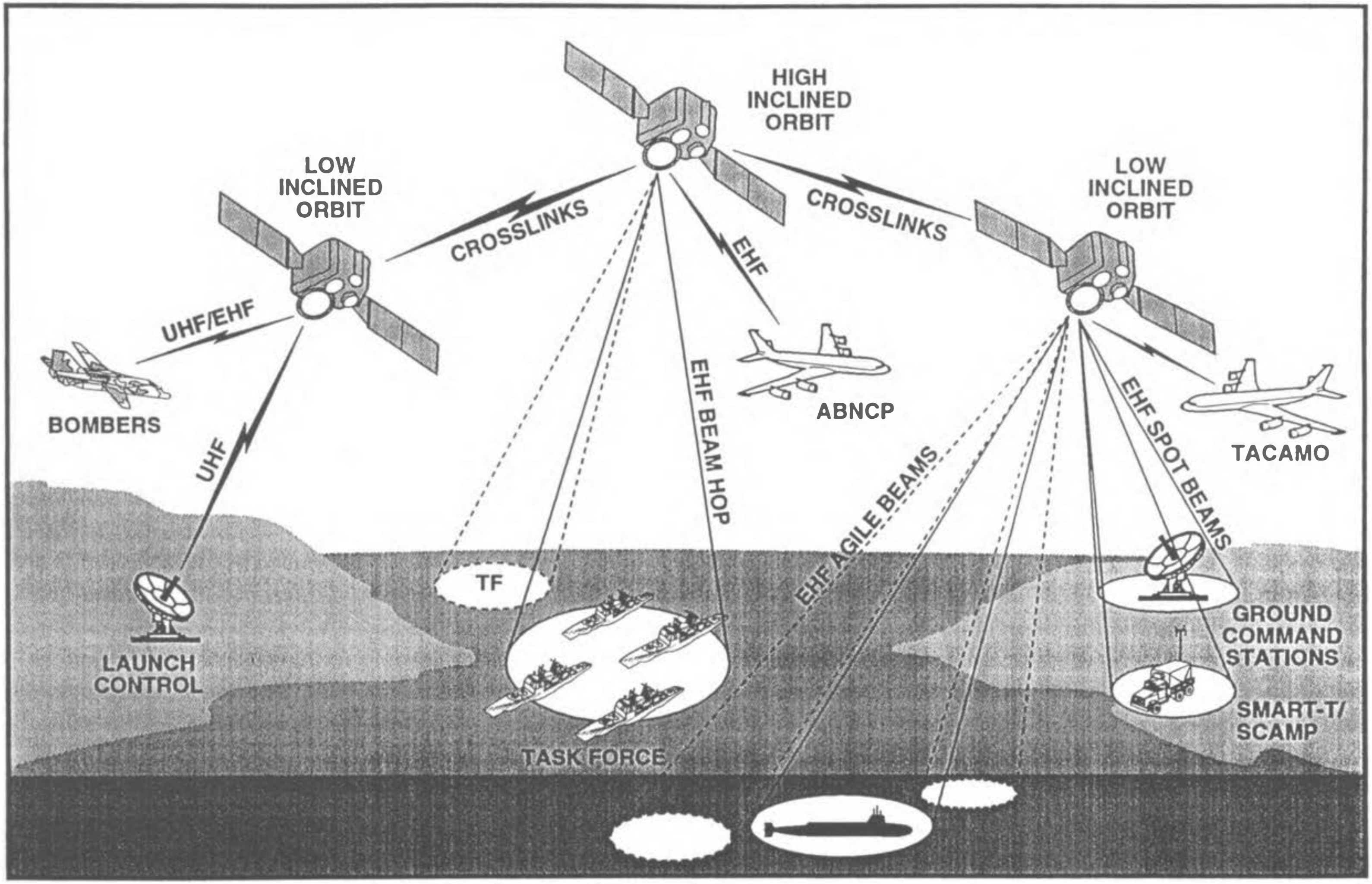
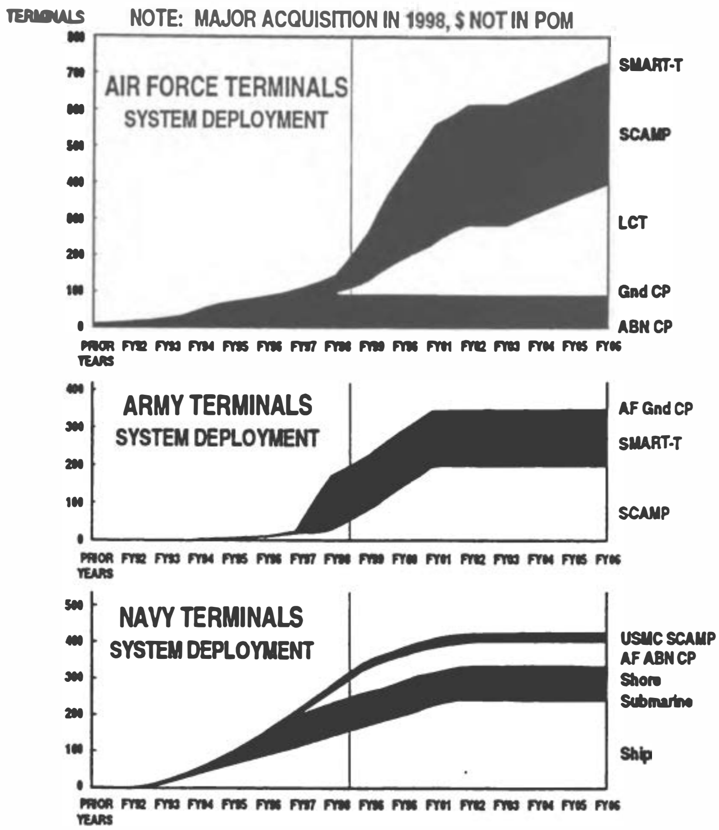


FIGURE 3.4 Planned MILSTAR configuration.



CORE REQUIREMENTS

1541 TOTAL TERMINALS

LDR:

AIR FORCE	• 104 COMMANDS • 305 LOW COST TERMINALS
ARMY	• 456 SCAMP
NAVY	• 343 NESP
OTHER	• 20 E-TSET

LDR/MDR:

ARMY	• 313 SMART-T

DEFERRED REQUIREMENTS

2650 TOTAL TERMINALS

LDR:

- 2549 SCAMP BLOCK II
- 55 NESP

LDR/MDR:

- 46 SMART-T

FIGURE 3.5 MILSTAR terminals summary.

The panel notes that ARPA is also sponsoring low-cost EHF experiments for low-, medium-, and high-data-rate capabilities. It recommends that the Navy foster and influence the ARPA activities, because the Navy has a large investment in EHF terminals, and there is great uncertainty about the future of the MILSTAR program. The Navy needs to have a fallback position at EHF if the MILSTAR capability is delayed.

In addition to MILSTAR, the panel reviewed NASA's Advanced Communication Technology Satellite (ACTS), NASA's Tracking and Data Relay Satellite (TDRSS) I and II, JAPAN SAT or Superbird, and ITALSAT. The panel concludes that, for the near future, the Navy should concentrate its efforts on EHF satellites at 44 and 20 GHz. The panel sees no reason for the Navy to be interested in ACTS at this time, since it is a CONUS-oriented 30/20-GHz single research and development satellite with an uncertain future. TDRSS, on the other hand, provides excellent Atlantic and Pacific Ocean coverage and could be used to support a number of Navy missions at Ku-band. The future of TDRSS II is uncertain at this time, but the TDRSS I program will likely continue. An assessment of selected geostationary satellites for Navy use is provided in Table 3.6.

TABLE 3.6 Qualitative Assessment of Geostationary Satellites

	COVERAGE	RATES	ANTIJAM	NUMBER OF SATELLITES
FLTSAT*	Worldwide	LDR/MDR	Low	4
UFO*	Worldwide	LDR/MDR	Low	4
INMARSAT	Worldwide	LDR/MDR	None	4
C-BAND	Worldwide	LDR/MDR	Possible	4
X-BAND	Worldwide	LDR/MDR	Good	6+ allies
K_u-BAND	Regional	LDR/MDR	Possible	Large number
TDRSS	Pacific and Atlantic Oceans	LDR → VHDR	Possible***	5
EHF**	Worldwide (future)	LDR, MDR (future)	High	Several

* Poor polar coverage
** MILSTAR, FEP, UFO/EHF
*** It is possible to use UAJM or lower cost commercial versions to provide AJ/LPI over C- and Ku-band links.

Direct broadcast satellite (DBS) technology is developing rapidly, and this technology was reviewed for possible applications to the Navy. Hughes is developing a Ku-band DBS, and a number of direct broadcast technologies exist within the European satellite community. The Hughes effort consists of a satellite with a number of Ku-band transponders operating at 120 W per transponder with an 85-in.-aperture antenna used to transmit digital TV signals to the ground. The ground receiving facilities consist of small 18-in.-aperture antennas. With this arrangement, a number of digital multiplexed TV channels can be received. DBS technology could be applied to the battle group if the case could be made for using DBS techniques over the ocean. At the moment, DBSs are confined to populated areas and therefore restricted to landmasses.

3.2.4 Satellite Crosslinks

Crosslinked satellites were also investigated by the panel. Satellites such as MILSTAR, TDRSS II, the Follow-on Early Warning System (FEWS), the French SYRACUSE III, and the commercial IRIDIUM low-earth-orbit constellation are typical of crosslinked satellites of the future. The characteristics of the crosslinks on MILSTAR are well known and are not discussed in this report.

Regarding the TDRSS II, the crosslinks were expected to provide 300-Mbps service using 20-GHz technology. FEWS expects to provide crosslinks using either RF (Ka-band) or laser technology to support several Mbps. SYRACUSE III expects to achieve tens of Mbps on its crosslinks using radio frequency technologies. IRIDIUM will have crosslinks of 12.5 Mbps between adjacent satellites at 20-GHz frequencies. The IRIDIUM satellites will be an interconnected 66-satellite constellation for worldwide communications between handheld mobile subscribers at L-band.

With respect to crosslinked satellites, the panel concludes that the Navy should concentrate its efforts on the use of MILSTAR at low and medium data rates. If TDRSS II materializes, then the Navy may wish to employ the TDRSS II crosslink via Ku-band shipboard terminals, but the uncertainty surrounding the TDRSS II makes such planning difficult. The panel advises the Navy not to consider TDRSS II as part of its medium-term options. FEWS, on the other hand, is scheduled to use the EHF MDR standards for its uplinks and downlinks at 44/20 GHz. Therefore, the Navy should consider FEWS as an option, given that the Navy will have deployed many EHF terminals by the time FEWS is operational.

The Brilliant Eyes Program, part of the Space Defense Initiative, also involves a crosslinked satellite with 44/20-GHz uplinks and downlinks, respectively. However, support for Brilliant Eyes is not strong at this time, and the panel advises the Navy not to consider it as a communications satellite option.

3.2.5 Future Commercial Low-Earth-Orbit Systems

Of particular interest to the Navy should be the future generations of low-earth-orbit satellites summarized in Table 3.7. These satellites tend to operate in the VHF-band for low-data-rate messaging or in the L-band and S-band for voice/data transmissions. Some set of low-earth-orbit satellite constellations will probably exist by the year 2000, and it is likely that this satellite capability will consist of one or perhaps two VHF data-only constellations, such as ORB COMM, and as many as two low-earth-orbit constellations for voice and data, represented by IRIDIUM, Odyssey, Global Star, or the results of INMARSAT Project 21, which is still under concept development. These potential low-earth-orbit satellite services should be viewed by the Navy as an alternate or complementary communications capability, when and where needed.

These systems are being designed to provide secure voice telecommunications with existing encryption equipment (STU-III). Certain proposed constellations such as Odyssey and Global Star will use spread spectrum pseudo-noise (PN) modulation techniques for user uplinks and downlinks and C-band feeder links to interface with the public networks.

With respect to store and forward satellites, solid-state technology will provide for several gigabytes of storage on a low-earth-orbit satellite, which can also forward the stored data to users at sea. These satellites can be equipped with uplink UHF capabilities for the protected insertion of data over friendly territories and UHF downlinks compatible with existing Navy receiving equipment on submarine and surface ships to bring about a store and forward capability for the Navy. The store and forward satellite could be used to transfer database information, imagery, weapons data updates, etc., at speeds of up to 10 Mbps.

TABLE 3.7 Proposed LEO Mobile Satellite Communications Systems

SYSTEM	COMPANY	# OF SATS	ORBITS	ALT (km)	FREQUENCIES (MHz)	SERVICES	TYPE OF SIGNAL
ARIES	Constellation Communications Inc Herndon, VA	48	4 polar	1018	1610-1625.5 uplink 2483.5-2500 downlink; 5150-5216 down 6525-6541 up	Position determination and reporting, two-way telephony, dispatch voice, facsimile, and data collection, distribution, and control services	SS/CDMA
ELLIPSO	ELLIPSAT Washington, DC	24	3 highly elliptical	2903 by 426	1610-1626.5 up 2483.5-2500 down	Will connect to a cellular phone to convert 800-MHz cellular to the 2.5-/1.6-GHz RDSS bands	SS/FDMA
GLOBALSTAR	Loral Cellular Systems Corp New York, NY	48	8	1389	1610-1626.5, 2483.5-2500, 5199-5216, 6525-6541, all bidirectional	RDSS, voice, data communications	SS/CDMA
IRIDIUM	Motorola Inc Chandler, AZ	66	11	765	1610-1626.5 bidirectional; 27.5-30 up 18.8-20.2 down 22.5-23.5 crosslink between satellites	Worldwide cellular telephony and portable phone service	N.A.
LEOSAT	LEOSAT Inc Ouray, CO	18	3	1000	148-149 up 137-138 down	Two-way communication and radio location for intelligent vehicle highway system	N.A.
ODYSSEY	TRW Inc Redondo Beach, CA	12	3 inclined circular	10,370	1610-1626.5 up 2483.5-2500 down 19,700-20,000 down 29,500-30,000 up	Voice, radio location, messaging, data services	SS/CDMA
ORBCOMM	Orbital Communications Corp Fairfax, VA	20	3 inclined 2 polar	970	148-148.9 up 137-139, 400.1 down	Two-way communication and radio location; slow, low-cost data transmission	N.A.
STARNET	STARSYS Inc Washington, DC	24	24 random	1300	148-149 up 137-138 down	Global two-way communication, data, radio location	Rule making for very high frequencies
VITASAT	Volunteers in Technical Assistance (VITA) Arlington, VA	2	single, circular	800	137.7 down 400.2 up; or 400.2 down 149.8 up	Data services and file transfer primarily for developing nations	N.A.

CDMA = Code-Division Multiple Access
FDMA = Frequency-Division Multiple Access
RDSS = Radio Determination Satellite Service
SS = Spread Spectrum
N.A. = Not available

3.3 TECHNOLOGY OPPORTUNITIES

Rapid advancements taking place in a number of technologies associated with telecommunications could greatly improve the Navy's ability to perform tactical missions. These technologies include microelectronics, antennas and transmitters, commercial worldwide telecommunication networks, communications security devices, multimedia technologies, and the ubiquitous use of GPS for network synchronization, network access, and network timing. Table 3.8 summarizes enabling technological opportunities that the panel has identified.

TABLE 3.8 Enabling Technological Opportunities

- Microelectronics
  - Greater computing power
  - Smaller size
  - Lower power drain
- Antennas/Transmitters
  - Large satellite multibeam antennas
  - Conformal arrays for missiles and aircraft
  - Adaptive shipboard arrays
  - High-power transmitters for missiles and aircraft
- Civil and Commercial Telecommunications
  - Wideband worldwide networks
  - Worldwide personal voice/data connectivity
  - TV and audio broadcasts worldwide
  - Small, smart, cheap terminals
  - Large ratio data compression/imagery compression
  - Smart multiplexers
- Networks
  - Intelligent, adaptive nets
  - Embedded COMSEC and automated key management (over-the-air rekey)
  - Mass multi-user accommodation
- Use of Other DOD Systems
  - Ubiquitous GPS
  - Combined GPS/communications in handheld terminals

3.3.1 Microelectronics

In the area of basic microelectronics, Table 3.9 summarizes the expected capabilities of dynamic and static random access memories (RAMs), processing speed, analog-to-digital conversion speed, and packaging associated with integrated circuits in the 1995 timeframe. These advances in microelectronics should provide the Navy with greater computing power, smaller size equipment, and in some cases, lower power equipment at lower cost. In addition to steady advances in microelectronics, antennas, which play a critical role in communications, appear to be moving toward multifrequency, multibeam configurations based on conformal, phased-array technologies that can be used on a variety of platforms, including ships, aircraft, and possibly missiles. Of particular interest is the ability of U.S. industry to develop and produce multifrequency antennas using stabilized parabolic reflector technology—an antenna that can be placed on board a ship. These antennas can operate at C-, X-, or Ku-band. Such an antenna aboard ship would provide for the serial use of available geostationary satellites at these three commonly used frequencies from a single parabolic antenna. Wideband feeds and wideband power amplifiers combine to make the multi-band stabilized parabolic antenna very attractive for shipboard use in the near term.

TABLE 3.9 Advances in Integrated Circuits

- Dynamic RAMS 2×10^7 bits/IC by 1995
- Static RAMS 3×10^6 bits/IC by 1995
- Throughput/IC 10^8 ops/sec by 1995
- Spaceborne processor 40×10^9 ops/sec by 1995
- Analog-to-digital converters
  - 14-bit resolution at 10 mega samples/sec
  - 10-bit resolution at 100 mega samples/sec
  - 8-bit resolution at 500 mega samples/sec
- 40 giga ops in 125 $in.^3$, 80 W by 1995 (ARPA)
- Advances in IC technologies allow processing trades to be conducted
- On-board (space) processing, bandwidth compression, storage can be traded against communications link capacities (relay satellite vs. direct downlinks) and ground-based processing

3.3.2 Wideband Networks

Worldwide telecommunications networks are under development by the U.S. intelligence community as well as the Defense Information Systems Agency (DISA). The so-called Joint Worldwide Intelligence Communication System (JWICS) is a Defense Intelligence Agency (DIA) network based on T-1 link capacity (1.544 Mbps) that will eventually connect 100 locations around the world. JWICS could be used by the Navy to convey information to and from remote locations.

The National Security Agency is developing an Integrated Services Digital Network (ISDN)-based network called the Global Telecommunications System to perform similar functions. ISDN-based systems should be of interest to future Navy telecommunications development efforts because these systems are designed to handle a variety of data traffic types, including interactive information services, electronic mail, digital voice, facsimile, file transfers, and wideband digital video services.

Further, DISA is developing the Defense Integrated Systems Network based on commercial offerings of broadband ISDN. Advanced Research Projects Agency (ARPA) and Defense Development Research and Engineering (DDR&E) are pursuing a Global Grid telecommunications system based on fiber optics and ISDN standards.

The Navy is therefore encouraged to take full advantage of these activities within the DOD and intelligence communities as well as commercial offerings leading to global wideband networks. These networks should provide the Navy with high-capacity connectivity to naval command centers and communications stations (or gateways to mobile forces) around the world.

3.4 GENERAL ASSESSMENT OF NAVAL SATELLITE COMMUNICATIONS

The Navy continues to be a major contributor to and user of tactical satellite communications. The outstanding performance of FLTSATCOM and LEASAT at UHF is well documented. These satellites support not only naval but also numerous joint command and control and intelligence missions. The performance of these UHF assets during Desert Storm, given existing throughput design limitations, was exemplary.

The Navy will be using UHF satellites for years to come and is planning for a UHF Follow-On (UFO) satellite to FLTSATCOM. There are several thousand UHF terminals deployed at present to serve a variety of users, such as submarines, surface ships, aircraft, and fixed sites.

The principal UHF satellite communications radio equipment for fixed sites and shipboard use is the WSC-3 transceiver and for aircraft, the ARC-210 transceiver. WSC-3 equipped platforms are considered the most capable and, in theory, should be able to support much higher data rates than currently employed in day-to-day operations over FLTSATCOM. Modern modulation and error-control coding techniques can support 48 kbps through the 25-kHz FLTSATCOM channels, thus realizing a sizable increase in capacity relative to current throughput rates. Likewise, modern access control techniques should provide a means to reconfigure and reallocate FLTSATCOM channels dynamically and rapidly, thus realizing a sizable increase in capacity relative to current throughput rates with increased user access. These techniques are referred to as multifrequency time division multiple access (MF TDMA) protocols. The combination of dynamic channel allocation and application of more modern modulation and coding could be used to realize a significant increase in FLTSATCOM channel efficiency and satellite throughput.

At present, with the exception of the FLTSATCOM broadcast channel, the UHF satellites are vulnerable to enemy jamming or inadvertent interference. Thus, while UHF satellites were effective during Desert Storm, a more resourceful enemy could easily disrupt a large percentage of our UHF satellite communications.

The Navy is taking steps to correct this problem with its investments in EHF satellite payloads (FEPs) and by placing EHF low-data-rate channels on the UFO satellite #4 and beyond. It would be highly desirable to have MDR channels on UFO in the future, and the panel advises the Navy to determine the feasibility of such a block change to UFO. EHF payload technology has progressed significantly since the development of the current FEPs on FLTSATCOM, and a combination of LDR and MDR channels on UFO is recommended. The panel recommends that user terminal rates, which are often artificially restricted to 2.4 kbps, be increased to match the capacities technically achievable over UHF channels.

INMARSAT, a worldwide system that continues to improve and evolve, is highly recommended to the Navy by the panel as a general-purpose peacetime satellite communications capability. The Navy is planning to install several hundred INMARSAT terminals, and it is recommended that the Navy examine the feasibility of achieving 56-kbps two-way communications over INMARSAT. The capability represented by INMARSAT is significant relative to its cost, and INMARSAT channel costs can be expected to drop to meet the competition from low-earth-orbit satellite systems of the future.

The Navy is implementing the SMQ-11 antenna system at S-band to receive meteorological data from the improving DMSP satellite system. DMSP is planning for a store and forward capability from which the Navy could benefit, for example in forwarding databases from shore to the battle group. The SMQ-10 antennas that reside on carriers, two on each platform, are currently configured as S-band receive-only antennas. These 8-ft parabolic antennas are being replaced by the SMG-11's phased arrays. The SMQ-10 space on the carriers could be used for improved communications. For example, the SMQ-10s could be modified to provide dual S-band and X-band receive-only capabilities for the carriers. The X-band receive-only terminal (ROT) modification would allow for one-way medium-data-rate transmissions to the battle group over X-band satellites. The S-band ROT capability could be used to receive transmissions over classified assets. As an alternative strategy, the SMG-10s could be replaced by 8-ft parabolics with two-way communications capabilities at X-band and perhaps C-band and Ku-band using a multiband stabilized parabolic antenna. Technology now provides for single-feed C-, X-, and Ku-band parabolics with single wideband power amplifiers covering the C-, X-, and Ku-band frequencies. Thus, the SMQ-10 locations on carriers could be used to provide new commercially available antennas for two-way communication. The panel advises the Navy to examine these options for near-term improved connectivity to the carriers. Antijam communications over these links could also be realized by using the UAJM.

The Space and Naval Warfare Systems Command (SPAWAR) is considering a new program that would provide an integrated sub-intermediate frequency (IF) modular set of equipment for two-way communications over either UHF or SHF satellites. The equipment could be used to access X-band or UHF satellites using standard protocols, demand accessing, and data rates supported by these satellites. If SPAWAR continues with the integrated UHF/SHF program, it should reflect the latest results on multifrequency time division multiple accessing and modern modulation and coding schemes that provide for more efficient use of channel capacity.

The Navy has not been a major satellite user at X-band, opting instead to invest heavily in EHF satellite payloads and EHF terminals. Recently, however, the Navy reexamined its place in the X-band satellite user community and has been actively testing and planning for increased participation. The Navy has an aggressive program in X-band demand assignment multiple access testing and is researching ways to achieve lower-cost X-band terminals for surface ships. Fortunately, low-cost commercial X-band terminals are available for surface ship deployment, and, as stated previously, these terminals can also be configured to operate at C- and Ku-bands with single feeds and single wideband power amplifiers.

The Navy is the leader in EHF satellite communications. It has a vigorous "on schedule" and "on cost" terminal program and has invested heavily in EHF payloads for FLTSATCOM and UFO. The MILSTAR program has been approved for the first three satellites with low-data-rate channels and a fourth satellite with LDR and MDR capabilities. MILSTAR, on the other hand, is a very expensive satellite and will likely come under continued DOD and congressional pressure for curtailment and/or downsizing. The Navy, because of its leadership role and heavy investments in EHF, is advised by the panel to promote an EHF satellite fallback position within the communications satellite community. Technology in industry and the laboratories can provide for much lower-cost geostationary EHF satellite solutions. The ARPA Advanced Satellite Technology program is a possible avenue for this fallback position. The panel also advises the Navy to determine whether its EHF shipboard terminals can be easily upgraded to handle MDR transmissions if an MDR space capability becomes available.

Also related to EHF, the Navy is contemplating a new towed buoy for SSN missions. The buoy will allow the submarine to remain at speed and depth while providing access to communications channels above the surface of the water. HF and UHF are likely candidates, but other frequencies could be examined, such as L-band over the IRIDIUM, Global Star, and Odyssey or VHF over ORB COMM, for use with the towed buoy. Some analysis suggests that a small EHF antenna could be placed on the buoy to communicate with EHF satellite assets. The towed buoy represents a resource for two-way communications for submarines. The communications options provided by this buoy should be identified for low-, medium- and high-earth-orbit satellites.

4
Goal Architecture—NAVSATCOM-21

Drawing upon the review of communications requirements related to Naval missions (Chapter 2), as well as the assessment of the capabilities of current and planned communications satellite systems, the shortfalls and issues associated with these systems, and the potential new capabilities afforded by emerging technologies (Chapter 5), the panel synthesized a goal Naval Space Communications Architecture for the Twenty-first Century (NAVSATCOM-21). This chapter describes the approach used to develop NAVSATCOM-21, emphasizing the enhanced communications services the architecture supports in a flexible, fiscally constrained manner. It contains suggestions for influencing the DOD military satellite communications decisions scheduled throughout the 1990s. It concludes with a list of recommended actions for implementing NAVSATCOM-21.

4.1 APPROACH

Four considerations significantly affected the development of NAVSATCOM-21: Naval strategy and missions, command and organizational structure, functionality and performance requirements, and system infrastructure. The goal architecture was designed to support the evolving naval strategy and mission responsibilities, which include flexibly projecting a U.S. presence and (as appropriate) responding to crises worldwide. It was recognized that future crisis response may involve the deployment of naval forces in concert with those of other U.S. and allied services. Accordingly, provisions for interoperable communications within a region of operations as well as connectivities to remote locations (e.g., CONUS) are provided.

Naval as well as joint task force organizational structures are accommodated by NAVSATCOM-21. As shown in Figure 4.1, the communications connectivities provided by the goal architecture can be partitioned into a four-tiered hierarchical structure. Large, geographically distributed networks with layers of interconnecting and interoperable regional and local area networks are included. The highest or global backbone level includes communications paths among the NCA and the national agencies. The second or theater level involves connectivities within and among CINC organizations. Provisions are also included for interactions with appropriate global and regional-level modes. At the regional level, NAVSATCOM-21 supports communications among JTF constituents. The lowest or tactical level provides connectivities among force elements, engaging units, and weapon and support platforms.

NAVSATCOM-21 was designed to provide communications both within and among the four levels shown in Figure 4.1. At the global level such connectivities supplement several other means of communications, such as terrestrial systems and commercial communications satellites. However, as one proceeds through the tiers toward the tactical level, the installations become more transportable and, eventually, highly mobile. At these lower levels, NAVSATCOM-21 connectivities may provide the only reliable communications.

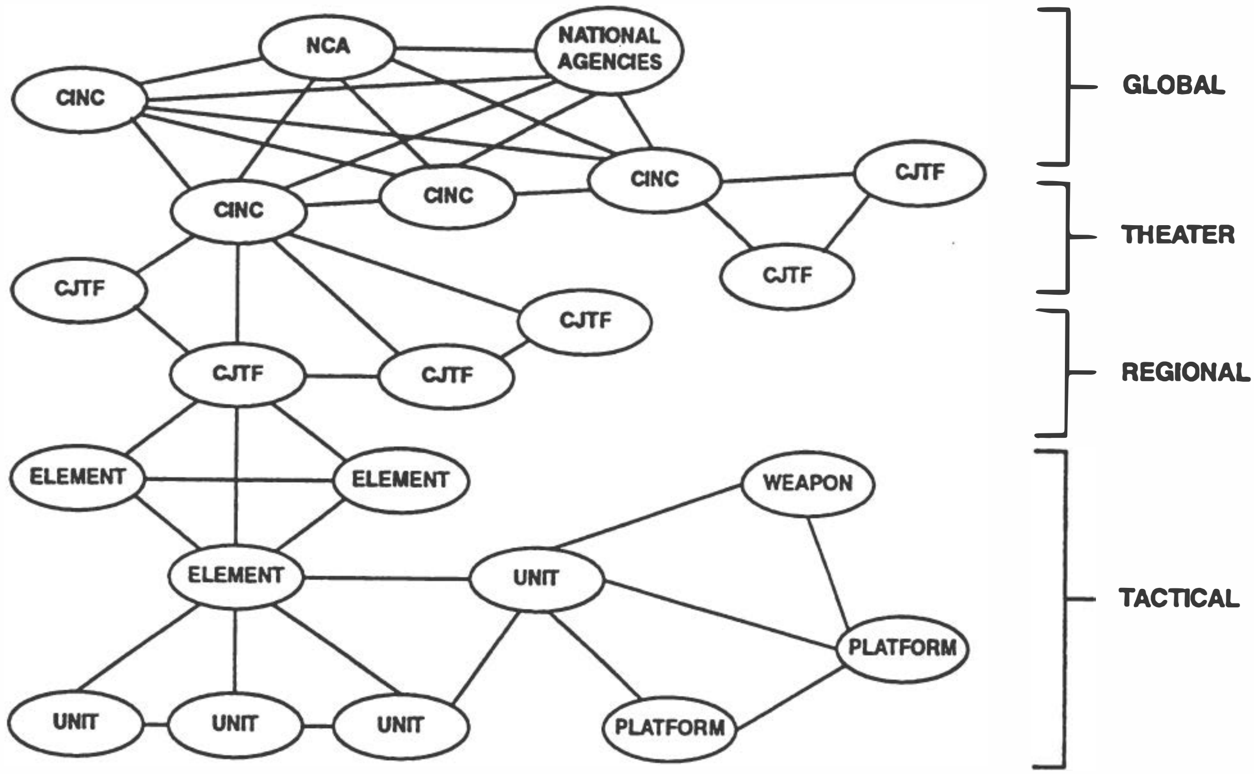


FIGURE 4.1 NAVSATCOM-21 structure.

The panel's methods for developing the goal architecture evolved from a vision of transition in the 1990s from the current communications systems to the enhanced capabilities of NAVSATCOM-21. The approach was selected to leverage the significant investments in the current systems as well as to be synergistic with DOD's efforts to modernize, during the same time frame, other military satellite communications capabilities. A number of constraints were recognized as affecting the transition plans. First, the goal system had to correct the performance shortfalls of the current communications satellite systems (capacity and protection; Chapter 3). However, the limited space available for antenna and electronics installations on many of the Navy's platforms, as well as the likelihood of future funding difficulties, dictates solutions that are low cost and involve small terminals. Accordingly, the panel investigated ways for the Navy to maximize the utility of major fielded/planned terminal programs, to augment critical communications services in a cost-effective manner, to incorporate dual-use systems, and to affect DOD's opportunity for modernization decisions on its scheduled military satellite communications.

To correct, within the above constraints, the performance shortfalls of current systems, the panel established five goals for NAVSATCOM-21: increased capacity; improved interference (antijam) and detection (low probability of intercept) protection; interoperability; flexible connectivity; and small terminal size. To meet these goals, the four enabling techniques listed in Table 4.1 were used. As indicated, spacecraft processing and switching contributes to accomplishing all five goals. Similarly, this technique, as well as use of higher frequencies, standard/robust transmission formats, and directive antennas, is integral to achieving robust communications connectivities, especially at higher data rates and/or from small terminals. The use of standardized transmission formats is a key element in achieving interoperability among naval units and with U.S. and allied forces.

TABLE 4.1 Implementation Approaches

Architecture Goals / Enabling Techniques	Higher Frequencies	Standard/Robust Transmission Formats	Spacecraft Processing and Switching	Directive Antennas
Increased Capacity	X		X	X
Improved Interference (AJ) and Detectability (LPI) Protection	X	X	X	X
Interoperability		X	X	
Flexible Connectivity			X	
Smaller Terminals	X		X	X

Directive antennas on a communications satellite concentrate their receiving and transmitting capabilities on regions of interest and thereby permit capacity increases and/or terminal size reductions. They also discriminate against interference sources that are outside the region. (Such antennas can also be given the capability to null interference sources located within a region of operations.) Finally, directive satellite antennas contribute to LPI protection by allowing the use of lower power terminals.

Figure 4.2 shows many of the considerations involved in selecting military communications satellite frequencies. Uplink bandwidth allocations increase considerably with the higher frequencies, ranging from approximately 100 MHz at UHF (300 MHz) to 500 MHz at SHF (X-band; 8 GHz) to 2,000 MHz at EHF (44 GHz). The increased bandwidth can accommodate larger capacities and/or spread spectrum modulations for improved AJ and LPI protection. As indicated, the uplink interference level required to disrupt a specific data rate from a fixed-size terminal is highest at EHF and lowest at UHF. Uplink satellite antenna discrimination can raise the required interference level by an additional 20 to 30 decibels (dB), but the relative antijam performance of the three frequency bands is the same. These results are the consequence of the wider bandwidth at EHF. Similarly, the detection footprint within which an airborne interceptor must be located to detect a small terminal's transmission is much smaller at EHF than at the lower frequencies. On the other hand, weather effects (especially rain) have a much larger impact on the EHF uplink (44 GHz) and upper SHF downlink (20 GHz) frequencies than on those in the X-band or UHF regions. These frequency considerations suggest that a system needing significant levels of AJ and/or LPI protection could use the EHF band and incorporate sufficient link margin to overcome the effects of weather.

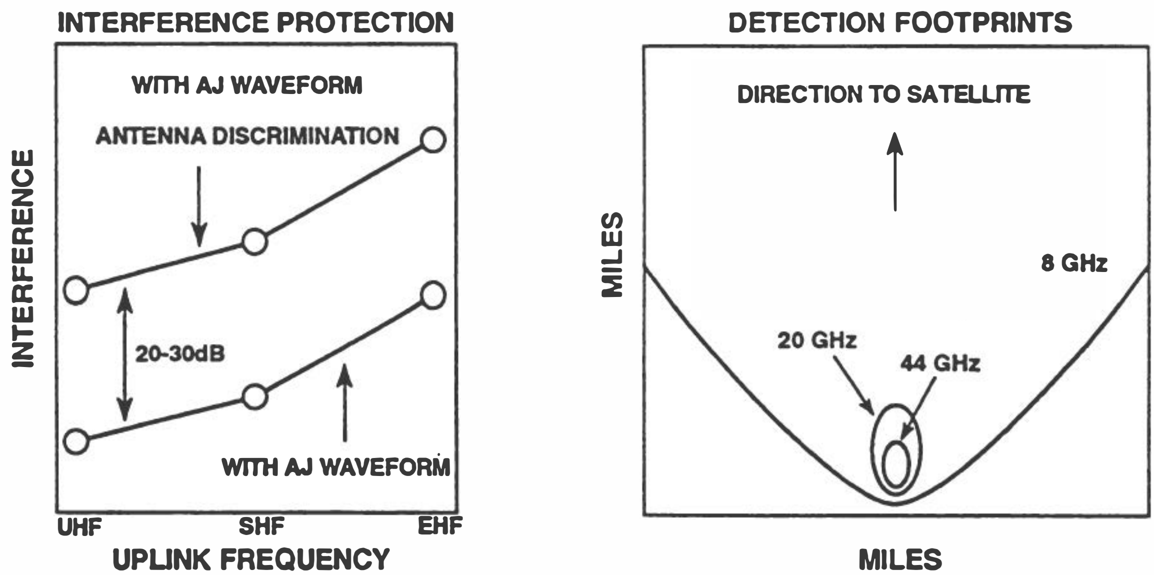
UPLINK ALLOCATIONS

FREQUENCY	BANDWIDTH (MHz)
UHF	100
SHF	500
EHF	2000

NOMINAL LINK MARGIN ALLOWANCES (dB) FOR WEATHER*

FREQUENCY	UPLINK	DOWNLINK
UHF	0	0
SHF	1	1
EHF	12	5

* 99% AVAILABILITY; 20° ELEVATION ANGLE; MID-LATITUDE LOCATION (REGION D)



FUTURE AJ/COVERT SYSTEMS USING EHF FOR INCREASED CAPACITY AND ROBUSTNESS; INCORPORATING SUFFICIENT LINK MARGIN FOR WEATHER

FIGURE 4.2 Frequency considerations.

Another significant factor in the design of a satellite communications architecture is the type of satellite processing used. The fundamental choice is between a transponding and a processing payload. In the former, the signals received on the uplink are shifted in frequency, amplified, and relayed on the downlink. The processing payload removes any spread spectrum features and demodulates the uplink signal before on-board routing and downlink modulation. As indicated in Figure 4.3, processing payloads offer significant advantages when multiple users are simultaneously accessing a satellite. The processing removes the need to carefully power balance the users, allows the downlink power to be concentrated on the disadvantaged services, permits efficient on-board routings, and allows independent optimization of uplink and downlink resources. Dynamic networks with a changing mix of large and small terminals are much easier to accommodate with processing payloads. In addition, only a processing payload can prevent interference sources from robbing downlink power and thereby denying a small terminal the full AJ protection that the system bandwidth should afford.

SATCOM PERFORMANCE IMPROVED BY SIGNAL PROCESSING

- Multiple Access
  - Reduces need to power balance
  - Allocates downlink power where needed
  - Connects users in different narrow beams
  - Optimizes uplink and downlink resources independently

- Jamming
  - Prevents power robbing
  - Allows small terminal to get full antijam protection of system bandwidth

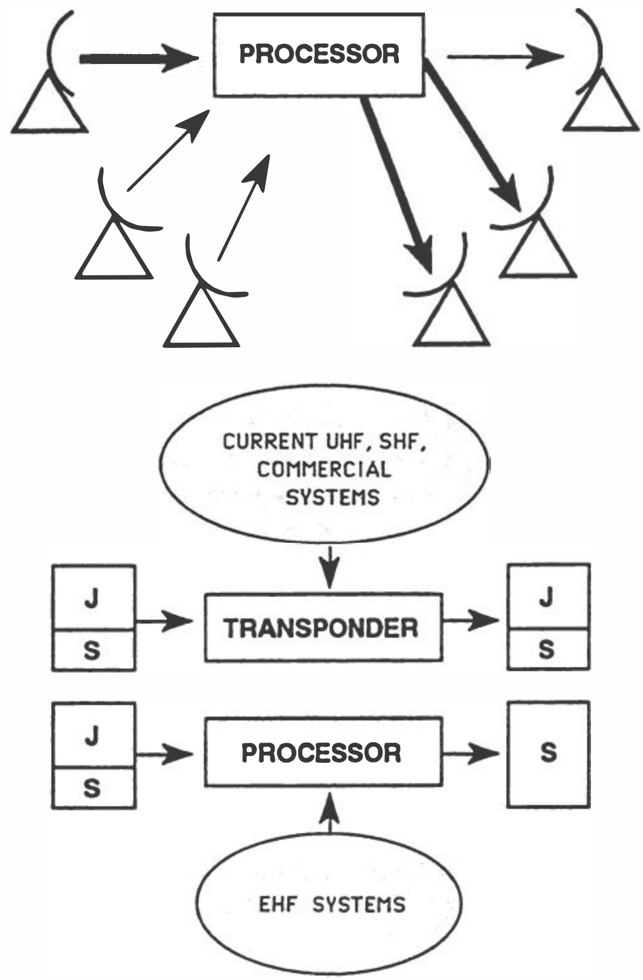


FIGURE 4.3 Processing versus transponding satellites.

Although more capable, processing communications payloads are more complex than transponding ones, to date, most UHF, SHF, and commercial communications satellite systems have been implemented with transponders. The developing EHF systems are incorporating processing for the increased protection and flexibility discussed earlier. In defining NAVSATCOM-21, the panel sought to incorporate an effective mix of both types of satellite payloads to enhance performance and leverage from current systems in a cost-effective manner.

4.2 ENHANCEMENT OF FUNDAMENTAL SERVICES

The requirements discussion in Chapter 2 mentioned three types of services: hard core, soft core, and general purpose. The first two types need AJ and (in some cases) LPI; the third does not. Table 4.2 shows qualitatively the mix (by volume) of most of these service types at each of the four hierarchical levels of NAVSATCOM-21 connectivities. As indicated, the required hard-core capacity is low at every level. However, the soft-core capacity needs are greatest at the tactical level; the general-purpose capacity requirements peak at the global and theater levels. In addition, the panel observed that the total throughput needs are much larger (about two to three orders of magnitude) than the hard-core capacity requirements alone and that soft core is a significant portion of the total capacity needs. (The possibility of high- or very-high-data-rate [HDR/VHDR] links to sensor/weapon platforms is addressed separately in Section 4.3.)

TABLE 4.2 General Navy Communications Mix (by Volume)

LEVEL	HARD CORE	SOFT CORE	GENERAL PURPOSE
Global	Low	Low	High
Theater	Low	Moderate	High
Regional	Low	Moderate/High	Moderate/High
Tactical	Low	High	Low/Moderate

Implication: Total throughput >> Hard core
NOTE: HDR/VHDR links to sensor/weapon platforms considered separately.

Table 4.3 summarizes the requirements to satisfy the objectives the panel established for NAVSATCOM-21. For capacity, the goal was to increase the link capacity available to most units from the typical current level of a few kbps to the Mbps range. At the same time, the current limited AJ/LPI protection was to be extended to the levels required for the hard-/soft-core services. Additional goals included flexible, easily reconfigurable, and interoperable connectivities. Achieving these objectives at limited cost requires leveraging planned DOD and commercial communications satellite efforts, minimizing the number of types of shipborne terminals, and maintaining compatibility with current Navy communications and networking modernization efforts (Copernicus and CSS).

TABLE 4.3 Requirements Satisfaction

FEATURE	CURRENT NAVSATCOM	NAVSATCOM-21 GOALS
Network Capacity	kbps	Mbps
Protection	Limited	Hard/Soft Core
Connectivity		Flexible
Interoperability		Transmission/Baseband Standards

NAVSATCOM-21 achieves its goals at limited cost by

- Leveraging planned activities in DOD and commercial SATCOM
- Minimizing the number of shipborne terminal types
- Maintaining compatibility with Navy communications and networking modernization efforts (Copernicus, CSS)

4.2.1 Hard-Core Communications

As described in Chapter 2, hard-core communications need the highest protection. In addition, they are typically low-data-rate ($\leq$9.6 kbps per channel) but often have to be supported from small, mobile terminals.

The Navy (and DOD) are planning to implement hard-core capabilities using processing communications satellites operating at EHF. Two test payloads (the EHF packages on FLTSATCOM-7 and 8) are currently on orbit and have been used to verify the potential of this frequency band and satellite-based signal processing. MILSTAR, which should be launched in 1993, is planned as the backbone, worldwide, hard-core system for all of DOD. These satellites will also have crosslinks and highly protected Fleet Broadcast (FLTBDCST) injection capabilities. In addition, the Navy is developing an EHF package that will be carried by the UHF Follow-On satellites beginning with the fourth flight, which is scheduled for 1994. These packages will augment hard-core communications and protected FLTBDCST injection capabilities.

An extensive Navy deployment of EHF terminals is under way. More than 150 have been procured, and more than 60 additional terminals will be procured within the next 5-year budget cycle.

The panel endorses the Navy's approach to implementing hard-core communications at EHF. In addition, the panel observes that polar coverage was not available from the planned MILSTAR and UFO deployments. Such service could be provided by a modest payload (200 to 400 pounds [lb]) that could be a secondary payload on an appropriate host or the primary payload on a small satellite.

Due to the critical nature of hard-core communications, the panel also addressed the role of crosslinks in maintaining connectivities. Most ship-to-ship and other links within a region of operations can be provided by a single satellite and, hence, would not use crosslink relays. However, many fleet-to-shore links are longer range than those in a regional operation. Such links can reach U.S.-controlled territory (CONUS, Hawaii, or Guam) with a single satellite hop if there are few constraints (e.g., due to international frequency coordinations) on orbital locations. If orbital placements are seriously restricted, at least one additional gateway/relay site in the Indian Ocean area is required (i.e., Diego Garcia). Crosslinks become essential for worldwide connectivity if properly placed gateway/relay sites are unavailable.

4.2.2 Soft-Core Communications

Soft-core connectivities require considerable antijam and LPI protection, yet the required data rates (up to the Mbps range) are one to two orders of magnitude higher than those for hard-core communications. An important observation is that all Navy platforms that have a soft-core requirement also have a hard-core one. At the time of this study, there was considerable debate within the DOD community about the best method for satisfying soft-core requirements. Accordingly, the panel considered a number of options, including military communications satellites operating at EHF and SHF and commercial SATCOM systems.

Representative soft-core communications capabilities that could be realized at EHF are indicated in Figure 4.4. Terminal antenna and transmitter parameters (1-m aperture and 250 W, respectively) corresponding to the LDR shipborne units now being procured were assumed. A processing EHF payload with a range of uplink (44 GHz) and downlink (20 GHz) antenna coverage capabilities was used. The coverage areas included earth coverage (implying an 18° beamwidth for payloads at geosynchronous altitude) and 800- and 400-nautical-mile (nmi)-diameter theaters of operation (2° and 1° beamwidths, respectively). As shown in Figure 4.7, the example terminal can achieve mid-range MDR services across an 800-nmi satellite uplink beam (2° beamwidth) and full-range MDR services from a 400-nmi theater beam (1° beamwidth). With a very modest 10-W, 20-GHz satellite transmitter, multiple soft-core uplink streams can be carried on the downlink to the example terminal (or to other users). Of course, shore terminal installations with larger antennas and/or transmitters could achieve greater capabilities. It should also be noted that the initial plans for the MILSTAR II (MDR) system include at least four times more downlink capacity than the payload in Figure 4.4.

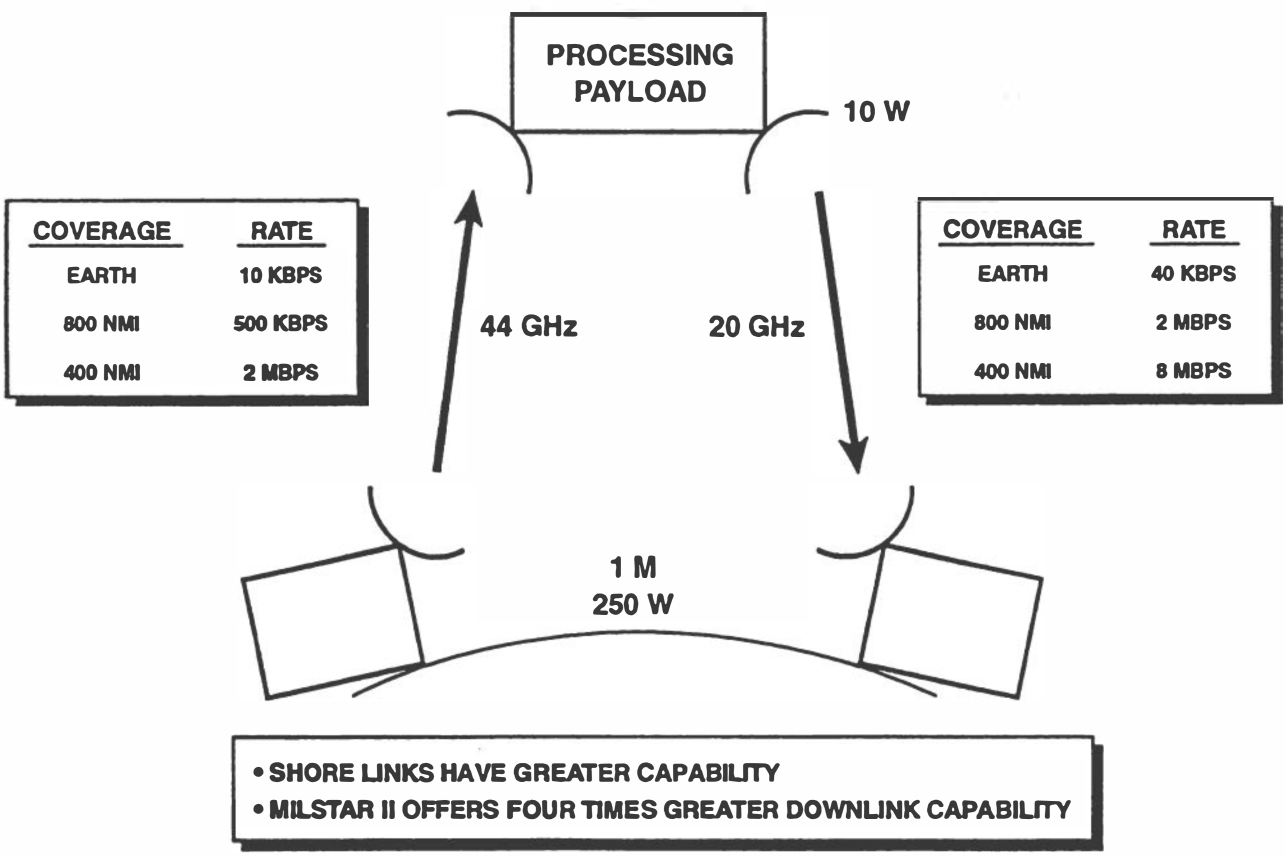


FIGURE 4.4 Soft-core communications: representative EHF capability.

EHF MILSATCOM systems were originally envisioned as providing highly protected (LDR) links to small, mobile terminals. As such, all planned EHF systems incorporate directive antenna and processing payloads. Hence, adding MDR capabilities to these systems primarily requires incorporating the appropriate signal processing features into the terminals' modems and the payloads' demodulation/remodulation subsystems. Furthermore, DOD has already restructured the MILSTAR program to incorporate an MDR capability on the fourth satellite, which at the time of this study is scheduled for launch in late 1998 or early 1999. The panel also observed that emerging payload technologies would permit small LDR/MDR packages (100 to 200 lb) to augment EHF service in polar regions or other critical areas. In addition, a proposed ARPA space demonstration[1] (ASTEC; 1996 launch) would provide an early MDR EHF terminal test opportunity.

To exploit this EHF option for soft-core service, the panel believes that the Navy should consider the following four actions:

- Develop an MDR modem enhancement for the LDR terminals now being deployed on all combat ships.
- Influence DOD MILSTAR II planning activities to ensure the incorporation of appropriate capabilities for Navy needs.
- Consider, at an appropriate programmatic time, an MDR enhancement for the EHF package on the UFO satellites.
- Explore possibilities for polar service.

The second option the panel addressed for soft-core communications capabilities involved satellite systems operating at SHF (8-GHz uplinks/7-GHz downlinks) with a transponder-type payload. As shown in the example configurations in Figure 4.5, the assumed shipborne SHF terminals' parameters[2] (4-ft antenna apertures and 500-W transmitters) are consistent with recent Navy development/procurement planning activities. The assumed payload uplink antenna coverage capabilities include Earth Coverage (18° beamwidth for payloads at geosynchronous altitude) and a 1,200-nmi theater of operations (3° beamwidth), while the downlink antenna coverage capabilities include Earth Coverage and 3° beamwidths as well as a 5° beamwidth (2,000-nmi theater of operations). As shown in Table 4.4, the DSCS III SHF communications satellites can produce all of these coverages, although the uplink beams are typically configured for Earth Coverage. With the 10-W payload downlink transmitter[3] in Figure 4.5, the example terminal can only achieve the low end of MDR data rates (60 kbps) when operating into Earth Coverage uplink and downlink antennas. However, by using a typical configuration involving an Earth Coverage uplink beam and a 5° downlink beam (2,000-nmi coverage), this terminal

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[1]ARPA did not receive the requested funding for a fiscal year 1993 initiation of ASTEC.

[2]Although these terminal parameters are larger than the corresponding values used in the above soft-core EHF service example, the panel does not believe that the differences would significantly affect relative comparisons among the options being considered.

[3]DSCS III has four 10-W transmitters and two 40-W transmitters.

can potentially achieve mid-range MDR rates (500 kbps). Alternatively, by using the most directive payload beams assumed in Figure 4.5, multiple MDR channels could be supported (5 Mbps total rate). As with the previous EHF example, larger sized shore-based terminals could achieve greater capacity. On the other hand, it is important to note that other users in the SHF payload's transponders could limit the achievable ship-to-ship rates to 10 percent or less of the values shown in Figure 4.5. The indicated example capacities were obtained by assuming that the terminal had exclusive use of a transponder.

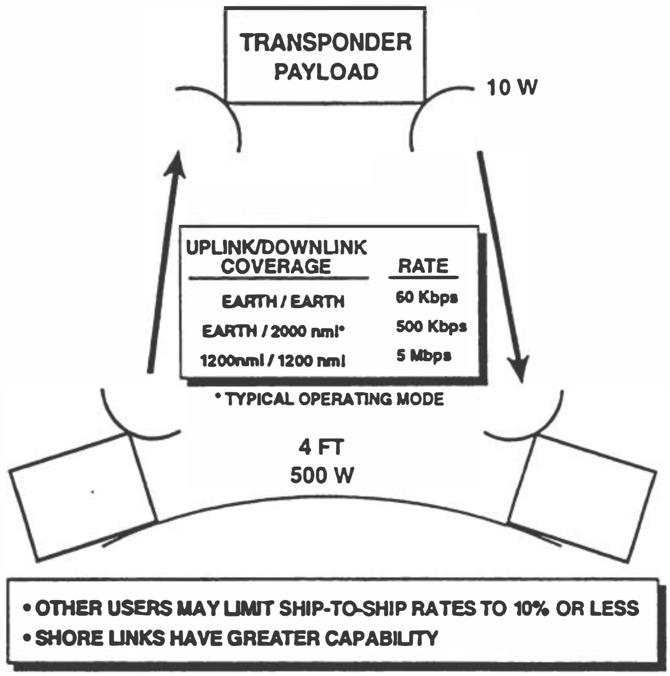

FIGURE 4.5 Representative SHF capability.

TABLE 4.4 DSCS III Antenna Coverage Capabilities

COVERAGE	UPLINK ANTENNA(S)	DOWNLINK ANTENNA(S)
Earth (18° beam)	61-EC Horn	EC Horn
	61-beam Multiple Beam Antenna (MBA)	19-beam MBA
2,000 nmi (5° beam)	61-beam MBA	19-beam MBA
1,200 nmi (3° beam)	61-beam MBA	Gimballed Dish Antenna (GDA)
NOTE: Typical MBA configurations are 61-beam uplink MBA → earth coverage (18° beam) 19-beam downlink MBA → 5° beam		

The SHF service example led the panel to conclude that an SHF/transponder-based satellite system (e.g., DSCS III and several allied SHF satellite systems) could potentially provide soft-core communications service, but the capacity achieved by a particular terminal is affected by the presence of other users more than with processor-based payloads. There are enough DSCS III and allied satellites either on orbit or in storage (DSCS III/construction, allied) for service into the next century. However, most of these systems, which have been configured primarily for connectivity among geographically distributed large ground terminals, are already significantly loaded with other users. Thus, the capacity that would be available to Navy shipborne terminals would typically be limited to the lower end of the MDR range. Improved Navy afloat SHF service would require some combination of the following two items:

- Larger allocation of payload power/bandwidth (e.g., dedicated transponder[s]).
- Increased satellite transmit power/antenna directivity (DSCS replenishment/follow-on deployments are not currently planned until 2000+, although DOD is considering modifying some of the DSCS III satellites now in storage).

In addition, the Navy would need to procure significantly more SHF terminals if this option is selected as the primary method for soft-core service. At the time of this study, approximately ten SHF terminals were installed on ships, and an additional 31 were budgeted in the Program Objective Memorandum (POM) for fiscal years 1994 through 1998.

The third option the panel considered for soft-core service used commercial communications satellite systems. Of the current operational systems, only those at C-bands (6-GHz uplinks and 4-GHz downlinks) and Ku-bands (14-GHz uplinks and 12-GHz downlinks) have sufficient bandwidth for the data rates associated with MDR. Directive shipboard antennas would be required in these frequency bands, as is the case in the military SHF and EHF bands. The commercial payloads are transponder based, and, consequently, the performance achieved by a particular terminal would be subject to the loading in the transponder that it is using. Because of the proximity in frequency of the C-, military SHF, and Ku-bands, as well as the transponder-type payloads used in all three of these frequency bands, a C- or Ku-band ship terminal would be similar in size to the one in the military SHF example (Figure 4.5) and the resulting capacity would be approximately the same (i.e., the lower end of the MDR range with earth coverage payload antennas and the upper end with payload antennas with high directivity). Such soft-core, commercial communications satellite terminals would have to be significantly more capable than the commercial terminals currently installed in Navy ships, which provide only LDR services. Two other factors could be important in the Navy's considerations of this soft-core option:

- Much of the service may be from international organizations (such as INTELSAT or INMARSAT), since domestic communications satellites have limited coverage of ocean areas.
- Several militarily significant features (e.g., highly protected telemetry and command systems, adaptive payload antennas, and military control of resources) may not be available on commercial service satellites.

After carefully considering each of the above three options, the panel recommends that the Navy use EHF as its primary soft-core system. This option is more robust because of the higher antijam/LPI thresholds at EHF and payload processing that decouples performance from user mix.[4] Also, the EHF option could be implemented to enhance terminals the Navy has already procured or programmed for hard-core LDR service. Avoiding installation of additional satellite communications antennas on many of the Navy's platforms was an important consideration to the panel.

The panel recognizes that DOD's current plans for MILSTAR II do not call for the deployment of MDR-capable payloads until late 1998 or early 1999. Accordingly, the panel recommends that the Navy deploy an interim SHF soft-core capability on selected platforms. Due to the DSCS III adaptive uplink antenna (61-beam MBA) and military control system, interim service at this frequency band will be better protected than if it were in commercial bands.

In addition, the panel recommends that the Navy investigate a low-cost, multiple-frequency-band (commercial and military SHF) terminal to enhance the flexibility of NAVSATCOM-21. In the near term, such a terminal could provide the recommended interim soft-core service at SHF. In the longer term, this terminal could be used on selected platforms to augment either soft-core (protected) or general-purpose services. Augmentation needs were seen as scenario dependent and perhaps even time varying. For example, when in a theater of operations, some ships may require additional protected capacity. But when in open ocean or near port areas, these ships may need to supplement their general communications resources. A rapidly reconfigurable terminal could supply both types of service and thereby avoid a requirement to install multiple augmentation-service terminals on a particular platform. The panel believes that with emerging technologies and the application of selected commercial terminal practices, it will be possible to obtain a multiband (C-, X- or military SHF, Ku-bands) terminal at an affordable price (a few hundred thousand dollars). Finally, the panel observes that the incorporation of a multiple-beam capability (MMBA) into the multiband terminal would permit simultaneous access to more than one satellite communications system.

4.2.3 General-Purpose Communications

All Navy ships require general-purpose communications capabilities; the capacity requirements are approximately the same as for soft-core services (i.e., up to about 1.5 Mbps per channel). However, there are no protection requirements. All Navy ships are equipped with UHF satellite communications terminals that provide LDR general-purpose connectivities (typically at 2.4 kbps). The planned deployment of automatic demand assigned multiple access (DAMA) capabilities will provide a three- to fourfold capacity increase (to about 10 kbps per terminal). In addition, some ships have INMARSAT terminals that provide additional LDR service at a few kbps. Several other commercial mobile satellite communications systems are

[4]Satellite-based signal processing has been incorporated into only EHF satellite communications systems at this time. It could potentially also be employed on SHF or commercial systems, but it would probably be incompatible with the large number of terminals already deployed in these bands.

in the planning stage. They could be used to further enhance shipborne LDR capacity. However, even with all of the above systems, the panel discerned a shortfall in meeting the projected general-purpose capacity requirements. The panel recommends that the Navy consider the following two actions:

- Improve the efficiency of UHF spectrum utilization. With modern technology, achieving modulation efficiencies of 2 to 3 bits/Hz should be possible for a general-purpose satellite communications system. This would imply 50 kbps (or more) through a 25-kHz UHF payload transponder such as those on the FLTSATCOM and UHF Follow-On satellites.
- Utilize additional commercial capabilities for those platforms with remaining general-purpose requirements. Again, the panel observes that the use of a low-cost ("commercial style") multiband terminal (C-, X-, Ku-bands) would enhance flexibility by permitting connectivity via a number of satellite communications services (i.e., NASA's TDRSS, DOD/allied SHF, and commercial satellites). Also, a multibeam capability would further enhance the utility of such a multiband terminal.

4.3 SERVICE EXTENSION OPTIONS

The panel believes that a key aspect of NAVSATCOM-21 is incorporation of the enhancements of fundamental (hard-core, soft-core, general-purpose) communications services discussed in Section 4.2. However, the panel also wants the goal architecture to be readily extendable to include other connectivity needs that might arise. This section contains descriptions of two such possibilities involving satellite communications with airborne Navy assets.

4.3.1 HDR/VHDR Sensor Connectivity

The first scenario includes a high- to very-high-data-rate relay (HDR/VHDR; up to approximately 300 Mbps) of information from an airborne sensor. This is a difficult task for a satellite communications system and should be seriously considered only if line-of-sight communications links are not available. As shown in Table 4.5, two frequency bands (EHF and Ku) were considered. For both, the use of Common Data Link (CDL) signaling formats and transponder-based payloads was assumed.[5] Two types of airborne platforms were envisioned. One involved an aircraft-mounted sensor with a terminal that has a 2-ft aperture and a 100-W transmitter. This platform was assumed to be flying at an altitude of several thousand feet, so that it is above much of the weather that could degrade EHF links (i.e., a modest link margin allowance was included). The other platform involved a cruise missile that could accommodate

[5]A processor-based payload for HDR/VHDR would require considerable payload power. Also, the current Ku-band TDRSS system is transponder-based.

only a 6-in. aperture satellite communications terminal with a 100-W transmitter. This second platform was assumed to be flying at low altitudes, so that full EHF weather margins had to be included in the link calculations (Figure 4.2).

TABLE 4.5 HDR/VHDR Sensor Connectivity

Two frequency bands considered; both use CDL signaling • Selected high-altitude aircraft (AC; 2 ft, 100 W) • Low-altitude cruise missile (CM; 6 in., 100 W)	
EHF	Ku-band (TDRSS)
6-ft S/C antenna (100 nmi footprint) 4 Mbps from CM 300 Mbps from AC Downlink to ≤10-ft terminal	16-ft S/C antenna (120-nmi footprint) 30 Mbps from CM 300 Mbps from AC Typically downlinks to CONUS ground terminal
NOTES: Data compression would ease communications impact Multiple beams needed for large area of operations Larger terminals/lower data rates → smaller satellite antennas TDRSS availability/EHF transponder deployment considerations	

As shown in Table 4.5, a 6-ft EHF satellite antenna could support the relay of 4 Mbps from a cruise missile to a 10-ft ground terminal. Alternatively, 300 Mbps could be relayed from an aircraft installation. Similarly, the 16 ft Ku-band antenna on NASA's TDRSS could support 30 and 300 Mbps from cruise missiles and aircraft, respectively, to a large ground terminal (currently based in CONUS). The footprints of the two example satellite uplink antennas are very narrow (100 nmi for the 6-ft EHF antenna; 120 nmi for the 16-ft Ku-band antenna). This means that multiple antennas would be needed for concurrent coverage of large areas of operations.

The panel also made the following observations:

- Data compression techniques on the sensor platform would ease the impact on the communications system.
- High data rates imply low protection.
- Larger terminals (perhaps difficult for airborne platforms) and/or lower data rates would result in smaller satellite antennas (i.e., lower cost, more easily implementable payloads).
- TDRSS availability and/or EHF transponder deployments would have to be considered.

4.3.2 LDR/MDR Beyond-Line-of-Sight (BLOS) Connectivity

The second extension service scenario considered also involved satellite communications connectivities to airborne assets (e.g., cruise missiles, UAVs, tactical aircraft, helicopters). However, in this scenario the desired data rate is in the LDR (< 10 kbps) to MDR (< 1.5 Mbps) range. Two possible approaches were considered. One involved the use of directional antennas (6-in. aperture at EHF or SHF) on the airborne platform, while the other used smaller omni-directional antennas (at UHF) that do not require a stabilized pointing mechanism. In both approaches, a 10-W airborne transmitter was assumed.

As shown in Table 4.6, LDR service can be provided either by an EHF approach with an Earth Coverage satellite uplink antenna or by a UHF technique. Alternately, the use of a directive EHF uplink antenna (1° beamwidth; 400-nmi coverage) would result in mid-range MDR capabilities. Similar results would be achieved with an SHF payload, but the protection would be somewhat lower and the payload antennas would be physically larger. Since corresponding payload antenna directivity at UHF would not be feasible, the EHF (or SHF) option should be pursued if MDR connectivities to airborne platforms are required. In addition, EHF (or SHF) equipped aircraft at altitude (6-in. aperture, 10-W transmitter) could achieve data rate increases of approximately two orders of magnitude (to the upper end of the MDR range with 1° payload antenna beams).

TABLE 4.6 LDR/MDR BLOS Connectivity

	EHF*		UHF*	
	Uplink Rate	Downlink Rate	FLTSAT	MUBL**
Earth Coverage 400-nmi Coverage	150 bps*** 25 kbps***	600 bps*** 120 kbps***	1.2 to 2.4 kbps —	2.4 kbps —
Terminal Parameters	6-in. antenna; 10 W Tx		OMNI antenna; 10 W Tx	
Cost	Comparable to cruise missile		<< cruise missile	
Multipath Degradation	Negligible		Severe	Negligible
Antijam	High		None	Moderate
Detectability	Low		High	Moderate

* Similar results for SHF (except less protection)
** Multiple path BLOS communications system (ARPA/Army-funded R&D activity)
*** 100× capability increase for aircraft at altitude (6 in.; 10 W Tx)

Other points of comparison between the approaches are also shown in Table 4.6. Antijam and signal detectability performance, as well as resistance to multipath degradations, is significantly superior in the EHF (or SHF) option. However, the cost of an EHF (or SHF) terminal with its directive airborne antenna may approach the cost of a cruise missile. On the other hand, the cost of a UHF terminal (with an omni-directional antenna) is modest, but the protection afforded in this frequency band for the example LDR signals is low. The cost advantages of UHF could possibly be preserved and the protection increased to moderate levels by using the Multiple Path BLDS Communications System (MUBL) concept, a CDMA-type technique that is compatible with existing UHF payload transponders. This technique is presently an ARPA/Army-funded R&D activity.

4.4 INTEROPERABILITY/NETWORK CONTROL CONSIDERATIONS

The NAVSATCOM-21 goal architecture accommodates a variety of link and baseband signal standards to promote increased interoperability among multiple-service forces of the United States as well as with appropriate allied units. As shown in Table 4.7, the architecture provides for interoperable EHF/processor-payload-based service at both LDR (MILSTD 1582C) and MDR (MILSTD 188-136). The former has been published by the United States and has been shared with the United Kingdom, Canada, and France. It is expected to become the basis for an eventual NATO Standardization Agreement (STANAG). MILSTD 188-136 is currently under development in the United States, and because of international interest in interoperable EHF/MDR systems, preliminary planning discussions have already been held with the United Kingdom and Canada.

TABLE 4.7 Interoperability

- Multiservice and allied
- Link and baseband standards required
  - EHF: MILSTD 1582c (LDR)
    - Shared with United Kingdom, Canada, France
    - NATO addressing STANAG

    MILSTD 188-136 (MDR)
    - United States developing
    - Discussions with Canada, United Kingdom
  - SHF: Universal modem (up to 64 kbps)
    - United States, United Kingdom, France developing
    - STANAG being prepared
    - Other interoperable modems exist
  - UHF: DAMA and other standards exists (25/5 kHz channels)
    - Being incorporated into equipment
  - High/very high data rates: CDL standard
    - Compatible with transponded systems at SHF, EHF, C-, Ku-bands

At SHF, the United States, the United Kingdom, and France are developing the Universal Modem, which will provide interoperable service over SHF/transponder-based payloads at data rates up to 64 kbps. A NATO STANAG based on the Universal Modem signal formats is being prepared. The Universal Modem features are fully compatible with NAVSATCOM-21. In addition, there are other interoperable SHF modems and several evolving SHF DAMA techniques that the architecture accommodates. Similarly, the emerging UHF DAMA and other link and baseband standards for both 25-kHz and 5-kHz UHF SATCOM channels can be used with NAVSATCOM-21. The architecture is also compliant with the provisions of the CDL standard for HDR/VHDR service over transponded systems at SHF, EHF, C-, and Ku-bands.

NAVSATCOM-21 has four provisions for improved network control:

- UHF (and SHF) DAMA techniques for more efficient use of transponder-based satellites.
- Signal processing "switchboard" features inherent in all planned EHF payloads.
- Compatibility with other Navy communications network modernization activities (e.g., Copernicus/CSS).
- Utilization of GPS for accurate location and timing information in order to permit rapid spatial acquisition (for platforms with directive antennas) and fast COMSEC/TRANSEC equipment synchronization. Obviously, there would be operational advantages if all Navy SATCOM-capable platforms were equipped with GPS receivers.

4.5 DEPARTMENT OF DEFENSE CONTEXT

The panel envisioned that NAVSATCOM-21 would be implemented as part of a DOD-wide MILSATCOM architecture evolution. Figure 4.6 shows the overall plan in which the existing baseline architecture (involving four space segments) would be modernized during the 1990s to better satisfy communications requirements, improve user flexibility/interoperability, and reduce costs. Over this period, there would be key decision opportunities at which the configuration of the next generation of a segment of the architecture would be decided. Concurrently, technologies for improved spacecraft, terminals, and networking and control would be developed and demonstrated. As indicated, technology insertion opportunities for the space segment portions generally correspond with the decision opportunities.

Some of the planned key DOD MILSATCOM decision opportunities are shown in Table 4.8. The panel thinks it is important for the Navy to leverage these to expedite implementation of portions of NAVSATCOM-21.[6]

[6]In the fall of 1992, Congress directed a restructuring of the MILSTAR system to increase its use by tactical forces. In addition to reducing its nuclear survivability, an MDR capability was added to the system. In the spring of 1993, as a result of an OSD MILSATCOM Bottoms-Up review, the MILSTAR system was reconfigured as a two LDR and four MDR satellite. The issue regarding polar coverage was deferred to a later date, and UHF and commercial systems were recommended to support general-purpose communications requirements. These actions reinforce the NAVSATCOM-21 architecture recommended in this report.

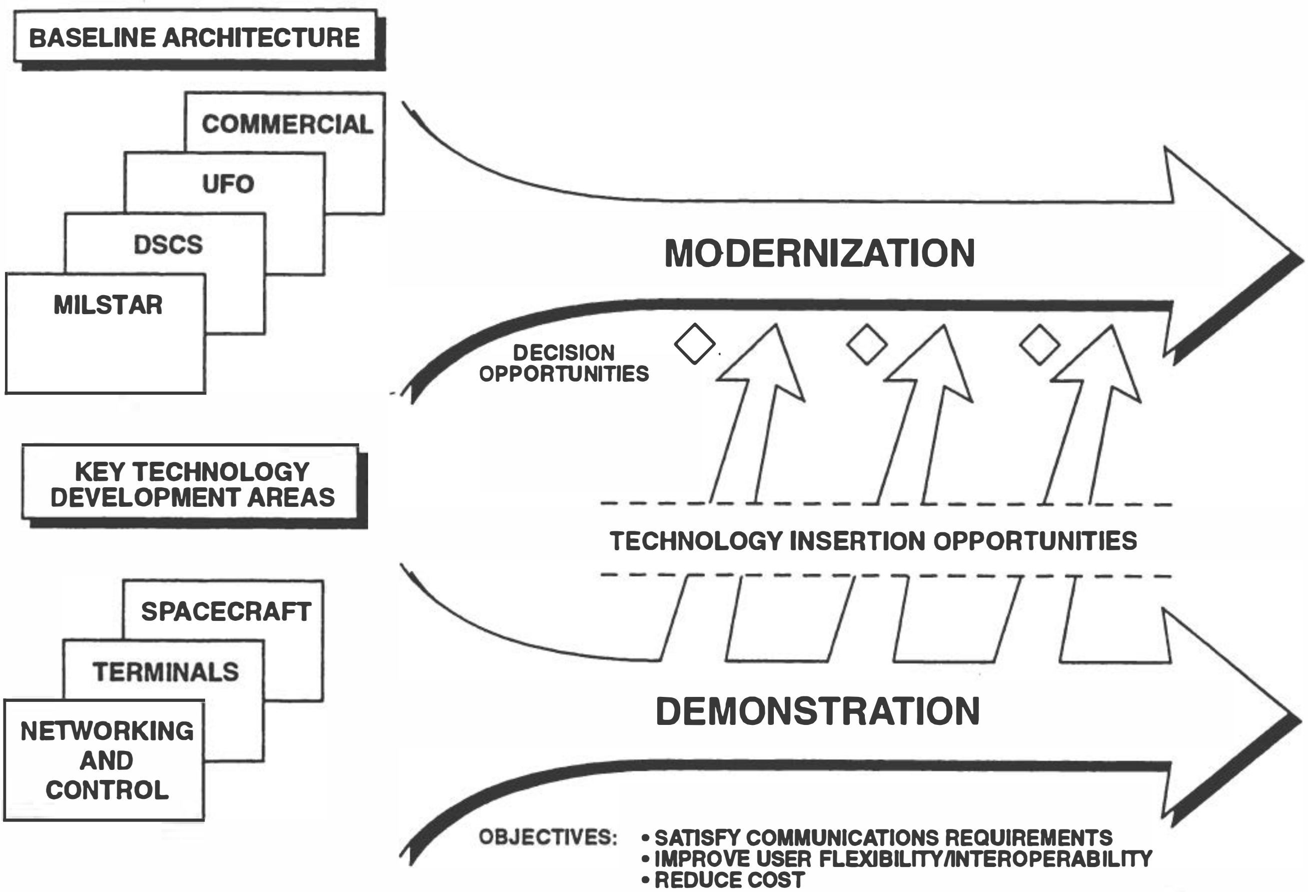

FIGURE 4.6 MILSATCOM architecture evolution.

TABLE 4.8 DOD MILSATCOM Decision Opportunities

OPPORTUNITY	TIME FRAME	EXPECTED EMPHASIS
1	1992	Mid-1990s EHF systems
1A	1993/1994	Polar coverage
2	1993/1994	SHF replenishment and commercial
3	1997/1998	Post-2000 EHF systems
4	1998	UHF replenishment
Two joint ARPA/service technology initiatives planned • ASTEC small LDR/MDR/VHDR EHF satellite • IMPACT terminal technology program		

4.6 FINDINGS AND RECOMMENDATIONS

The panel concludes that an adaptable, affordable, global satellite communications system for evolving Navy requirements is feasible. This overall finding is supported by the following results from the areas investigated:

- Projected EHF capability (augmented with MDR) satisfies Navy hard- and soft-core requirements.
- UHF can be enhanced, for tenfold increase in general-purpose capacity.
- SHF can provide near-term, limited soft-core/general-purpose MDR capability for selected platforms.
- Commercial SATCOM could augment general-purpose service.
  - INMARSAT currently utilizes LDR.
  - Other mobile services possible for LDR.
  - Ku-/C-bands for MDR.
- Standards for interoperability are well under way.
- Direct (single hop) connectivities are possible to U.S. territory with most satellite deployments.
- Links to small airborne platforms are feasible.
- There are benefits to having GPS on all SATCOM-capable Navy platforms.

Figure 4.7 contains an overview of the NAVSATCOM-21 goal architecture for Navy satellite communications. The basic services are obtained via EHF (hard /soft core), SHF (interim soft core on selected platforms; possibility for long-term backup via multiband terminal), UHF (general purpose), and commercial space segments (general purpose). All of the links conform to interoperability standards, and connectivities can be provided to airborne platforms. It is noteworthy that only two basic types of terminals are required for most ships: EHF for hard-/soft-core communications and UHF for general-purpose service. Selected platforms may have additional installations for interim soft-core communications at SHF and/or augmented general-purpose service via commercial satellites. As previously noted, a multiband terminal (C-, X-, and Ku-bands) would offer enhanced flexibilities for selected platforms.

The panel developed the following five general recommendations pertinent to the implementation of NAVSATCOM-21:

- Foster utilization of EHF.
  - Primary hard-/soft-core backbone for mid to far term.
- Improve efficiency of DOD UHF.
- Continue SHF soft-core/general-purpose service for major combatants.
  - Near-term interoperable LDR/MDR soft core.
  - General-purpose MDR capability.
- Use commercial services for general-purpose supplement if
  - Additional services/capacity is needed.
  - Service cost is low.
  - Shipboard installation is affordable.

- Investigate low-cost, multiband (SHF and commercial), perhaps multibeam, terminal as flexibility-enhancing feature.

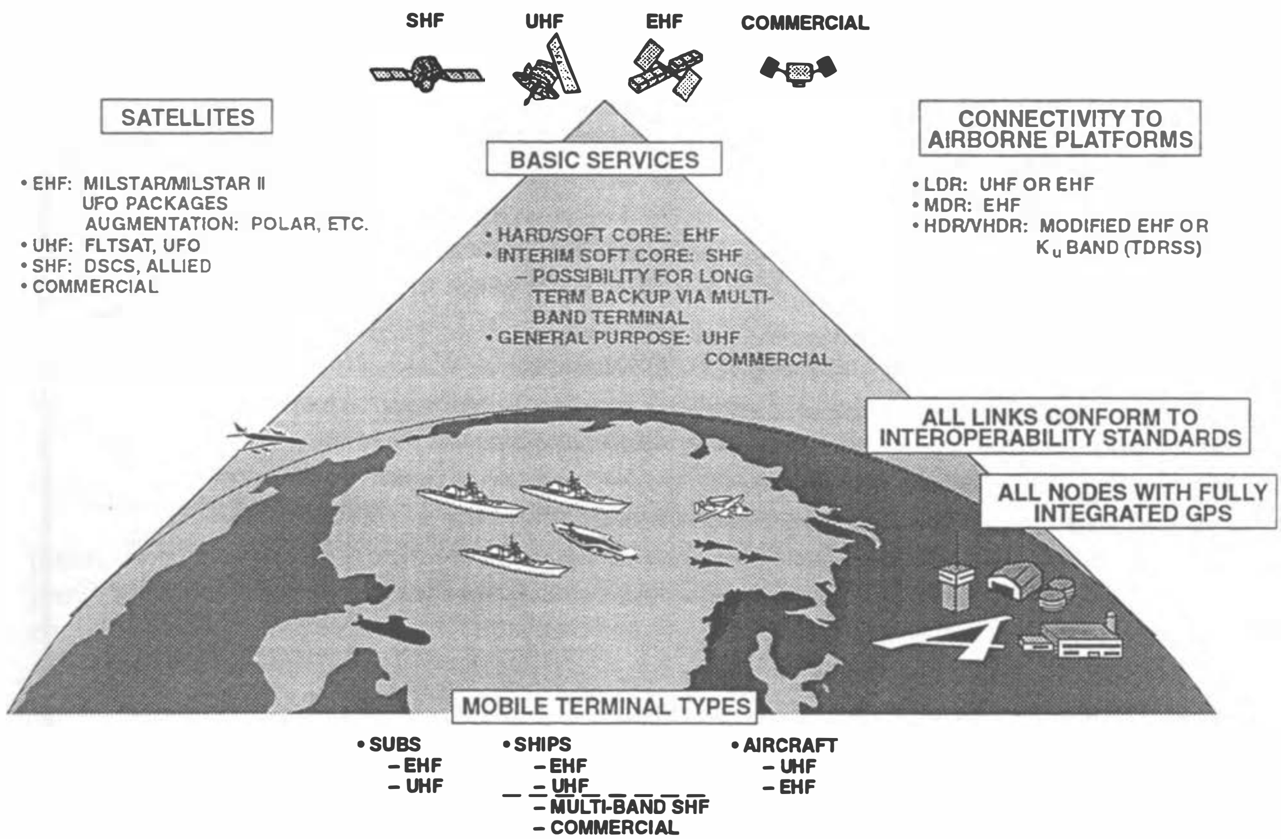

FIGURE 4.7 NAVSATCOM-21 overview.

To achieve the potential of NAVSATCOM-21 in a timely manner, the panel developed the suggested actions listed in Table 4.9. As noted, these suggested efforts were keyed to the general recommendations as well as to enhancing capabilities to airborne platforms and to leveraging other DOD MILSATCOM activities. The suggestions have been partitioned into three time periods: near term (1992-1997), mid-term (1997-2005), and far term (2005-2015). Some of the potentially highest leverage activities are the suggested near-term efforts to

- Demonstrate an MDR upgrade for the LDR EHF terminals being deployed.
- Consider an MDR upgrade/backfit for the UFO/EHF package.
- Demonstrate low-cost/multiband/multibeam SATCOM terminal.
- Continue SHF DAMA developments.

TABLE 4.9 Suggested Actions

	NEAR TERM (1992-1997)	MID-TERM (1997-2005)	FAR TERM (2005-2015)
Foster EHF	Continue LDR deployment Demonstrate terminal upgrade for MDR Consider MDR backfit to UFO	Deploy MDR Augment space segments Deploy airborne terminals	Add HDR Add EHF buoy for subs
Exploit DOD UHF	Demonstrate and develop 10-fold enhancement	Field upgraded modem	Shift to commercial
Utilize DOD SHF	Track universal modem development Demonstrate low-cost multiband/beam terminal	Install universal modem (if affordable) Field multiband/beam terminal	Exploit as available
Commercial Services	Selective installation for additional general-purpose capability		
Small, Airborne Platforms	Develop cruise missile terminal	Deploy cruise missile terminal	Increase data rates
Participate in DOD Activities			
Technology	ARPA satellite and terminal initiatives	Wideband gateways EHF buoy	EHF beam hopping
Programmatic	MILSTAR II + augmentation SHF replenishment Commercial utilization SHF DAMA	Post-2000 EHF UHF replenishment	Low-cost replenishment terminals

The panel believes very strongly that NAVSATCOM-21 provides economical corrections for current shortfalls in Navy satellite communications (capacity, protection, interoperability, connectivity) as well as the flexibility to evolve in response to changing requirements and technology advances. Aggressive implementation is recommended.

5
Navy Operational Capabilities Enabled

The NAVSATCOM-21 goal architecture has identified communication attributes that enable enhancements in information transfer critical to the Navy's warfighting ability. This architecture supports the battle space expansion for naval strike missions and flexibility for cruise missile attack and allows for real-time battle damage assessment; increases joint and allied interoperability; enhances battlefield intelligence; expands the quality of command conferencing; improves communications covertness and survivability; and facilitates operational training. In short, major capabilities can be achieved if the Navy enhances information access and use. Each of these capabilities is discussed in turn below.

5.1 EXPANDED BATTLE SPACE

The effective battle space is the volume in which a target can be located and identified, weapons delivered, and assessment of damage obtained. When the battle space is dynamic, as with mobile forces or in crisis situations with little warning, there is a burden on communication to and from the on-scene forces.

Today we do not have sufficient communications capacity to support the volumes of plans, images, and continued updates of on-scene information from national or other sensors to provide timely informed and coordinated military operations. This situation is further complicated when the target area is in excess of organic sensors (1,000+ miles) but within range of current cruise missiles.

The NAVSATCOM-21 recommends implementation of the planned EHF-MDR by modification of the programmed EHF terminals, to operate at the higher data rate, employ a commercial and lower-cost version of the SHF terminal and modem, and increase the capacity of the current UHF terminals by application of available modern technology. Augmenting these initiatives with the potential of commercial satellite service and flexible and controlled routing of data in a standard format over the projected alternate communications paths will make it possible to support the projected need. This rich interconnect with available satellite resources will result in an adaptable global communications network.

As an example, the Air Tasking Order (ATO) in Desert Storm (500 pages) could be transferred by the EHF-MDR communications in less than 23 seconds. An image (20 megabits) could be transferred from a flagship or delivered in less than 15 seconds. This richness in capacity and connectivity provides the task force commander access to all available information necessary for the operation.

To further refine the NAVSATCOM-21, a high-capacity MDR backbone must be established to support in-theater coordination. This backbone must be accessible by local or organic communications systems, and information should be passed in a seamless manner. Emphasis must be placed on gateways between and among forces to realize the benefits of the available communications capacity and connectivity. Where possible, commercial communications standards should be employed with the intent to divide data and communications standards into a common form. An objective of the division would be to allow data in distributed databases to be interconnected in a transparent manner independent of the communications system involved.

To support the expanded battle space, the NAVSATCOM-21 includes the control and receipt of information from an in-flight cruise missile. The cruise missile can be updated to change flight profile or target area during its nearly 2-hour flight to target. When the cruise missile is entering the final phases, indications of the weapon effectiveness can be relayed to the release authority for rapid retargeting or placing a high confidence on the mission's success.

The EHF-MDR service with a small terminal for aircraft and cruise missiles can support this operational cruise missile weapon delivery. The architecture allows this capability to be accomplished by a UAV or E2-C for shorter-range engagement. However, the panel recommends that the information transfer for this extended weapon control and battle damage assessment be independent of the relay platform.

A foundation for the adaptive communications services is knowledge of the force location and uniform timing. Integration of GPS allows this information to be available for all force units.

5.2 FLEXIBLE CRUISE MISSILE ATTACK

In-flight updates provided by the goal architecture permit adjustment and alteration of preplanned targets and flight paths loaded into cruise missiles. This capability permits the use of dynamic battle management concepts. At present, cruise missiles accommodate a single route plan, which can be used for alternate targets. Future variants will incorporate multiple route plans, each of which can accommodate alternate targets. The combination of multiple aim points and the ability to choose among them permit great flexibility in the development of pre-planned attack options against relocatable targets. This flexibility can be exploited in air attacks using combined aircraft and cruise missiles. When an attack is being executed under the direction of an E-2C or AWACS, missiles may be reallocated to higher-priority targets that are beyond the air defense suppression zone. An important example of this capability is the opportunity to engage newly emergent targets (like the SCUD or a mobile surface-to-air missile [SAM] battery) that could pose unacceptable threat to a manned aircraft or follow-on cruise missiles delivering ordnance to a target area.

5.3 REAL-TIME BATTLE DAMAGE ASSESSMENT (BDA)

Currently, BDA requires delayed imagery assessment requiring considerable judgment to interpret of target status and determine the effectiveness of strikes. With flexible relay of imagery data from cruise missiles or UAVs as provided in the goal architecture, prompt assessment and decisions to restrike can be taken—perhaps during the execution of the original strike with the possibility of vectoring returning aircraft with unused munitions to re-attack the selected target. The NAVSATCOM-21 also provides for integration of GPS on the cruise missile platform, providing for BDA information by relaying attack missile profile and preimpact position. It is noteworthy that in-flight updates of missiles permit attacks on deep, relocatable targets even before air defenses can be suppressed and with fewer weapons through improved dynamic battle management.

The source of imagery includes the terminal guidance sensor of precision guided munitions or UAVs with specially designed payloads that penetrate deeply into defended territory. The current reconnaissance systems include specially configured aircraft in addition to national systems.

The capabilities enabled through the use of UAVs for battle damage assessment are not much different from those available from national systems (assuming comparable quality and resolution). However, UAV sorties may provide the functions of a ferret from which SAM site radars and operations can be observed. When ferret sorties are combined with in-flight replanning of missiles, the hostile air defense system can be "mapped" and targeted. This tactic was used with great success by the Israelis in the Bekaa Valley and resulted in the destruction of many Syrian SAM sites. At times of crisis, tasking of national systems may lead to less than timely responses on a sufficiently large target set, making UAV augmentation desirable.

The contribution of terminal guidance sensors to battle damage indications can be considered in three alternatives. Each alternative assumes that the missile relays the image from its terminal guidance through some range-extending communications relay (be it SATCOM or UAV).

- The first alternative uses the weapon's own imagery from its terminal guidance to perform battle damage indication before impact. This results in an indication of probable damage and enables mission planning for possible re-strike.
- The second alternative assumes that subsequent missiles fired after the initial salvo image the prior missile target as they makes their way toward a nearby target. It is important to delay the second salvo to permit smoke, fire, and dust to clear before an attempt is made to image the second first-salvo targets.
- The third alternative uses this type of imagery to identify the targets for follow-on attacks, just as airborne reconnaissance would image likely targets for the intelligence preparation of the battlefield.

In each case the capability enabled is improved timeliness and accuracy of damage assessments from aircraft and missile attacks to aid in the planning of follow-on attacks. The military benefit is the reduction in the number of sorties required to achieve a given level of damage expectancy, the increased effectiveness and economy in the use of weapons, and the diminished number of personnel exposed to lethal threats.

5.4 INCREASED JOINT/ALLIED INTEROPERABILITY

The goal architecture, through employment of communications standards, will provide the following new capabilities for joint, allied, and coalition communications:

- The ability for naval forces to exchange information with other components of whatever larger forces they are assigned to.
- *True* joint command structures, in which integration of forces is absolutely essential. Reliance will be placed primarily on jointly developed and fielded systems and capabilities, so that information created on Navy systems is consumable in Air Force systems and vice versa.
- More focus on *commonality* of equipment and software. Where system limitations preclude commonality, interoperability will be achieved by translation at the best location.

5.5 ENHANCED BATTLEFIELD INTELLIGENCE

The ability to integrate data from a variety of national and organic sensors into a meaningful representation for battle management is a challenge. The data today reside in a variety of data storage media and with varying amounts of detail for numerous applications.

The goal architecture will make possible the exchange of data in various systems through a robust, high-capacity communications network. The transport media are transparent to the data, with the objective of information exchange limited only by the compatibility of the databases and their manipulation.

Real-time sensor products can be presented to the command forces with the proper historical prospective and mensuration. The ability to massage the information with a common understanding produces the best available information. The goal architecture does not create artificial barriers to information exchange.

5.6 EXPANDED COMMAND CONFERENCING

In organized undertakings where humans are involved, direct human interaction is vital. This fact has always driven the need for increased voice capacity with adequate voice recognition. Commanders in war need to have the utmost confidence in the capabilities, commitment, and self-confidence of their subordinates. More data cannot provide this information, and knowledge of past performance in similar conditions, although reinforcing, is not sufficient. Data transfer is important to provide specific details that enhance "situational awareness," but transfer of digital information does not convey to the commander those elements of information critical to building and maintaining confidence.

Personal confidence and convictions are better conveyed by voice. They are best conveyed in face-to-face meetings, when the levels of human emotional response can be observed and gauged. Since the introduction of the secure voice radiotelephone, military leaders have relied on simple voice communications to obtain the necessary human interaction. Voice alone is not adequate for some human interactions. Pictures plus voice is an outstanding information transfer medium. It is the best way to teach, and the best way to conduct human interaction, absent face-to-face meetings. NAVSATCOM-21 provides sufficient data rates to conduct video teleconferencing (VTC). VTC allows the commander to brief his seniors and subordinates on the plans of action, the current situation, the expected outcome, and results of military actions.

Once the capability for VTC is established, the other aspects of video transmission fall quickly into place. VTC obviously can support news gathering. The public relations confidence building that comes from informal, rapid news gathering is accelerated by effective video transmission. Wars, after all, are more about national will than about dispassionate data, and TV provides powerful boosts to confidence, either affirmatively (as in Desert Storm), or adversely (as in Viet Nam), to the warfighter or to the nation as a whole.

VTC can substitute for the physical presence of instructors, allowing for greater scope of education and training. VTC also provides inputs from experts on subjects broadcast from distant sites.

An extension of VTC can be employed to support reception of multiple channels of TV for situation awareness. Only the receiver sets need to be enhanced to support these capabilities. Satellites usually support both VTC and broadcast TV, so another antenna may not be necessary.

5.7 IMPROVED LOW PROBABILITY OF INTERCEPT/ANTIJAM

NAVSATCOM-21, based on expanded data rates and higher frequencies, favors significant improvement in communication operations for LPI/LPD and communications survivability against jamming and nuclear environments.

LPI/LPD results from allowing very little energy to be received by detection sources outside the direction of the intended signal. Two techniques are employed. First, the narrower the beamwidth of the radiating element, the less energy is available for detection. The higher-frequency antennas provide narrower beamwidths. Second, spread-spectrum transmission techniques and available bandwidth determine difficulty in detecting signals. Direct-sequence spread-spectrum signals offer the best protection. The probability of exploiting the signal for some intelligence varies between the spread-spectrum techniques. As "New World" shifts focus on regional conflicts with tactical operations emphasized, more LPI/LPD operations are expected.

Survivability of command and control (C^2) communications depends on ability to resist jamming and to propagate through a nuclear-disturbed environment. In both of these areas the use of higher frequencies provides more capability. For antijam, the wider bandwidths and narrower antenna beams force jamming signals to overcome the advantages of antenna discrimination and wide bandwidths over which C^2 signals can be spread. For anti-nuclear propagation, the higher frequencies, coupled with frequency hopping and interleaving coding techniques, provide less disruption to communications when operating. Survivable communications will contribute significantly to operations by relaying intelligence information without jeopardizing mission or personnel.

5.8 IMPROVED OPERATIONAL TRAINING

NAVSATCOM-21 provides significant enhancements for training of naval forces by providing high-capacity links between naval units and to joint and allied units. Operational training is the basis on which warfighting effectiveness is honed. There is absolutely no substitute for training, under conditions and scenarios as realistic as possible.

The goal architecture has provided major improvements in warfighting capabilities. The training environment will need to expand into the same communications regimes for exercises and training. Beyond-line-of-sight real-time links between ships, amphibious forces, air surveillance assets, and weapons such as cruise missiles will be possible at entirely new levels of capability. Access to large-scale databases in real time will provide the user with transparent intercommunications in which the data and type of communication transport do not constrain or impede the end user.

Because of the growing requirements for naval forces to operate in a joint service environment and to function effectively with allies and coalition forces, effective communications will be required. Again, expanded communications capabilities, as defined in the goal architecture, are tied to interoperability, which will provide the basis to exercise and train in expanded force configurations to ensure that warfighting capabilities will be present when needed.

5.9 RECOMMENDATIONS

The NAVSATCOM-21 goal architecture provides the Navy with an opportunity to take a significant step forward in increasing its warfighting effectiveness. It supports far greater capability in naval strike missions, either alone or as part of a joint force, and at the same time it provides for survivable and protected information exchange, including rapid access to independent databases for battlefield awareness and much improved command conferencing. The expanded capabilities provided by the goal architecture also support a commensurate increased level of peacetime training.

It is clear that Navy communications cannot be enhanced without careful planning and programming. The goal architecture can be time phased, as discussed earlier in this report, to evolve to its objectives. Therefore, the panel recommends that NAVSATCOM-21 be implemented through judicious enhancement of current naval communications.

The principal features of the goal architecture are summarized in Table 5.1, which relates these features to naval operations today (circa 1992) and those of the future if the architecture is implemented. (The letters in the arrows in this table indicate those specific features of NAVSATCOM-21 that enable respective future operational capabilities.)

TABLE 5.1 Future Operational Capabilities Enabled by NAVSATCOM-21

NAVSATCOM-21 GOAL ARCHITECTURE	OPERATIONS TODAY	→	OPERATIONS ENABLED
A) ADAPTABLE GLOBAL COMMUNICATIONS NETWORK	• BATTLE SPACE ≈ 300 MILES	A,B,C,D,E,F,G	• BATTLE SPACE EXPANSION TO 1000+ MILES
B) MDR INTEROPERABLE BACKBONE	• CM FIXED TARGET AREA AND FLIGHT PROFILE AT LAUNCH	A,E,F	• FLEXIBLE IN-FLIGHT ATTACK OPTIONS
C) GATEWAYS TO INTERCONNECT BACKBONE TO WANs	• LOS RECONNAISSANCE FOR CM-BDA	A,E,F	• REAL TIME BLOS BDA FOR CM RETARGETING
D) AUTOMATED AND DYNAMIC NETWORK MANAGEMENT OF DISTRIBUTED SYSTEMS	• LIMITED JOINT AND ALLIED COMMUNICATIONS	B	• EXPANDED INTEROPERABILITY
E) SMALL TERMINALS FOR AC AND CMs	• INDEPENDENT DATA BASES	B,C,D,G	• RAPID DATA SHARING FOR BATTLEFIELD AWARENESS
F) INTEGRATION OF GPS INTO ALL PLATFORM SYSTEMS	• COMMAND VOICE CONFERENCING	B	• COMMAND VIDEO CONFERENCING
G) TRANSPARENT TO DATA OR OTHER USER TRANSPORT	• SPECIALIZED LPI/AJ CAPABILITY	E,G	• ENHANCED LPI/AJ
	• UNIT LEVEL OPERATIONAL TRAINING	B,C,G	• INTEGRATED OPERATIONAL TRAINING AMONG OWN, JOINT AND ALLIED UNITS

6
A Comparison of NAVSATCOM-21 With Current Navy Communications Architecture

6.1 THE COPERNICUS ARCHITECTURE

The description below of the Copernicus architecture is very abbreviated. More information can be found in recent articles in *Signal* magazine.[1,2] In this report, the panel emphasizes the Tactical Information Exchange System (TADIXS), primarily because it contains the communications systems that use space assets. The subarchitecture that achieves the aims of the Copernicus architecture is the Communications Support System (CSS). This system will provide the flexibility, survivability, and connectivities needed to implement the TADIXS pillar and the intra-battle force segment of the Copernicus architecture.

The Copernicus architecture[3] is a restructuring of the Navy's command, control, communications, computers, and intelligence (C^4I) system to take maximum advantage of commercially developed communications and computer technologies, allow for transition from present communications systems so that available capacity can be flexibly used and controlled by operational forces, standardize services and formats, and make Navy C^4I systems jointly interoperable with capabilities of DOD services and allied forces.

In an effort to give substance to the visionary goals of the Copernicus architecture, it can be described in terms that include operational employment, connectivities and information flow paths, and investment strategies and decisions.

6.1.1 Operational Employment

It is recognized that the Navy carrier battle group is limited in its surveillance capabilities. The volume that the battle group is capable of observing is called the battle space. Using today's surveillance systems organic to the battle group, this volume is on the order of a 500-nmi surface on the earth with a zenith of about 35,000 ft. This space would extend considerably if the battle group had near-real-time access to so-called nonorganic sensor information. Such information comes from shore-based surveillance systems such as the high-frequency direction finding (HFDF) sites located around the globe, sensors in space, and theater assets such as maritime patrol aircraft (P-3s) and DOD surveillance aircraft (U-2, Rivet Joint, and Senior Span). The possibility enabled is access to information about a theater of operations

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[1]Loescher, LCDR M.S. "Navy Reshapes, Develops Copernicus Architecture," *Signal*, pp. 58-63. July 1990.

[2]"New Intelligence Networks Improve Command and Control," *Signal*, pp. 45-47, August 1990.

[3]CNO Document, Director, Space and Electronic Warfare, "Phase I: Requirements Definition, The Copernicus Architecture," August, 1991.

on a near global scale. The promise of this capability is realized if the communications resources are available to provide this information to the JTFC in a usable form at the quality and quantity wanted by the forces afloat. The new warfare area of Space and Electronic Warfare (SEW) and the associated SEW Commander (SEWC) have been established, and a doctrine for this warfare area is emerging. The SEWC will use the C^4I system to systematically use the sensors, communications circuits, and information fusion capabilities ashore and afloat to dynamically support operations under the CWC concept.

6.1.2 Connectivities

Copernicus will provide four "pillars" (GLOBIXS, CCC, TADIXS, and TCC) in the information flow architecture. The GLOBIXS connects the shore establishment to the CINC Command Complex (CCC). The CCC serves as an information and command and control gateway to the deployed forces, such as carrier battle groups or joint tactical forces. Finally, TADIXS is the information flow from the CCC to the Tactical Command Complex (TCC). It is composed of deployed or afloat intelligence and command centers. Another way of looking at this is to label TADIXS as the shore-to-ship and ship-to-shore communications medium. By extension, one can complete the picture by including a battle group IXS (BGIXS) for the information flow required for ship-to-ship within the deployed forces. The Copernicus systems for connectivity and information flow are depicted in Figure 6.1.

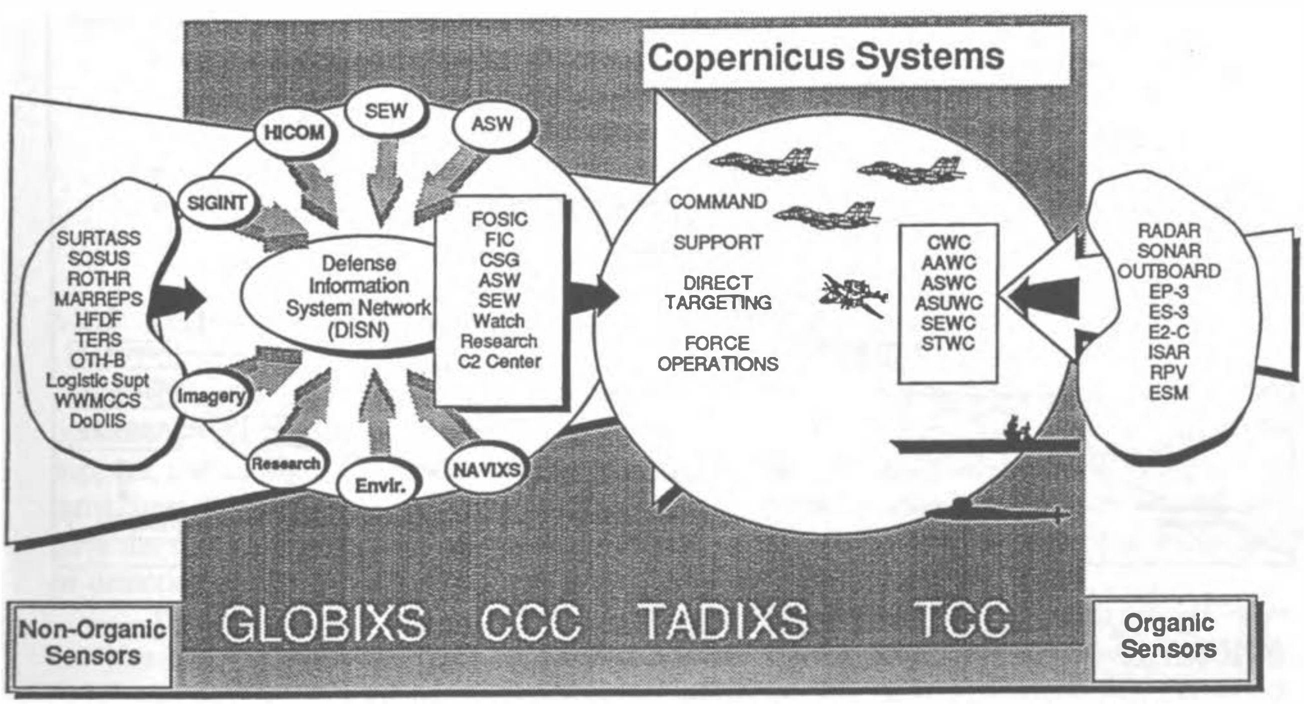

FIGURE 6.1 Copernicus systems for connectivity and information flow.

6.1.3 Investment Strategy

The Navy Copernicus community has articulated an investment strategy that determines what course the six-year development plan will take. Underpinning this strategy is the use of commercially developed technology, rapid reaction in procurement to forestall technological obsolescence, recognition of budgetary constraints, and building a C^4I system that reflects the perceived threat.

6.2 COMMUNICATIONS SUPPORT SYSTEM (CSS)

CSS provides the hardware and software that allows users of Navy communications to share communications resources, including transmission systems. In this system, one user has, in theory, access to all available communications channels. It also provides the capability for multiple users to share a common communications channel. This system gives the nodes in the Navy communications system (i.e., surface ships, planes, submarines, and shore stations) the ability to participate in a dynamic adaptive system that is responsive to the needs of the high-burst-rate data transmission user as well as the voice and large-continuous-stream data users. Figure 6.2 is a graphic description of the operational goals.

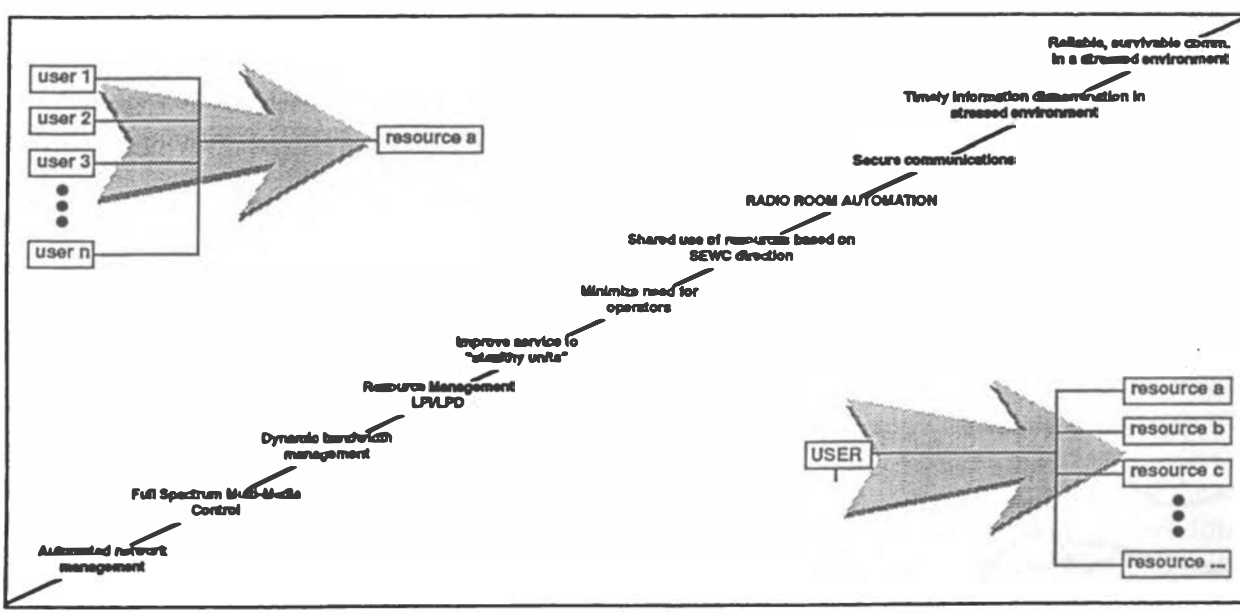

FIGURE 6.2 CSS operational goals.

The Navy views this system as a basis for providing reliable, survivable communications services in a stressed environment. By exercising control and management, CSS allocates capacity where it is needed to achieve timely information dissemination in a stressed environment. CSS uses a common hardware suite and a standard human-to-machine interface so that it can be readily adapted to a large set of users and service requirements without altering the architecture or requiring additional systems. Many problems associated with joint and coalition force interoperability can be overcome by internetworking the Navy communications systems using CSS and gateways to connect to other systems.

6.2.1 Concept of Operation

The goal of CSS is to operate all available communications capability as a service to users. It will serve each communications need based on quality of service required by the user, the priority and precedence of traffic, and the destination of the traffic. It can be compared to a utility such as the public switched telephone network. The utility serves all users, regardless of data type. It has the same interface with each user, and it is centrally managed and operated to provide the quality of service needed by the consumer. Ownership of transmission resources belongs to the utility, but access is provided to all.

6.2.2 Functional Requirements

Functionally, CSS provides the following:

- Automated network management
- Dynamic management of bandwidth/capacity of the communications resources
- Minimal need for human operators
- Information security (COMSEC, TRANSEC, and COMPUSEC)
- Voice, data, imagery, facsimile, and message services to all Navy users.

6.2.3 Technical Requirements

CSS will serve as the information exchange system essential to support warfighting operations of naval forces. It will provide an evolutionary architecture, system engineering support, and an integration framework to develop the required capabilities. The resulting system must meet the information exchange requirements for all naval missions. The system will also have the system characteristics needed, including security, anti-interference, and low probability of detection or intercept.

The system must support all naval platforms and be interoperable with that of other services, allied forces, and coalition forces. System development must be affordable and take maximum advantage of planned and fielded equipment of the Navy and other DOD forces. It should use commercial off-the-shelf and nondevelopmental items to achieve maximum cost savings as technology is inserted.

CSS capability will support user-prioritized, multi-net controlled, and multimedia shared information exchange resources. For satellite communications, this means that available channels will be under centralized management and used to support the priorities of the task force commander. As previously stated, the EHF, low-data-rate MILSTAR capability will be primarily for nuclear command and control, a hard-core warfighting function. SHF, EHF medium-data-rate MILSTAR, and EHF packages on UFO will be for soft-core functions when some robustness is required, but not as severe a penalty is paid in throughput as in hard-core functions. UHF will be for general-purpose communications and warfare support operations. These capabilities will constitute the communications channels of CSS. A general representation of the CSS architecture is given in Figure 6.3. The previously described satellite capabilities, and others, will be interconnected to multiple users to form a fully integrated system as depicted in Figure 6.4.

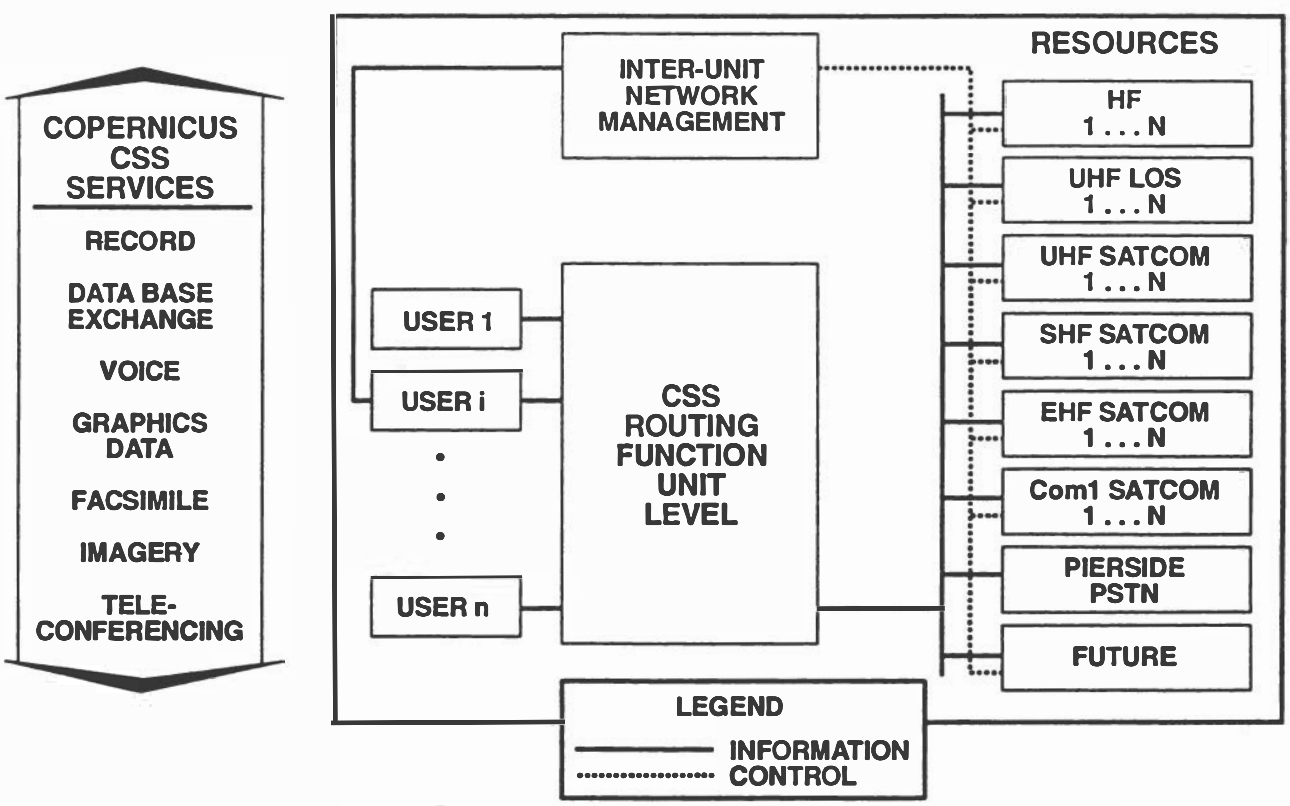

FIGURE 6.3 CSS architecture.

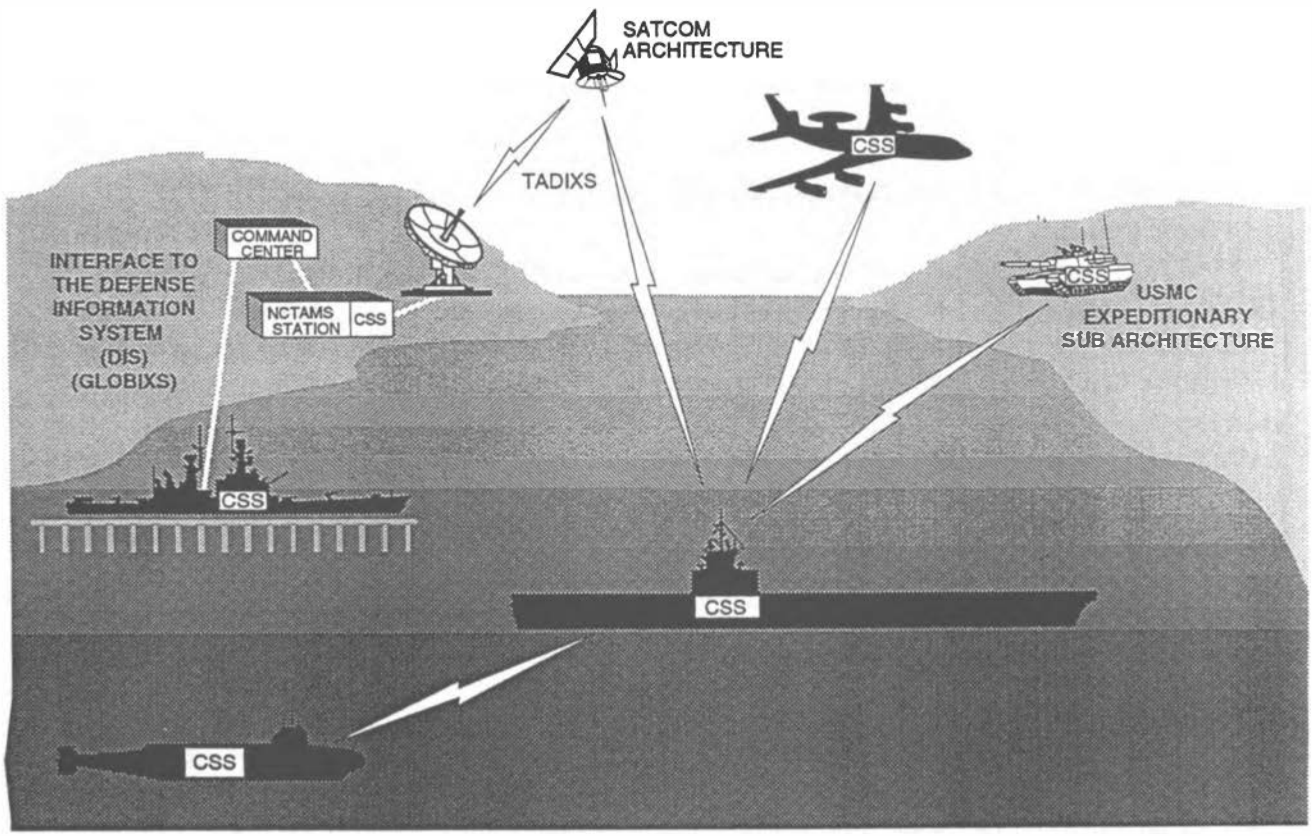

FIGURE 6.4 A fully integrated naval communications architecture.

6.3 NAVSATCOM-21 GOAL ARCHITECTURE

The NAVSATCOM-21 goal architecture is composed of four segments: the UHF, SHF, EHF, and commercial SATCOM segments. These segments are expected to serve the mission needs from strategic connectivity, with high survivability requirements, to general-purpose communications, with low survivability requirements. The different segments will be allocated to carry traffic that matches the quality of service associated with that segment. A given segment's quality of service is usually described by the throughput achievable at specific bit error rates. Other terms descriptive of quality of service are latency of information flow, connectivity, availability, and area of coverage.

The information that must be transported over these segments has some associated attributes. These are usually quantified in terms of timeliness, accuracy, and reliability. These attributes are descriptors of information types such as imagery, voice, teleconferencing, record messages, database transfers, and facsimile, to name a few. The technological challenge is to assemble the data so that the high-capacity links associated with the segments are used most productively. This is a design and implementation issue that bears directly on the achievement of interoperable communications, efficient use of scarce resources, user flexibility, and system responsiveness. There are a number of technical approaches for solving this problem, including multiplexers, multiple access schemes, and frame relays, or asynchronous transfer mode devices.

6.4 FINDINGS AND RECOMMENDATIONS

Given that the quality-of-service issue is adequately addressed, one can compare the NAVSATCOM-21 goal architecture with the Navy's Copernicus/CSS architecture. The findings from such comparison are included in Table 6.1. Note that selected features of the goal architecture have been highlighted and contrasted to the manner in which Copernicus/CSS addresses this feature in its architecture. Based on this comparison, recommendations applicable in the near, mid, and far term are provided, as follows:

- Near Term (1992 to 1997)
  - Expand the Copernicus architecture to be consistent with NAVSATCOM-21. Extend it to cover the complete scope of Navy communications requirements, including the full dimensions of communications at the tactical level.
  - Continue engineering and development efforts to fully implement Copernicus/CSS principles as discussed in the above comparison.
- Mid Term (1997 to 2005)
  - Develop guidelines for fleet users on quality of service offered by Copernicus/CSS engineering initiatives.
  - Implement network management techniques to provide optimal network employment.
  - Implement programs to correct shortfalls in effective use of capacity, SATCOM coverage robustness of links, tactical throughput, and utilization of GPS.
- Far Term (2005 to 2015)
  - Continue heavy Navy involvement in definition of new satellite payloads to achieve Copernicus-like information flows.

TABLE 6.1 Comparison of NAVSATCOM-21 With the Copernicus/CSS Architecture

NAVSATCOM-21 GOAL ARCHITECTURE	COPERNICUS AND CSS ARCHITECTURE	FINDINGS
Adaptable global communications network	GLOBIXS and TADIXS user transparency	Copernicus/CSS are conceptual approaches to a baseline adaptable global communications network
MDR interoperable backbone Gateways to interconnect backbone to WANs Automated network management Small terminals for AC and CMs	SHF/EHF TADIXS Network management and interface standards (OSI) Dynamically switched radio network and integrated services digital network (ISDN)	CSS concept includes gateways and information security architectures needed for true interoperability CSS network management architecture has the potential for automated network management CSS does not include links to weapons such as CMs and tactical surveillance assets CSS extension to aircraft and submarines is planned
Integration of GPS into all platform systems	Full implementation of GPS	Current implementation limited; GPS needs to be more substantively addressed by CSS

7
General Findings and Overall Recommendations

In this report, the panel takes a comprehensive look at naval communications, focusing principally on space communications including UHF, SHF, and EHF systems. The panel discusses the changing world environment and its impact on the national security, the military strategy, and in turn on naval strategy for the next 10 to 20 years. The panel notes that this new naval strategy (i.e., *From the Sea*[1]) represents a fundamental shift from open-ocean warfighting to regional conflicts involving littoral warfare. The panel notes the need for a robust C^3 system to support these strategies at all levels of command and points out the need for survivable global communications and the role of satellite communications systems to support this need.

The panel characterizes naval communications requirements at the global through joint tactical command levels and observes that coverage around the globe is necessary but is primarily significant in the mid-latitudes. The degree of robustness is shown to vary from a hard-core warfighting capability with sufficient protection and security to unprotected general-purpose communications. A range of services to both fixed and mobile users is identified, including voice, data, facsimile, video, and imagery transmission, with data rates that extend from less than roughly 10 kbps (LDR) to upward of several hundred Mbps (VHDR), depending upon the specific user. The panel notes that interoperable communications systems are a necessity to support joint operations and activities involving allied and coalition forces. Finally, to support future power projection and precision strike operations, the panel notes that communications volumes and capacities can become very high (>1 Mbps) for most tactical circuits, and that time to establish necessary circuits is severely compressed (generally less than a few seconds).

The panel recommends that a continuing analysis of communications requirements be maintained, particularly in light of the changing tactical and strategic environments, and that these data be incorporated in DOD requirements documents (i.e., the Integrated Satellite Communications Requirements Document (ISRD) and be used to support necessary Navy engineering development efforts and programmatic decisions.

The panel has taken a broad look at current and planned military, civil, and commercial satellite communications capabilities and concludes that selected combinations of these systems could meet most identified requirements. There are some exceptions, however. The panel believes that an abundance of technology exists and could be applied to resolve these remaining issues. The panel observes that current Navy satellite communications is highly structured, with little flexibility to dynamically shift or reconfigure resources. Overall, the current systems have limited throughput capacity and are vulnerable to unintentional interference and jamming.

The panel observes, however, that the Navy has strong programs at UHF and EHF in terms of both on-orbit and planned systems and terminal development efforts. The panel notes,

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[1]*From the Sea*, Navy and Marine Corps strategy document, Secretary of the Navy, September 28, 1992 (unclassified).

also, that the Navy has taken dramatic steps to improve its throughput capacity by making greater use of SHF systems on its principal command and combat (Tomahawk-capable) ships.

Finally, the panel observes that the Navy makes only limited use of commercial satellite communications services, but the panel recognizes that careful consideration of a number of factors is necessary before any large-scale use is made of commercial capabilities. These factors include (1) *coverage*—commercial systems provide only limited oceanic coverage and are driven more by the market potential over landmasses, (2) *frequency* assignments and compatibility with existing Navy terminals, (3) *shipboard electromagnetic interference* from local high-power transmitters, (4) *throughput* capacity available to military users, (5) *cost of service*, and (6) *treaty restrictions* on military use.

The panel concludes that the "ideal" or goal naval communications architecture (NAVSATCOM-21) should reflect a multilayered structure of interconnecting networks that are geographically dispersed, employ differing topographies (mesh, hub-spoke), and allow point-to-point as well as broadcast services to network users. The architecture should include a global, high-capacity (>1 Gbps) backbone network, with both fixed and mobile gateways to selected task force elements and tactical units. High-capacity (several Mbps) tactical networks should be used to provide connectivities between and among selected platforms and should interface directly with the platform's local area network. The architecture should permit dynamic network management and control and interoperable operations with joint, allied, and coalition forces using terminals that are adaptable to specific user need (in terms of size and performance).

For those links that provide connectivity to selected fixed but predominately mobile users, the links should be implemented using integrated UHF, SHF, and EHF military capabilities and heavily augmented by commercial systems, where practicable.

The panel recommends that the Navy maintain and reinforce continued investment in EHF as the principal hard-core and soft-core satellite communications resource. The Navy should add an MDR capability to LDR and EHF terminals and investigate the cost and schedule feasibility of an MDR engineering change to the UFO satellites.

The Navy should continue its efforts at SHF, particularly the demand assignment multiple access (DAMA) activity to increase the use of available SHF channels.

Also recommended is Navy investment in a low-cost multiple-frequency shipboard terminal (C-, X-, and Ku-bands) for increased access to services at SHF. Particularly important to the realization of this multifrequency terminal is a suitable antenna system. The panel endorses Navy efforts to develop a multimission, multi-user broadband antenna (MMBA) to achieve a robust SHF capability with minimal space and weight requirements.

The panel acknowledges the Navy's expansive use of UHF as a general-purpose service and recommends that the capacity of these UHF systems be enhanced with more efficient modems to achieve roughly a tenfold increase in information throughput at relatively low cost.

The panel recommends the expanded use of GPS in all communications nodes as a straightforward way to improve control and operation of all Navy satellite communications in terms of improved positional knowledge (especially for mobile users) and timing synchronization.

The panel concludes that a robust satellite communications capability would have a significant role in all expanded strike operations and significant impact on the effectiveness of these operations. (See Table 5.1, which summarizes the principal features of the

NAVSATCOM-21 goal architecture and relates these features to naval operations today with future operational capabilities enabled if the architecture is implemented.)

New tactical missions involving littoral strike operations against hard-to-find relocatable targets will require a mix of both line-of-sight and satellite relay links to support concepts involving advanced airborne sensor platforms and new applications of cruise missiles (including battle damage assessment and health and status reporting) and remotely piloted vehicles. It is noted that these missions will severely compress timelines for data and imagery transmission and greatly increase the volume of data to be transmitted. A judicious tradeoff of cost and achievable performance is recommended to the Navy for resolution of issues concerning airborne versus satellite relay for these applications. The panel notes that ongoing joint exercises, such as Tandem Thrust '92 and '93 and Ocean Venture '93 would provide the opportunity to demonstrate many of the satellite communications concepts identified by NAVSATCOM-21. For example, the panel specifically urges the Navy to devote at least a portion of these exercises to assessing the vulnerability of selected circuits to intentional jamming in order to more accurately specify the degree of jamming protection actually required.

In comparing the NAVSATCOM-21 architecture with Copernicus/CSS, the panel concludes that many features discussed in NAVSATCOM-21 are similar to the planned objectives of Copernicus/CSS. The panel notes, however, that the Copernicus architecture does not fully address tactical information exchange at the unit level and should be extended accordingly. The panel recognizes that the CSS effort has begun to introduce an engineering approach for dynamic routing and resource management that is totally consistent with NAVSATCOM-21 and should continue to do so, but CSS will also expand efforts to more fully integrate GPS into all existing and planned communications elements for enhanced control and management of these resources.

Appendix
List of Acronyms and Abbreviations

AAW	Antiaircraft Warfare
AC	Aircraft
ACTS	Advanced Communications Technology Satellite
AJ	Antijam
ARPA	Advanced Research Projects Agency
ASTEC	Advanced Space Technology for EHF Communications
ATO	Air Tasking Order
BDA	Battle Damage Assessment
BGIXS	Battle Group Information Exchange System
BLOS	Beyond Line of Sight
bps	bits per second
C^2	Command and Control
C^3	Command, Control, and Communications
C^4I	Command, Control, Communications, Computers, and Intelligence
CCC	CINC Command Complex
CDL	Common Data Link
CDMA	Code Division Multiple Access
CECOM	Communications and Electronics Command - U.S. Army
CHBDL	Common High Bandwidth Data Link
CINC	Commander-in-Chief
CJTF	Joint Task Force Commander
CM	Cruise Missile
CNO	Chief of Naval Operations
COMPUSEC	Computer Security
COMSEC	Communications Security
CSS	Communications Support System
CV	Aircraft Carrier
CWC	Composite Warfare Commander
DAMA	Demand Assign Multiple Access
DBS	Direct Broadcast Satellites
DCS	Defense Communications System
DISA	Defense Information Systems Agency
DISN	Defense Information Systems Network
DSCS	Defense Satellite Communications System
ECM	Electronic Counter Measures
EHF	Extremely High Frequency
ELF	Extremely Low Frequency
ELOS	Extended Line of Sight
FEP	Fleet EHF Package
FEWS	Follow-On Early Warning Satellite

FIC	Fleet Intelligence Center
FLTBDCST	Fleet Broadcast
FLTSATCOM	Fleet Satellite Communications System
FOSIC	Fleet Ocean Surveillance Information Center
GEO	Geosynchronous Earth Orbit
GLOBIXS	Global Information Exchange System
GP	General Purpose
GPS	Global Positioning System
HALE	High Altitude Long Endurance Aircraft
HC	Hard Core
HDR	High Data Rate
HF	High Frequency
HFDF	High Frequency Direction Finding
ID	Identification
IMPACT	Insertion into MILSATCOM Products of Advanced Communications Technologies
ISDN	Integrated Services Digital Network
ISRD	Integrated Satellite Communications Requirements Document
JIC	Joint Intelligence Center
JTF	Joint Task Force
JTIDS	Joint Tactical Information Distribution System
JWICS	Joint Worldwide Intelligence Communication System
LDR	Low Data Rate
LEASAT	Leased Satellite Communications Systems
LEO	Low Earth Orbit
LF	Low Frequency
LOS	Line of Sight
LPI	Low Probability of Intercept
MBA	Multiple Beam Antenna
MDR	Medium Data Rate
MF	Multifrequency
MILSATCOM	Military Satellite Communications
MILSTAR	Military Strategic and Tactical Relay System
MILSTD	Military Standard
MMBA	Multimission Multiuser Broadband Antenna
MOD	Moderate
NATO	North Atlantic Treaty Organization
NAVSATCOM-21	Naval Space Communications Architecture—21st Century
NCA	National Command Authority
NCTAMS	Naval Computer and Telecommunications Area Master Station
NCTC	Naval Computer and Telecommunications Command
NESP	Navy EHF Satellite Communications Programs
NRT	Near Real Time
OTH-B	Over-the-Horizon Backscatter Radar

RAM	Random Access Memory
R_c	Range from communicator to intended receiver
R_i	Range from communicator to interceptor
R_j	Range from jammer to intended receiver
ROT	Receive Only Terminal
ROTHR	Relocatable Over-the-Horizon Radar
SATCOM	Satellite Communications
SC	Soft Core
SCAMP	Single Channel Advanced Man-Portable Terminal
SCINT	Scintillation
SEW	Space and Electronic Warfare
SHF	Super-High Frequency
SIGINT	Signals Intelligence
SMART-T	Secure Mobile Anti-Jam Reliable Tactical Terminal
SPAWAR	Space and Naval Warfare Systems Command
STANAG	Standardization Agreement
TADIXS	Tactical Information Exchange System
TCC	Tactical Command Complex
TDMA	Time Division Multiple Access
TDRSS	Tracking and Data Relay Satellite System
Transec	Transmission Security
T_x	Transmitter
UAJM	Universal Antijam Modem
UAV	Unmanned Air Vehicle
UHF	Ultra-High Frequency
UHFFO	UHF Follow-On Satellite System
USCINCPAC	Commander-in-Chief, U.S. Pacific Forces
VHDR	Very High Data Rate
VLF	Very Low Frequency
VTC	Video Teleconferencing
WAN	Wide Area Network
WWMCCS	Worldwide Military Command and Control System