DSCS--Past, Present, and Future

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Abstract

This is a critical point in the long history of the Defense Satellite Communications System. This workhorse communications system has developed from the humble beginnings in the 1960's into today's highly capable backbone of US Government Communications. After a long delay we are finally launching these satellites again and plan to quickly rebuild this critical national asset which has been held together by determination and sweat following the Challenger disaster. Our critical issue is what services shall DSCS provide in the future. We are now in the process of defining the SHF communications capability of the next generation of these satellites to support the military needs of the next century.

The DSCS Experience

I think it's helpful to review the DSCS experience of the last 25 years and attempt to project where the growth in MILSATCOM might lead us in the future. I will also attempt to see what changes in this service are indicated by our recent experience in Desert Shield/Desert Storm, and I'll conclude by summarizing the drivers leading to the next generation of DSCS satellites.

Initial Defense Communications Satellite Program

The DSCS program started with the Initial Defense Communications Satellite Program (IDCSP) in the early 1960's. This pioneering satellite program was a fine, early example of the utility of small satellites, and at least for communicators, gave the operators and the system managers a deep appreciation of the difficulties associated with operating non-geosynchronous satellites. The satellite itself was very small and had extremely limited capability. Its single channel had a 3.5 watt TWTA and low gain antenna, and was limited to operations only with very large ground stations. Nonetheless, the satellites provided very useful communications during the Viet Nam War and were a considerable improvement over the worldwide HF communications networks commonly in use at the time. Among the advanced capabilities first demonstrated by this satellite system was the transmission of photo reconnaissance images rapidly to Washington for analysis. No doubt this rapid battle damage reporting and targeting help was considered a mixed blessing by the soldiers in the theater.

Defense Satellite Communications System, Phase II

To the surprise of the people working on future communications at SAMSO Secretary of Defense Robert McNamara dramatically announced this program in a speech, from then on the program was playing catchup. The DSCS II spacecraft was very much more capable than the IDCSP. It featured a more sophisticated bus with telemetry and command capability, but it's communications suite was the real improvement. It sported two twenty-watt TWTAs, covered the entire 500Mhz bandwidth available at X-Band and featured both earth coverage and gimballed spot antennas. These improvements allowed use of smaller ground stations--as small as 8 ft. and 500 watts--and ignited an explosive growth in satellite terminals and satellite communications services. The last four satellites of this series were modified to include forty watt power amplifiers, doubling their capacity for most users.

Defense Communications Satellite Program Phase III

With the advent of DSCS III the threat posed by high power jammers and the potential for attack by exo-atmospheric nuclear weapons became important considerations in the spacecraft design.

The program pioneered the techniques necessary to 'harden' the spacecraft to nuclear effects. While shielding had been a common technique on previous satellites, the DSCS III development provided useful methods to analyze and prevent self-generated electromagnetic pulse (SGEMP) from interrupting service or disabling the satellite. The satellite was also the first to be tested in underground nuclear tests to verify the hardening concepts as a complete spacecraft.

The program, with the help of Lincoln Laboratory, developed an extremely sophisticated receive antenna which was capable of contoured gain patterns across the earth and could also be used to suppress interfering or jamming ground stations. The transmit antenna suite also used a variant of this antenna to provide increased downlink EIRP to support smaller users.

The DSCS III satellite divided the band into six channels (vs two for DSCS II), two of these channels were 40 watt and the remaining four were 10 watt. Through the production program continuous changes were made to the communications subsystems to improve performance. Early in production the tunnel diode amplifiers and limiters were replaced with Gallium Arsenide Field Effect Transistors (GaAsFETs) and the low noise amplifiers and the driver amplifiers replaced with GaAsFET equivalents that exhibited better performance. At vehicle III-B8 the channelization was changed and the guard bands reduced to 15 MHz.

Power amplifiers have been a particular interest item for the program which has long been plagued with continual removal and replacement of TWTAs as defects were detected and corrected. The actual orbit history of TWTAs has been much better than could be expected from the removal rate on the ground. These problems have resulted in the program pushing solid state power amplifier development. The first production DSCS III carried a demonstration ten watt solid state amplifier in channel six to prove on-orbit performance. Later spacecraft contained two improved 10 watt amplifiers backed up by a TWTA. Current spacecraft have four channels with ten watt solid state GaAsFET amplifiers in both prime and redundant positions. Continuing development has improved solid state GaAsFET efficiencies to the point that we have retrofitted the last seven spacecraft (in launch order) with 16 Watt units in two channels and are planning to retrofit the last four spacecraft in four of the channels. Only the forty watt channels will continue to have TWTAs as power amplifiers.

Launch vehicles have been a continuing source of frustration for the DSCS III program. First the spacecraft was integrated to all the variants of Titan -- Titan IIIC/transtage, Titan 34D/transtage, Titan 34D/IUS, and Titan IV/IUS. then it was integrated to the Shuttle/IUS. The first four launches of the program were all first time events, fortunately they were also all successful. Following the Challenger accident the program could not launch -- shuttles were not available and all the Titan boosters were committed to 'higher priority missions'. After considerable delay DSCS III was allowed to switch to a medium launch vehicle, the Atlas II. Our first Atlas II launch restarted the replenishment of our constellation on 10 February 1992.

The DSCS Desert Shield/Storm Experience

Desert Shield found the DSCS constellation in sad shape. The spacecraft were old and were being held together with bandaids and chewing gum. The DSCS architecture consists of five orbital locations to provide worldwide coverage. The Indian Ocean satellite at sixty degrees east supporting Saudi Arabia and other locations in Southwest Asia had an aging DSCS II, one of two orbital locations being served by DSCS II satellites which had exceeded twice their design life. The other three locations were served by three DSCS III spacecraft of more recent vintage.

Initial conditions in the theater were dismal-- hardly any ground communications infrastructure existed and virtually all the necessary services had to be built from scratch. In early August only five terminals were in theater, but by the start of the ground offensive the terminal count had grown to over 112 DSCS terminals. Total military communications traffic exceeded 160 Mbits/second, DSCS alone accounting for 125 Mbit/second of that total.

To support this heavy communications load the DSCS satellites were reconfigured to provide maximum support to the forces. One DSCS II satellite had a degrading TWTA switched to a better performing unit, the DSCS III had its antennas repointed to increase over-the-Atlantic capability, and an aging reserve DSCS II with only partial capability was moved around the world to bump up total capability.

Desert Storm/Desert Shield was an experience without precedence for military communicators. A large force deployed to an area of the world without any significant communications infrastructure in place. This force then generated a completely unexpected and unprecedented demand for worldwide communications. Communications which had to be very sophisticated and of high quality to tie together the integrated, dynamic networks characteristic of the high technology battlefield.

The DSCS system has traditionally been a strategic, long-haul, trunking system providing the connection for deployed forces to command and control centers in the battlefield rear and to other forces and control centers outside the theater. In desert shield more military communication links of this type were provided between AOR and CONUS (335) than exist between Europe and CONUS (197). DSCS was the primary supplier of these services.

The approach to satisfying theater communications needs was first to assign a DSCS link, then wait for commercial terminals and service installation, transition the military communications to a commercial link, and redeploy the DSCS terminal asset to tactical units to support combat operations. This progressive assignment process permitted expanding the tactical communications pipelines using in-theater assets.

For the first time in a contingency operation DDN services were available in the AOR. A DDN trunk to Saudi was established by September and eventually six gateways were established. The packet traffic through the DDN was enormous, approaching 1 million packets a day in January and over 1.8 million by March. The services have become highly dependant on reliable communications links for data systems.

An important part of the success of Desert Shield/ Desert Storm communications was the interoperability of the equipments used in the theater. The joint command structure and the fast pace of operations demanded that the services communicate well with each other. Interoperability was achieved due to the centrally managed (DISA) procurement of communications equipment and where better communications capability was required the services "loaned" equipment as needed.

The war also proved the need for highly mobile, easy to use communications equipment. The rapid pace of deployment, maneuver, and advance and the large distances covered precluded the use of traditional microwave relays or cable connections. To provide the necessary communications trunks more DSCS satellite terminals had to be deployed and soldiers mounted them on flat bed trucks to gain mobility and reduce setup time. Apparently it worked.

Desert Storm/ Desert Shield also highlighted the complete dependance of these high tech, highly mobile, precision weapons on communications and lots of it. The proliferation of surveillance platforms necessary to support precision targeting and attack dump huge amounts of data on mission planners who must pass on this data in their combat planning documentation to the frontline troops. Indeed, the major complaint about support during the operation was the lack of timely reconnaissance information at the pilot level.

Future DSCS Service Needs

I think the trend of the future is clear. Smaller and more mobile terminals, higher data rates in the tactical environment, and flexibility.

Historically DSCS has concentrated on providing "Strategic" communications services. In particular the primary service has been providing high capacity trunks between the CONUS and US operating locations overseas. These networks generally consist of large, fixed earth terminals closely associated with a large signal multiplexing, switching system--characteristics similar to those of commercial ground terminals.

The most important DSCS users of the future will be the mobile forces, principally the Army and Navy. Both of these services found themselves with significant disadvantages during the gulf war and both are clearly stepping forward rapidly to correct the problems they detected. A clear consequence of this rethinking is the increased emphasis on mobile service--mobile in this case means small, light, and easy to use. Of course we cannot forget the bread and butter of the DSCS world, long-haul telephone circuits for the large fixed sites of the Defense Communications System and our large, high data rate customers that collect and disseminate data to defense agencies worldwide. These customers will continue to need service on DSCS but are expected to transition large portions of their current service and future growth to commercial satellite systems. Connections between these large, high data rate users and the small tactical user must be satisfied by any future DSCS satellite.

Desert storm heralded an explosion of technology on the battlefield. This explosion would have been impossible without reliable, secure communications systems and in this war that meant satellite communications. All of those smart weapons needed lots of data to be targeted accurately, and rapidly retargeted following strikes. Not only did the weapons require lots of data, the computers deployed with the units needed the ability to communicate over networks with each other and with the unit support in the states. 75 bit teletype data simply isn't adequate for the sophisticated military user. This growth in data rates has probably just begun, only a small fraction of the bombs dropped were smart bombs, and only a small fraction of the possible uses of computers were employed.

Communications employed in Desert Storm were unique. A DISA planning team setup and dynamically designed the network and controlled the terminals and satellites. No one expected the sheer volume of terminals and data used in the war. The only way this volume of communications could be supported by the aging DSCS constellation was by drawing on every resource available and cleverly orchestrating it into a workable system. Keepin it working in a dynamic environment required tremendous discipline and innovation on the part of the planners. The flexibility inherent in the DSCS system allowed the creative use of satellite resources to solve the problems of the moment and react to unexpected service demands.

Future DSCS Designs

A wide range of potential DSCS communications subsystems have been proposed for our replenishment satellite program currently planned for FY95. All of these concepts treat wideband user needs by expanding on the available bandwidth through some form of frequency reuse. Usually this reuse is generated by spatial discrimination between the antennas. Polarization discrimination has been studied and current results suggest that the existing terminals do not have a low enough axial ratio to avoid interference.

These services also must be provided protection from jammers. In the DSCS system this is achieved primarily by providing antenna discrimination or nulling between users and jammers. Currently the DSCS III spacecraft uses a 61 beam array with an aperture of 45 inches. This antenna provides adequate performance for our wideband users who generally have substantial power available and are usually located far from threatening jammers. To meet the needs of the next century both nulling depth and resolution must be improved. Resolution can be improved by increasing the aperture of the antenna and depth of null can be improved by more accurate pointing using on-board automatic nulling.

Tactical users share the problems of large wideband users but always operate from small terminals. Providing communications services to these terminals at reasonable data rates in a substantial jamming environment is very difficult. It requires very large aperture antennas with high resolution and deep nulls. The downlink needs substantial gain and power and ideally the channel is constructed to operate linearly in the expected jamming environment. Generally the effective aperture that is needed for jammer resistance is nearly sixteen feet in diameter and the EIRP to support small terminals is 50 dbW or more.

Further improvements in performance can also be gained by effectively giving each channel it's own multibeam antenna, a trick that can be accomplished by installing several beam forming networks on a single set of antenna feeds. Low noise amplifiers in the feeds preserve the G/T characteristic and filters separate the channels. This approach will optimize the gain and discrimination from the same shared antenna aperture for each channel.

The DSCS program office is currently investing its limited R&D funds in technology developments to reduce the risks of the replenishment program. Investments are being made in both ferrite and MMIC technologies for receive antennas. We're examining high power TWTs and active aperture antennas to support high EIRP needs. Analysis of the performance capability of distributed array and large reflectors is on-going. Finally we are developing algorithm concepts for autonulling. These technology efforts are badly underfunded and limited data and hardware will exist when the full-scale development contract is awarded.

The future of DSCS communications satellites is bright. Current funding limitations will require more risk in the development of a suitable replacement than is desirable. The winning contractor will need to show how these risks can be minimized in the early stages of development.

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FOLLOW-ON TACTICAL CORE USER SUPPORT OPTIONS

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ABSTRACT This is a critical decision time in the development of the military satellite communications systems for the next century. The direction of military satellite communications will be driven by the expressed and documented requirements of today's communications user. Currently, requirements reflect little recognition of the explosive changes of the last ten years in individual communications, computer networks, and smart weapons and even less of what may happen in the next ten years. Ideas and concepts exist that could permit both high data rate communications in a highly likely threat environment and operate with much more mobile terminals. Does the DoD need this capability?

Situation

The Air Force's MILSATCOM Joint Program Office (MJPO) projects that DSCS III satellite communications service will drop below the minimum required constellation in approximately 2003, and that work must start immediately to define and develop a successor communications system. The acquisition cycle requires about three years for approval to start Engineering and Manufacturing Development, and for new systems the typical design, fabricate and test cycle requires an additional six years. OSD and the services are currently conducting studies to define the requirements a future SHF satellite must meet and how such a satellite fits into the overall MILSATCOM architecture.

User Requirements

The first step in defining a new system is a survey of user requirements--both those currently existing and satisfied, and those projected into the future. DSCS satellites have been traditionally designed for fixed site, high data rate users, and pre-Milstar era support to the nuclear forces command structure. Only a small portion of the resource has been directed toward supporting the tactical user represented by the ground mobile forces and other mobile users. A result of this approach has been a satellite focused on support to large terminals. This led to satellites with limited EIRP, concentration on protection against very large fixed jammer sites, and an essentially static communications control concept. This situation is rapidly changing as low cost fiber networks increasingly interconnect most of the US based strategic nodes previously serviced by DSCS.

Projected Growth

Recognition of these changes is slow. Future user requirements as currently compiled by the Defense Information System Agency (DISA) from the approved/validated Integrated System Data Base (ISDB) do not show a large change in the requirements. This is at least partially because the users are reluctant to abandon services that have supported them well in past years until the reliability and capability of new communications are proven. None-the-less some changes are becoming evident.

DISA is projecting that the Defense Information System Network (DISN) (chiefly large fixed site users) will need to accommodate increasingly higher data rates using asynchronous transfer mode (ATM) and SONET protocols. A significant portion of this service within the CONUS and at permanent sites overseas will be loaded on fiber terrestrial systems. DSCS is expected to provide the connection between these DISN fixed sites and the deployed, mobile forces. This capability on DSCS is expected to be demonstrated in the near future. It's not yet clear what effect these very high data rates and low bit error rate communications will have on the design of future military communications satellites.

The tactical and mobile communications need is less clear. The lessons of Desert Shield/Storm seem to indicate that tactical communications will be a big consumer of future satellite communications capability. In addition, the communications services to be provided to tactical users by the Milstar II LDR/MDR satellite and those that will be provided by a future SHF replenishment satellite are being defined in an on-going architecture definition process. The uplink jammer threat that needs to be met by future communications satellites is being reduced as a result of changes in threat perceptions. The principal factors of mobility, high data rate capability, and ease of use appear to be the driving communications system requirements instead of the strategic ECCM capability that has been the focus of previous military satellite communications services.

User requests for future services appears to be limited by the limitations of existing equipment and systems and the perception that dramatic and costly changes are necessary to enhance performance. The limitations of the existing SHF system prevent users from asking for services that can't be supported today, but might be feasible in future systems. Among the more limiting of these paradigms is the historic high cost and large size of terminals useful with MILSATCOM, the perception that access to the satellite is time-consuming and difficult, that ECCM capability necessarily results in a drastic reduction in data rate, and that military satellite communications is a scarce resource to be strictly allocated at the highest national level. This paper attempts to describe a system that could overcome these obstacles and provide enhanced communications services with minor changes in cost.

Future Trends

One can envision the military satellite communications future of fixed site, general purpose service transitioning from military SATCOM to commercial service. Certainly virtually all of the domestic interconnections will be reallocated to optical fiber, and much of the general purpose international service will also transition to lower cost communications services. We expect the current emphasis on switched trunk communications to continue, but be more oriented to tactical interconnection. The digital data (i.e., computer network and information dissemination) should grow into a significant fraction of the through-put and to be vitally important to the tactical user.

A military broadcast communications system similar in many respects to the commercial direct broadcast television systems is desirable. Low cost, portable, receive only terminals could provide emergency warning, terrain maps, weather information, troop deployments, intelligence data, training, and even entertainment to the lowest level organizations.

Desert Storm/Shield highlighted the dependence of high tech, highly mobile, precision weapons on communications and lots of it. The proliferation of surveillance platforms dump huge amounts of data on mission planners, who must assess this information and pass it on to the front-line troops. One of the major complaints about support during the Desert Storm was the lack of timely reconnaissance information at the pilot level. The communications infra-structure to disseminate this mass of data from the headquarters to the troops does not exist. You can easily imagine the massive communications needs of an Air Force bomber carrying numerous smart weapons that need to be retargeted enroute to handle real time changes in targeting. Potential requirements such as these are not reflected in the user requirements documents.

The current commercial developments in terminals has resulted in extremely low cost commercial terminals, a trend that will eventually be felt in the military terminal market. Substantial reductions in terminal cost could lead to explosive growth in the use of satellite communications. DSCS today supports in excess of 500 terminals world wide, if terminal cost were to drop to ten percent or less of today's price the number of terminals supported would double or triple in the near term. UHF satellite service is a good example: because UHF SATCOM radios are low-cost no one knows how many exist, but 10,000 is a low estimate.

I think the trend of the future is clear. Smaller and more mobile terminals, higher data rates in the tactical environment, and flexibility to handle evolving needs. The most important DSCS users of the future will be the mobile forces. The disadvantages the tactical forces discovered during the gulf war must be reduced. Unfortunately the requirements that could force these new capabilities are not reflected in the approved and validated user communications requirement database.

Current Activity

A wide range of potential SHF communications system concepts have been proposed for the SHF replenishment program that is currently projected to start in late FY95. The MILSATCOM program office is currently starting an architecture study to analyze these concepts and estimate their performance and cost. The results of this activity should define the future SHF communications system concept and quantify its performance and cost, and provide evidence that other options provide less capability or have prohibitive cost penalties. As a part of this study an international cooperative alternative will be examined to determine if significant cost savings are possible by developing and producing communications satellites in cooperation with the United Kingdom and France.

A preliminary evaluation of satellite communications systems suggests that the SHF architecture of the future cannot be very different from the current architecture and concept. The need to interoperate with the existing terminal and control structure probably forces the system to look very much like today's system with a few significant upgrades. Obvious places for upgrades include much higher EIRP to support smaller terminals, frequency reuse to allow more efficient use of scarce RF spectrum, sophisticated antennas with ability to manage user access by providing directive gain to authorized users and suppressing unauthorized users.

Supporting Technology

The MILSATCOM Joint Program Office is currently investing its limited R&D funds in technology developments to reduce the risks of the replenishment program. Most of the SHF satellite communications technology investment is funded by the MILSATCOM program office through a Rome Laboratory Broad Area Announcement, with some support from other organizations. Our major thrusts are in sophisticated antennas for receive functions and high power amplifiers and antennas for improved EIRP.

The MJPO is examining high power amplifiers, both TWTs and solid state GaAsFET designs. There should be two solid state forty watt amplifier designs by the end of the year, and a combiner that could combine four of these amplifiers to make a single 160 watt unit. There also is a 160 watt TWT demonstration underway which will scale current Ku band TWT technology to X band. Active aperture antennas provide an alternate means to support future high EIRP requirements. Together with DISA/CFE we are supporting the fabrication of two demonstration sub-array antennas which will provide a test bed to evaluate the wide band RF performance, channel characteristics, and linearity of these antenna concepts.

Receive antenna improvements focus on light weight technology to permit carrying many multiple beam antennas to permit dedicated channel assignment of independent multiple beam uplink antennas. Hardware development is underway for both ferrite type BFN technologies as well as MMIC technologies. A MMIC based antenna is currently being tested on the Rome Laboratory range and the light weight ferrite antennas are under development. The MJPO is also exploring ways to enhance the resolution of the receive antennas to permit precise control of both gain and null pointing. A functional test of the distributed antenna concept at Rome is planned for next year.

Antenna control is an area that merits special attention. The current satellite uses open loop pointing techniques and both the gain pattern and the null must compensate for errors in location estimation and random pointing errors of the satellite. Most current jammer suppression algorithms are oriented toward detection and suppression of large jammers and the achievement of very deep nulls. Future algorithms will instead address low level interference sources that could heavily impact small tactical terminals and be concerned with maintaining network connectivity instead of achieving the ultimate null. Closed loop suppression techniques on board the satellite offer a means to substantially increase nulling effectiveness by greatly reducing the position errors associated with open loop pointing. For this autonulling to be effective, sophisticated analysis methods must be developed to discriminate between authorized communicators and interference sources. An extension of autonulling may permit terminal control by measuring individual terminal uplink power using Fast Fourier Techniques (FFT)and telemetering this information back to the terminal providing closed loop power control. This idea may permit the elimination of dedicated ground control stations, allowing any terminal within sight of the satellite to monitor and manage the satellite access, and potentially to allow a gateway to re transmit the control information to the CONUS for central control. Studies are currently researching improved algorithms to do all these functions.

New Concept of Operation

The MILSATCOM program office is evolving a new concept of operation for the future SHF constellation that should provide very good performance in a severe jamming environment for small terminals at medium data rates. This concept combines the characteristics of the Universal Modem CU2 wave form with satellite high power channels and autonulling. Early estimates suggest that four foot terminals could operate at T1 data rates against transportable jammers and a 75 MHz channel could carry as much as 50 Mbps of protected traffic. Effectively this concept permits users to operate in strong jamming environment at FDMA unstressed data rates.

The key issue in this concept is to always operate in the ECCM mode with a wave form with good Eb/No performance. The wave form should have significant error correction coding, frequency hop at a high hop rate, and operate in an orthogonal mode (non-interfering) with other users in the channel. These characteristics are typical of the UM-CU2 modem. The terminal helps the satellite identify unauthorized users by providing both quiet time slots and quiet frequency slots. The satellite would detect users in these slots and apply signal suppression techniques to minimize the power levels in these slots and frequencies. Modems of this type could also provide DAMA services by sharing time slots under a central control, and could comply with Navy requirements to intermittently halt emissions to improve detector sensitivity in target tracking equipment.

The space segment must provide substantial EIRP to the user terminal (in excess of 52 DBW), provide adequate uplink gain, and strongly suppress interfering sources rapidly using on-board nulling techniques.

Using these techniques, the current distinction between unstressed communications and stressed frequency hopping AJ wave forms should be eliminated. Hopping wave forms could be loaded at the current density level in the channel and full FDMA channel capacity will be available to the ECCM users. Users without a doctrine or OPLAN based requirement for AJ support would be required to use the UM/CU-2 modem's frequency hopping wave form to operate in these satellite channels to increase capacity and resilience to interference, improve interoperability, and avoid the operational impact of interference reaction.

Cost Management

A vital consideration in creating a new program is to control costs. Recent Life Cycle Cost work done in the MILSATCOM program office estimated the total cost to acquire and operate the DSCS constellation is roughly $12 billion for twenty years of constellation life. Approximately half of that cost is satellite procurement, launch vehicle, and control segment. The remainder is terminal acquisition, and operation and support costs. The space segment and launcher cost is difficult to reduce substantially, but both terminal costs and operations and support cost can be reduced by satellite changes to reduce terminal size and reduce manning needed to operate terminals and control stations. Also our analysis shows a substantial number of users are not co-located with ground terminals, but use terrestrial systems to get their communications to distant large terminals. These users incur a large last-mile terrestrial cost. Future systems must include this "last mile" cost in their LCC estimates to permit cost trades with less capable premise based terminals which might reduce garrison costs and increase user mobility.

Conclusions

The technology and capability exists to substantially improve the capability of a new generation of military communications satellites and to provide new services to the theater commander. The CINCs and Services have not requested new capabilities because the limitations of existing systems lead them to believe substantial performance enhancement is not feasible or because they believe new systems are inherently expensive. The commercial communications satellite industry has sharply reduced the cost of satellite communications equipment, both on the ground and in space. The military should press hard for higher data rate communications, ability to operate against high probability threats, and ever smaller terminals to enhance mobility. Preliminary studies indicate that these things can be done at reasonable cost.

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