TECHNOLOGIES FOR FUTURE HIGH CAPABILITY MICRO-MILSATCOM SYSTEMS

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ABSTRACT

Satellite communications systems are a vitally important component of our Defense infrastructure for both tactical and strategic missions. In particular, satellite communications (whether military or commercial) have become increasingly important to support tactical operations, as was clearly demonstrated during Operations Desert Shield and Desert Storm. In the emerging doctrinal shift to a CONUS-based force structure with capabilities for rapidly responsive lethal power projection to meet global crises, the vital necessity for SATCOM to provide an omnipresent communications infrastructure for immediate support of the developing theater will become a key element in the successful realization of our new warfighting strategy. This infrastructure must provide RF bandwidth on demand and access to ATM switches and B-ISDN or SONET services as required from any worldwide location for any type of terminal. DARPA is developing the enabling technologies to give future systems the ability to realize their potential for becoming more affordable, more capable and more accessible by a theater commander. Advanced technologies are facilitating microminiaturization of key subsystems for communications satellite payloads, their host satellite buses, terminals and interfaces with terrestrial systems. These technologies can enhance the "capability density" of large spacecraft, as well as facilitate small, highly capable space and terrestrial assets, which can be labeled "micro-MILSATCOM" systems.

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INTRODUCTION

Satellite communications systems have been and will continue to be a vitally important component of our Defense infrastructure for both tactical and strategic missions, although these missions are undergoing a significant alteration. The threat that shaped military forces for decades has been replaced with a host of powerful threats that are reshaping world order, military planning and our national force structure. Today's national military policy requires a more diverse and flexible force structure that is capable of quickly projecting overwhelming combat power to terminate conflicts swiftly and decisively. As the size of the force is reduced and altered in response to dynamic changes in world events, joint, combined and interagency operations will become the standard requiring forces that are capable of striking quickly. The instantaneous communications infrastructure provided by communications satellites will be a vital element of this new force structure. Advanced space technology will enable the national force structure to be smaller, more lethal and faster reacting. [1]

Historically, application of advanced technology has been vital to the strength of our national defense. The importance of research and development will continue to increase as the worldwide competition for advanced, militarily-applicable technologies increases. Information processing and communications systems have recently undergone explosive development that has positioned these capabilities to have a great impact on the control and execution of warfare. One can expect a massive heterogeneous network to exist in the future, capable of linking powerful, personalized, portable information systems with one another, as well as with ultra high speed networks that provide distributed processing and distributed data base access.

The possibilities for defense operations are staggering, ranging from dispersed, distributed information processing and decision-making to unrestrained movement of data, enabling order of battle and operational plans to be dynamically tailored in real-time. Massive quantities of sensor and intelligence data will be available through high capacity communications networks to facilitate sensor-to-shooter engagement cycles of exceedingly short duration. Connectivity among isolated cells on the nonlinear battlefield and within the logistical infrastructure will require high speed/high capacity communications systems with an instantaneous global reach. Communications satellites have the unique attributes required to complement the high speed terrestrial networks that will connect static headquarters with highly mobile operational forces. With the application of appropriate enabling technologies, satellite communications have the potential capability to transform the emerging crystal grid into a ubiquitous global grid network. The sophisticated technologies that will enable these phenomenal future warfighting networks require long-lead enabling technology developments that must be initiated today. Satellites are capable of providing an omnipresent communications infrastructure for immediate support of a developing theater.

Emerging national military doctrine involves battle engagements where critical tactical military requirements for satellite communications are beset with the disparity between high data rates and small, mobile terminals. Ideally, tactical military satellite terminals would communicate at high data rates while on the move, operate through all threats including jamming or dense foliage, and be transparent to the user and non-detectable by unfriendly forces.[2]

The Army's Battlefield Information System 2015 Strategic Plan serves as a good illustration for the vision of future capabilities that are likely to exist in the field in the year 2015. Four general levels of information transfer are envisioned, each having its own unique communications requirements. The first level is medium-speed bursty data communications for special-purpose computers embedded in items such as vehicles, robots, and weapons. The second level is low to high data rate support directly to the soldier in the foxhole. According to the vision, every soldier in the year 2015 will have a personal, pocket-size radio/computer and image display capability for interaction with an assortment of computerized devices for night vision, image collection, weapon control, map display, general communications and medical monitoring. The third level is common computer assets that are supported by dedicated ATM (asynchronous transfer mode) switches with the necessary bandwidth to carry virtual reality imagery and interfaces to B-ISDN (broadband integrated services digital networks), ISDN (integrated services digital networks), and the SONET (synchronous optical network). The fourth level is the individual functional area systems such as fire support and maneuver control systems networked to facilitate intelligent, real-time, high speed information processing and data exchange of synchronized events.[3]

DARPA has been developing enabling technologies that will make it possible for future MILSATCOM (military satellite communications) systems to support this emerging national military doctrine. Advanced technologies are facilitating microminiaturization of key space communications subsystems including communications payloads, host satellite buses and all categories of terminals. These technologies can enhance the capability density of large spacecraft and terrestrial terminals, as well as facilitate small, highly capable assets that can be labeled "micro-MILSATCOM" systems.

SMALL SATELLITE DEMONSTRATIONS

At the outset of DARPA's Advanced Space Technology Program, a major project was initiated to apply readily available technology to build small, relatively low cost satellites to demonstrate the utility of direct space system support to tactical commanders. Two MACSATs (Multiple Access Communications Satellites), and seven Microsat "bent-pipe" communications relay satellites were developed and demonstrated by DARPA in a number of military exercises as a testbed for illustrating applications and examining the utility of affordable small satellites for tactical support and augmentation of the backbone MILSATCOM system.

Two MACSATs were launched in tandem into a 400 nautical mile, circular, polar orbit aboard a Scout booster on May 9, 1990. These spacecraft provided global, long-haul, point-to-point data message relay, analogous to electronic mail services, between tactical users located anywhere on the globe. The satellites interfaced with unattended sensors by extracting data and issuing commands to them from a central control facility. The capabilities of the MACSAT and results of numerous demonstrations and experiments have been previously published.[4] Here we highlight some of the more important results that directly relate to the utility of a defense worldwide instantaneous communications infrastructure. Although the satellite capacity and data rate were limited, the ability of MACSAT to provide an unattended interface to terrestrial local area networks and digital networks was significant.

Army Special Operations Forces and Marine Corps Expeditionary Units found this capability to be particularly suited to their need to communicate directly with their headquarters from any worldwide location using mobile equipment. The ability to interface with unattended stations connected to digital networks and local area networks provided a message delivery time of about 30 minutes. These units needed to interface with communications systems capable of providing direct data relay between worldwide locations using small, lightweight equipment without waiting for the major theater communications infrastructure to be established. The future infrastructure will be far more highly capable than MACSAT, but the MACSAT provided a system for hands-on experimentation with creative concepts in support of projected diverse and flexible force structures.

The ensemble of seven Microsats was launched on July 17, 1991, aboard the second flight of the Pegasus air-launched space booster. [The results of the Microsat launch have been previously presented.[5]] Within 24 hours after launch, communications were established with the Microsats. After a two-week checkout phase, the Microsats began to successfully demonstrate their communications capability. Communications networks could have been initiated within days of the flawless deployment from the bus; however, complete on-orbit checkout was allowed to proceed in a conservative manner due to the experimental nature of the satellites.

Although a lower-than-desired orbit altitude was achieved, the seven Microsats successfully demonstrated a number of exciting small spacecraft control concepts and participated in a number of tactical communications demonstrations until their re-entry on January 22, 1992. Two of the satellite control concepts involve the use of the smallest autonomous attitude control system ever deployed in space and a miniature cold gas propulsion system. The autonomous attitude control system established the correct attitude and spin rate within a few days after launch. A stationkeeping capability was successfully demonstrated through the use of the cold gas propulsion system using nitrogen gas under an initial pressure of 6000 pounds per square inch. Although small, the total impulse of 30 feet per second was sufficient to maneuver the 49-pound satellites within their orbital plane to space them in relation to one another as desired; within 60 days from launch, the satellites were equally spaced in the orbital plane. Various spacing configurations were demonstrated and tested during establishment of the orbital constellation. Equal spacing about the orbit plane could have been achieved within 30 days if the testing of other phasing concepts had not been conducted. This cold gas propulsion system was an outstanding success and maintained the desired spacing configuration until imminent re-entry.

During the six-month life of these satellites, a number of important experiments and demonstrations were conducted. The most significant demonstration took place in support of Operation BALIKATAN, in which Microsats provided highly effective support to the 6th Infantry Division's three-week humanitarian relief deployment during the aftermath of the Mount Pinatubo volcanic eruption in the Philippines. Numerous communications experiments were conducted with the U.S. Naval Academy, including:

- A Microsat-to-FLTSAT crosslink that enabled Microsat 2-watt terminals to be received over one-third of the earth's surface;
- The reliable use of 2-watt handheld transceivers for two-way voice communications between deployed field units and headquarters;
- High quality communications among terminals on the move, including vehicles and ships; and
- Beyond line-of-sight transmission of packetized data from Naval ships.

The Microsat experiments were highly successful and demonstrated military utility of small communications satellites, as well as technical demonstrations of sophisticated miniaturized subsystems.[6]

EVOLUTIONARY CONCEPTS

Lessons learned from these demonstrations and experiments are helping to establish a baseline for development of enabling technologies to make it possible for future MILSATCOM systems to support the requirements of the emerging national military doctrine. Although the capabilities of the MACSAT and Microsat constellations were limited, many lessons were learned that have resulted in enhanced capabilities for follow-on systems. An evolutionary baseline communications package developed for Naval low earth orbit satellites has leveraged many of the desirable features of the DARPA satellites. The design for this innovative communications package implements a memory capacity on the order of 1 gigabyte; selectable, error-free data packet transfer rates of 2400 bps through 1 Mbps; multiband UHF and SHF operation; bandwidths from 5 KHz to 3 MHz; and transponder or store-and-forward data relay, which is user-definable or transparent to the user as desired. In addition to the communications package, selection of the orbit and number of satellites impact the level of support provided.[7] Satellites such as these can be an important augmentation of the standard geosynchronous MILSATCOM transponder satellites to provide diverse services necessary to instantaneously support rapid projection of military power. These satellites enable support to be quickly dedicated to meet continuous communications requirements of a force while enroute to a battle zone and, later, within the battle zone without an immediate need for larger, portable terminal systems. High speed communications will allow logistics data base updates, operational plans, imagery, intelligence and other vital data to be relayed with little delay. Terminals can be designed to automatically transmit collected data in an unattended mode if desired. Information can be received and processed in a similar fashion. By interfacing with compatible networks in CONUS, data bases can be accessed and updated, plans can be modified, medical information can be monitored, maps updated, financial records updated and other similar actions taken. Digital relay satellites of this type are an evolutionary step toward realization of a future communications satellite system capable of providing a ubiquitous global infrastructure.

CURRENT COMMUNICATIONS TECHNOLOGY PROGRAMS

A major DARPA goal is the development of high pay-off, high risk emerging and enabling technologies to dramatically improve the affordability, performance and capability of space systems. Ten advanced technology projects crucial to the achievement of these goals and six SBIR (Small Business Innovation Research) projects in the area of advanced space communications technologies have been undertaken over the past few years. Most of the technologies are generic and can be adapted to multiple space systems or terminals.

MILSATCOM in the VHF band has been a cornerstone in our defense satellite communications architecture for two decades. DARPA is sponsoring an innovative approach to MILSATCOM in the UHF band that emphasizes improvements in current UHF SATCOM vulnerabilities. The new concept enables UHF satellite communication systems to again become competitive with other bands in the areas of resistance to interference, jamming and increased capacity through a greatly enhanced waveform and signal processing scheme. Although the other frequency bands offer increased performance in a highly jammed environment, the UHF band offers the lowest cost systems and provides a significant advantage for transmitting through dense foliage and heavy rain. Currently, UHF terminals provide adequate performance in the smallest package at lowest cost and enhanced UHF designs may be an appropriate candidate for the soldier's personal SATCOM-capable radio of 2015.

Technologies to enhance EHF systems are the major focus of the advanced satellite communications technology investments by DARPA. Several projects are analyzing systems engineering issues for small EHF communications satellites and are pursuing aggressive space system hardware developments. EHF subsystems developed include a MILSTD-1582 communications uplink processor incorporating an FFT-based digital demodulator; a direct digital synthesis (DDS) frequency generator and a high efficiency, solid state power amplifier (SSPA) utilizing the permeable base transistor (PBT). Various antenna designs were investigated that resulted in several innovative configurations. These designs include a wide-field-of-view, mechanically steered antenna; a variable beamwidth antenna; and a spherical lens antenna designed to handle the high gain and wide field-of-view requirements for an EHF satellite in an elliptical or low earth orbit. The latter antenna includes a very high density feedhorn topology that clusters 271 horns on a concave spherical feed-surface behind the spherical dielectric lens. A related high density multibeam antenna has been designed to extend the lightweight, high density technology into a form more suitable for a geosynchronous orbit. This antenna, which uses a planar dielectric lens, is presently being evaluated for its performance in high resolution, spatial, nulling applications. If a multibeam antenna of this class were to be built for an operational mission, it would employ very high density ASIC-based electronics for switching and control of the phase-amplitude distribution across the active cluster (up to seven horns). The antenna design also uses small, highly innovative, ferrite-based phase shifters and switches and lightweight, flangeless waveguides. A highly advanced technology program is in progress to develop an extremely compact, high performance EHF communications system based on all MMIC RF/IF electronics and a SIMD massively parallel computer.[8]

ADVANCED NETWORKING

Development of advanced MILSATCOM systems are key to achieving a defense global grid infrastructure. Future warfighting systems will place an unparalleled priority on leveraging information technologies for battlefield superiority. The global grid will provide immediate access to a fully distributed, dispersed, adaptive and transparent multimedia communications network from any point on the globe. Communications support for personal, pocket-size radio/computers will result in significant data flows that can utilize SATCOM, as well as terrestrial, channels. The advanced multiband radio concept known as Speakeasy initially will be capable of operating in the HF, VHF and UHF bands, with an SHF capability to be added later. This radio incorporates many microminiaturization devices such as MMIC, ASEM MCMs and active aperture, phased array antennas. Speakeasy technology may play an important roll in the future global grid architecture, and has the potential to support both satellite and terrestrial communications modes.

Increased traffic volume and bandwidth requirements, proliferated communications devices and requirements for instantaneous use will demand ever more efficient use be made of the radio frequency spectrum.[9] Future systems must provide dynamic bandwidth allocation to low volume users, multiband operation and multimedia networking. Small, lightweight, highly capable micro-MILSATCOM systems can help to provide a seamless communications system capable of establishing connectivity for any user on demand. Tremendous capabilities will be available to future mobile military forces that are networked via SATCOM to the worldwide fiber optic infrastructure. It is vitally necessary to invest in the technologies that will enable space systems to provide an omnipresent communications infrastructure for immediate support of worldwide military operations. DARPA and NASA are cooperatively developing satellite terminals to demonstrate advanced high data rate networking capabilities compatible with NASA's Advanced Communications Technology Satellite (ACTS). The terminals will support high data rate applications with point-to-point, point-to-multipoint and mesh network topologies. Advanced networking experiments are being defined, and lessons learned from this experimentation will help guide the development of technologies to enable the defense global grid vision of 2015.

CONCLUSIONS

This brief paper has attempted to illustrate how SATCOM systems are expanding their role as a vitally important component of our defense infrastructure for both tactical and strategic missions. SATCOM can provide an omnipresent communications infrastructure for immediate support of a developing theater. Through the application of appropriate enabling technologies, SATCOM systems will continue as a key element in the successful realization of capabilities to support our new defense doctrine. Interfaces with terrestrial RF and fiber systems and the ability to quickly extend B-ISDN and SONET services to the battlefield will become a necessary capability for SATCOM systems. DARPA is developing the enabling SATCOM technologies to give future warfighting systems the network support they will require. Application of advanced technologies will lead to enhancement of the capability density of large spacecraft and will facilitate small, highly capable satellites and user terminals as vital elements of the defense global grid infrastructure.

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