Chapter 14

Satellite Communications

Maj Bryan Eberhardt, USAF;
MAJ Kenneth Kemmerly, USA; and Maj Paul Konyha III, USAF

This is the President of the United States speaking. Through the marvels of scientific advance, my voice is coming to you from a satellite traveling in outer space. My message is a simple one: Through this unique means I convey to you and all mankind, America's wish for peace on Earth and goodwill toward men everywhere.

—Pres. Dwight D. Eisenhower
19 December 1958

On 19 December 1958, a recorded Christmas message from Pres. Dwight D. Eisenhower was broadcast worldwide via shortwave radio frequency from the Army's Signal Communications by Orbiting Relay Equipment (SCORE), which lasted for only 13 days until the battery failed. This led to the realization of British scientist Arthur C. Clarke's vision, in 1945, for global communications via artificial satellites in 24-hour orbits stationed above the earth.[1] Through countless developments since the SCORE broadcast, the US military has become increasingly dependent on satellite communications (SATCOM) for military operations.

This chapter purposely minimizes technical jargon as much as possible and provides the war fighter and his or her staff with a basic understanding of the capabilities of primarily military, but also some commercial, SATCOM systems. Military dependency on SATCOM for bandwidth grew 30 times within the 13 years from Operation Desert Storm to Operation Iraqi Freedom (OIF).[2] Furthermore, over 80 percent of SATCOM bandwidth used by the military to conduct OIF and Operation Enduring Freedom (OEF) has been commercial SATCOM. United States Strategic Command (USSTRATCOM), who forwards bandwidth requirements to the Defense Information Systems Agency (DISA), determines commercial SATCOM requirements. As the Department of Defense (DOD) designated contracting authority, DISA obtains commercial services via an existing contract vehicle or generates a new contract as necessary.[3]

Military SATCOM (MILSATCOM) provides minimum essential war-fighting connectivity, including systems designed to provide antijam and survivable nuclear command and control. It is unlikely (and unaffordable) that future MILSATCOM systems will fully meet rapidly expanding capacity requirements. Therefore, commercial SATCOM (COMSATCOM) will be needed to fill the gap.

The dependency on radio repeaters in space (i.e., satellites) will only increase in the future because satellites are a key method of connecting the isolated war fighter to the US military's Global Information Grid (GIG) and ultimately enabling network-centric warfare. The GIG is defined as the globally interconnected end-to-end set of information capabilities, associated processes, and personnel for collecting, processing, storing, disseminating, and managing information on demand to war fighters, policy makers, and support personnel.[4]

All encompassing, the GIG includes all owned and leased communications, computing systems and services, software applications, system data, security, and other associated services necessary to achieve information superiority. Eventually, the GIG will connect all soldiers, weapons platforms, sensors, and command and control nodes. At its basic level, the GIG is "networks which provide voice, data, video, and facilitate more than just the passing of targeting information through sensor-to-shooter loops; such a grid also provides, for example, real-time collaboration and dynamic planning."[5]

Satellite Communications Basics

Simplistically, SATCOM is a large radio repeater or relay situated on high ground. In this case, the high ground is space. Meanwhile, on Earth, satellite terminals are required for picking up (receiving) and sending (transmitting) the signals (frequencies) from and to the satellite. The frequency used by a SATCOM terminal to the satellite is the uplink frequency, and the frequency from the satellite to the SATCOM terminal is the downlink frequency. A SATCOM terminal is defined as any terminal used to connect a user to a satellite through the electromagnetic spectrum. The terminal may be an airborne, naval, or ground facility and can be fixed, mobile, or stand-alone.

The purpose of the space-based radio relay is to overcome the challenges of distance or obstructions inherent in terrestrial-based architectures for radios like microwave transmitters. However, the disadvantage posed by the great distances involved is the signal attenuation, or loss of some signal over the distance, requiring much greater transmit power and receiver sensitivity. In today's current satellite systems, this delay time primarily affects voice communications and can take "nearly 240 milliseconds [due to the] required propagation time."[6] Additionally, the great distances produce signal attenuation, or loss of some signal over the distance.

These satellite systems also contain segments that have space, satellite, and ground components. The space segment is the area of the electromagnetic spectrum between the ground terminal and the physical satellite, through which the satellite signals pass, and includes the orbits and coverage areas of the satellite (see chapter 6). The physical satellite itself is typically a member of a constellation of other satellites that can provide continuous coverage to an area of responsibility. The ground terminal can be the user terminal (either mobile or fixed) or the ground control station that provides the user with connectivity back to the GIG or has personnel who operate and maintain the satellite.[7] Note that joint, Army, and Air Force doctrine describes these segments a little differently; however, the inherent meanings are still similar (table 14-1).

Table 14-1. Names for segments in joint, Army, and Air Force doctrine.

Document	*Segment*		
	Space	*Satellite*	*Ground*
Joint Publication (JP) 3-14[a]	Link	Space	Ground/control
Field Manual (FM) 3-14[b]	Communication links	Satellite	Ground station/user segment
Air Force Doctrine Document (AFDD) 2-2[c]	Data links (control and mission)	Spacecraft	Ground and airborne stations

[a] JP 3-14, *Space Operations*, 6 January 2009, IV-7.
[b] FM 3-14, *Space Support to Army Operations*, May 2005, D-3.
[c] AFDD 2-2, *Space Operations*, 27 November 2006, 5.

Communications Satellite Modules

In general, a communications satellite is comprised of two modules: the spacecraft bus or service module and the communications payload. Generally, the spacecraft bus or service module consists of five subsystems:

1. The *structural subsystem* provides the mechanical base structure and shields the satellite from extreme temperature changes and micrometeorite damage.
2. The *telemetry subsystem* monitors the onboard equipment operations, transmits equipment operation data to the earth control station, and receives the earth control station's commands to perform equipment operation adjustments.
3. The *power subsystem* is comprised of solar panels and batteries. The solar panels charge the batteries, and the batteries supply power to the satellite subsystems, including when the satellite passes into Earth's shadow.
4. The *thermal control subsystem* helps protect electronic equipment from extreme temperatures due to intense sunlight or the lack of sun exposure on different sides of the satellite's body.
5. The *attitude and orbit control subsystem* is typically comprised of reaction wheels, electromagnets, and small rocket thrusters, which work together to keep the satellite in the correct orbital position and keep antennas pointing in the right directions.

The second major module, the communications payload, contains the transponders, antennas, and, for some communications satellites, crosslinks. A transponder provides the capability to amplify received radio signals from the uplink antennas. It also sorts the input signals and directs the output signals through input/output signal multiplexers to the proper downlink antennas. The antennas receive radio signals from SATCOM terminals and transmit to SATCOM terminals. Crosslinks provide connectivity between satellites without going through a SATCOM terminal.

Radio Spectrum

According to AFDD 2-2, "Where communication lines cannot be laid, or when terrain and other line-of-sight radio frequency limitations hamper terrestrial based communications, space communications keep forward and rear echelons in contact."[8] SATCOM systems contain a number of components that provide the ability to communicate effectively worldwide. These include the frequencies available for utilization within the electromagnetic spectrum through which SATCOM systems operate.

The SATCOM systems used today typically operate in the ultra-high frequency (UHF), super-high frequency (SHF), or extremely high frequency (EHF) ranges. Some of the systems that operate in these frequency ranges are described below in table 14-2, which also provides information on the radio spectrum, or the bands used by respective satellites, and the corresponding utilization of those bands.

Table 14-2. Bands and their utilization.

Band	*Frequencies*	*Utilization*
UHF	300 MHz to 3 GHz	TV broadcast, mobile satellite, land mobile, radio astronomy, air traffic control radar, global positioning systems, Mobile User Objective System (MUOS), UHF follow-on (UFO)
L band	1 to 2 GHz	Aeronautical radio navigation, radio astronomy, Earth exploration satellites
S band	2 to 4 GHz	Space research, fixed satellite communication
SHF	3 to 30 GHz	Satellite TV, Defense Satellite Communications System (DSCS), Wideband Global SATCOM (WGS)
C band	4 to 8 GHz	Fixed satellite communication, meteorological satellite communication
X band	8 to 12 GHz	Fixed satellite broadcast, space research
Kurtz-under (Ku) band	12 to 18 GHz	Mobile and fixed satellite communication, satellite broadcast
K band	18 to 27 GHz	Mobile and fixed satellite communication
Kurtz-above (Ka) band	27 to 40 GHz	Intersatellite communication, mobile satellite communication
EHF	30 to 300 GHz	Remote sensing, military strategic and tactical relay (Milstar), Advanced Extremely High Frequency (AEHF) System, Transformational Satellite (TSAT) Communications System
Millimeter	40 to 300 GHz	Space research, intersatellite communications

Adapted from K. V. Prasad, *Principles of Digital Communication Systems and Computer Networks* (Boston, MA: Charles River Books, 2004), 154; and Sky Scan, "The Electromagnetic Spectrum," http://www.skyscan.ca/the_electromagnetic_spectrum.htm (accessed 21 January 2008).

Current Military Satellite Communications Enterprise

The current MILSATCOM enterprise consists of four areas: protected, wideband, wideband broadcast, and narrowband. See figure 14-1 for the capabilities inherent in each of these areas. A fifth area, commercial SATCOM systems, also integrates with MILSATCOM services to give war fighters additional capacity and greater flexibility through redundancy.

Each system within these five areas offers unique advantages, making it particularly suitable to fulfill specific war-fighting needs. Together, they provide a robust, cost-effective integrated MILSATCOM architecture that satisfies critical Department of Defense requirements.

Today, the DOD SATCOM enterprise architecture comprises four primary systems (all in geosynchronous orbits), operating in UHF, SHF, and EHF ranges:

1. UHF follow-on (UFO) satellites.
2. SHF Defense Satellite Communications System (DSCS).
3. Wideband Global SATCOM (WGS) satellites.
4. EHF Milstar satellites.

Ultra-High Frequency Communications

After replacing the Navy's fleet SATCOM system, the UFO constellation became the primary DOD system for tactical mobile communications. Now providing UHF, EHF,

PROTECTED	WIDEBAND	WIDEBAND BROADCAST	NARROWBAND	COMMERCIAL
EHF Q/Ka-Band MILSTAR I/II • High protection (AJ, LPI, LPD, EMP) • Comm crosslinks • Survivable comm AEHF • Improved throughputs • Improved coverage TSAT • Wideband/ protected • Platform COTM • IP-based, network-centric	SHF S/Ka-Band DSCS • High data rates for tactical and enterprise users • Reachback for DISN • Some AJ WGS • Increased throughputs • Platform COTM • Adds Ka-band	Ka-Band UFO • GBS Ka payload on UFO satellites • High throughput • Small antennas • Smart push/pull WGS • WGS—X & Ka bands • Return channel; 2-way Ka-band	UHF P/L-Band UFO • Lightweight, mobile, terminals; COTM • Low data rate • Push-to-talk combat C2 MUOS • 6–10X legacy capacity • Handheld terminals • Networking OTM • Full GIG integration	L, C, Ku, Ka-Band • Growing capability • High throughput —Telemedicine —CSS —Split-based ops —Video • No protection • Pay for services • Mobile Satellite System for COTM
Military and Commercial Satellite Systems Are Essential to Provide Critical Communications for the Deployed War Fighter				

Figure 14-1. DOD SATCOM enterprise overview. (*Adapted from* Keith Hollinger, USA SMDC, "Narrowband SATCOM Support—Current/Future," presentation, 2006 LandWarNet Conference, 23 August 2006).

and Global Broadcast Service (GBS) capabilities on a worldwide basis, the UFO satellite system plays a vital role in meeting DOD's voice, data, and video transmission needs. The most prevalent users are ground forces (both Army and Marine Corps) which "account for 85 percent of the users of ultra-high frequency satellite communications."[9] As mentioned earlier, the Air Force oversees most of DOD's space systems; the Navy is responsible for narrowband satellite communications. The UFO constellation consists of "eight active spacecraft plus an in-orbit spare,"[10] which are in geosynchronous orbits. In addition to supporting ground forces, UFO "supports the Navy's global communications network, serving ships at sea"[11] and other government entities, including the White House, State Department, and Department of Homeland Security.

Besides the basic capabilities of the UFO satellites, specific satellites have additional capabilities depending upon when the satellites were fielded. For example, starting with UFO satellite Flight 4 (F4):

> The EHF subsystem . . . provides enhanced anti-jam telemetry, command, broadcast, and fleet interconnectivity communications, using advanced signal processing techniques. Beginning with UFO F7, the EHF package was enhanced to provide 20 channels through the use of advanced digital integrated circuit technology. The GBS payload carried on F8 through F10 includes four 130-watt, 24 megabits-per-second (Mbps) military Ka-band transponders with three steerable downlink spot beam antennas as well as one steerable and one fixed uplink antenna. This modification resulted in a 96 Mbps capability per satellite.[12]

Also, satellites F8 and F10 (F9 is no longer active) "include protected fleet broadcast to all Navy ships plus command and control networks to selected aircraft, ships, submarines and ground forces. UFO F11 is equipped with a UHF and EHF payload and an advanced tunable digital receiver that will enable this spacecraft to offer 41 channels. The F11 spacecraft [will] sustain the constellation until the advent of DoD's next-generation Mobile User Objective System."[13] The most recent UFO, F11, was successfully launched 17 December 2003.[14]

UHF satellite end-user terminals, or antennas, are typically "small and portable enough to be carried deep into military theaters of operation. The UHF frequency offers the capability of penetrating jungle foliage and inclement weather, as well as urban canyons."[15] There are around 20,000 terminals in use across the DOD today.[16]

Super-High Frequency Communications

Two military satellite systems operate in the SHF range: the Defense Satellite Communications System and the Wideband Global SATCOM satellites.

Defense Satellite Communications System. The Defense Satellite Communications System is a worldwide military satellite network managed under USSTRATCOM by DISA. DSCS consists of space and satellite segments along with ground terminals that operate in the SHF band to provide long-haul multichannel communications connectivity.[17] The system is an important part of the comprehensive plan to support globally distributed military users on the ground, at sea, or in the air.

DSCS evolved in three phases, starting with the Initial Defense Communications Satellite Program (IDCSP) satellites in Phase I (sometimes called DSCS I). Phase II began in 1971 with the launch of two DSCS II satellites. The third phase began in 1982 with the launch of the first DSCS III satellite.[18] Currently, there are 14 operational DSCS satellites with five Phase III DSCS satellites in geosynchronous orbit circling the earth at an altitude of 22,300 miles.[19] The five primary DSCS III satellites provide overlapping footprints for worldwide communications between 65° north latitude and 65° south latitude.[20] This highlights one of the disadvantages of geostationary satellites in "that they cannot be seen from the polar regions. . . . Fortunately, there is not a heavy telecommunications demand in these part[s] of the earth."[21] The five-satellite constellation of DSCS allows some Earth terminals to access two satellites (fig. 14-2).

Figure 14-2. **DSCS satellite**. (USAF photo)

The satellite system includes single- and multiple-beam antennas. Each DSCS III satellite also carries a special-purpose single-channel transponder used for disseminating emergency action and force-direction messages to nuclear-capable forces.[22] Each DSCS satellite has six SHF transponder channels (one of which provides limited antijam capability) capable of providing worldwide secure-voice and high-data-rate communications.[23] A single steerable dish antenna provides an increased power spot beam that is flexible to suit the needs of different sizes of user terminals.[24]

The DSCS III spacecraft is a three-axis, momentum-stabilized vehicle with an on-orbit weight of about 2,550 pounds with propellant. The spacecraft's rectangular body is 6.5 feet on each side, with a 38-foot span (with solar arrays deployed). The solar arrays generate 1,100 watts, decreasing to 837 watts after five years.[25]

The DSCS frequency plan falls within the SHF spectrum (X band) with uplink frequencies of 7,900 MHz to 8,400 MHz, which the transponders down-translate to the downlink frequencies of 7,250 MHz to 7,750 MHz.[26] The DSCS service life extension program (SLEP) upgraded the last four DSCS III satellites with improved solar panels and transponders providing more power, more sensitive receivers, and additional antenna connectivity options.[27]

The DSCS system is flexible enough to meet many different needs: "The DSCS Earth Terminals come in many shapes and sizes, conforming to the needs of the users it [sic] supports. There are two general types of terminal categories in the ground segment that are directly related to the type of user: strategic [enterprise] and tactical."[28] Key sites, known as teleports, are located around the world and are primarily used to connect to the GIG or to interface between systems.

DSCS launch, on-orbit operations (station-keeping), telemetry analysis, tracking data for orbit determination, and commanding of onboard subsystems are the responsibility of the 3rd Space Operations Squadron (3 SOPS). 3 SOPS is a component of the 50th Operations Group, 50th Space Wing at Schriever AFB, Colorado.[29]

Under the Army Space and Missile Defense Command (SMDC), 1st Space Brigade, the 53rd Signal Battalion's (Satellite Control) mission at Ft. Detrick, Maryland, is to provide communications network control for the DSCS.[30] The battalion operates the wideband operations centers (WOC) at five SATCOM locations around the world to oversee all use of the DSCS, ensuring that users receive the optimal SATCOM support authorized. They control the satellite links for tactical and strategic war-fighter communications networks. The battalion also provides payload control to the satellite as well as the technical and troubleshooting assistance required to ensure maximum support to the user. The WOCs provide real-time monitoring and control for the DSCS and perform payload control, which involves making changes to transponder and antenna configuration.[31]

Wideband Global SATCOM. The Wideband Global SATCOM (fig. 14-3), previously known as the Wideband Gapfiller Satellite System, provides additional capability to the current DSCS constellation and will eventually take over for DSCS and reduce the amount of commercial satellite communications capability that is required by the Department of Defense today. The WGS Block I satellites provide DOD with the "highest capacity communication satellite, offering a quantum leap in communications bandwidth for airmen, soldiers, sailors and Marines."[32]

Although planning for the WGS constellation began during the 1990s, the first WGS was successfully launched on 10 October 2007 and was transferred to the Air Force on 18 January 2008. DOD has contracted for a total of six WGS satellites. Two more were launched during 2008, one will be launched in 2011, and the last two in 2012 and 2013. The first satellite, *WGS-1*, is currently located over the Pacific and met initial operational capability in January 2009. The next two satellites will be placed over the European Command and Central Command areas of responsibility. These new satellites are expected to provide service to DOD for 14 years.[33]

The system includes eight X-band phased-array antennas, 10 Ka-band gimbaled-dish antennas, and one X-band Earth coverage antenna. The eight X-band antennas are considered steerable due to the advances inherent in phased-array technology.[34]

The WGS spacecraft is based on a commercial Boeing design and has an on-orbit weight of about 7,600 pounds.[35] The commercial satellite platform provides enhanced technologies such as "xenon-ion propulsion system (XIPS), highly efficient triple-junction gallium arsenide solar cells, and deployable radiators with flexible heat pipes."[36] The XIPS is nearly 10 times as efficient as conventional fuel and requires less fuel for station

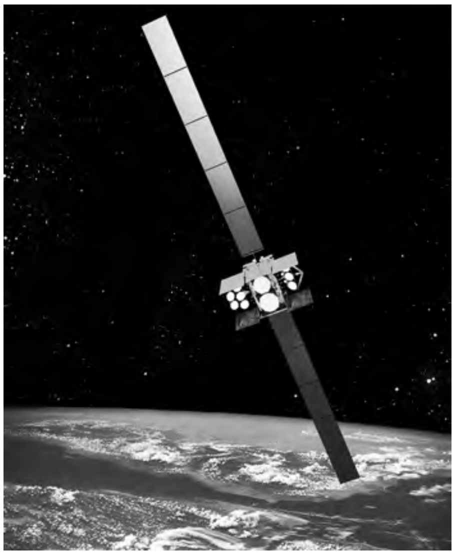

Figure 14-3. WGS satellite. (USAF photo)

keeping.[37] The solar arrays generate 11 kilowatts, nearly 10 times the current DSCS satellite power.[38] The radiators and heat pipes provide a "more stable thermal environment" for the satellite, thus increasing "reliability over service life."[39]

The WGS frequency plan falls within the SHF spectrum using X band and Ka band in the 7–8 GHz and 20–21 GHz frequency range, respectively, with the ability to cross-band between the X and Ka bands.[40] The Block II satellites, first launching in 2011, will provide a radio-frequency bypass for airborne intelligence, surveillance, and reconnaissance (ISR) assets to provide high bandwidth to unmanned aerial vehicles (UAV).[41] The WGS will provide enough bandwidth to allow UAVs to utilize military SATCOM resources in order to reduce today's complete reliance on commercial SATCOM.[42]

Transmission rates for end-user terminals depend on user requirements, antenna size, and modulation utilized. Typical throughput for each WGS satellite will be between 2.1 gigabits per second (Gbps) and 3.6 Gbps. In comparison, "a DSCS III satellite will support up to 0.25 Gbps."[43]

After the WGS satellites complete their initial systems checks by Boeing, they are turned over to the 3 SOPS to take over monitoring and control of the satellites.[44] The Army will control the payloads from four wideband satellite operations centers (WSOC) that allow them to control up to three satellites at one time with Boeing-designed software and hardware.[45]

Extremely High Frequency Communications

Although the term Milstar was originally based on the Military Strategic and Tactical Relay acronym, government sources no longer refer to it as an acronym, but a system (i.e., Milstar vice MILSTAR). The Milstar satellite system is a joint asset developed by the Air Force and has a satellite cross-linking capability that enables control from anywhere on Earth. Milstar provides highly robust, secure, and survivable communications among fixed-site and mobile terminals. Milstar's unique capabilities enable US forces to maintain information superiority throughout all levels of conflict, enhancing full-dimensional protection and ensuring that war fighters retain freedom of action through continuous, secure, jam-resistant communication.[46]

Milstar has a couple of features that distinguish it from earlier satellite communication systems. First, the Milstar satellite serves as a smart switchboard in space, allowing users to establish critical communication networks on the fly. Secondly, the Milstar system uses a satellite-to-satellite cross-link to provide worldwide connectivity without the use of vulnerable and expensive ground relay stations.[47] Milstar's flexible capabilities also allow users to utilize crossbanding and processed UHF-to-UHF communications. Crossbanding is the ability for EHF/SHF terminals to communicate with UHF terminals.[48] Milstar provides replacement of the Air Force SATCOM UHF networks by crossbanding EHF/SHF command systems to modified UHF Air Force SATCOM terminals on bombers and other force elements. Milstar will provide this until the legacy UHF terminals can be replaced with EHF terminals around 2014. AEHF will not continue the crossbanding capability.

The first Milstar satellite launched on 7 February 1994, and the final satellite successfully reached orbit on 8 April 2003. The Milstar constellation consists of five satellites positioned around the earth in low-inclined geosynchronous orbits at an altitude of approximately 22,300 miles. They provide coverage from 65° north to 65° south latitude in their assigned orbital position.[49]

The first two satellites possess the original strategic communications low-data-rate (LDR) payload (75–2,400 bps) capability. The third and subsequent satellites add the medium-data-rate (MDR) payload (to 1.544 Mbps) in addition to the LDR. Lockheed produced four Block II vehicles; however, the first Milstar II failed to reach orbit in April 1999 due to a Centaur stage software error.[50] The higher data rates provided by the Block II satellites "provide the user the ability to transmit large amounts of data in a short period of time."[51] See figure 14-4 for additional details.

Protected SATCOM Throughput	Milstar I LDR 0.002 Mbps	Milstar II MDR 1.5 Mbps	AEHF XDR 8 Mbps
Air Tasking Order 1.1 MB	1.02 hr	5.7 sec	1.07 sec
Tomahawk Tasking Order 0.03 MB	100 sec	0.16 sec	0.03 sec
Imagery 8x10 Annotated 24 MB	22.2 hr	2.07 min	23.6 sec
# Networks # Terminals Reconfig Time	30–100 1,000 Months	~1,500 1,000 Days–months	4,000 6,000 Minutes

Figure 14-4. Data throughput. (*Adapted from* Lt Col Luke Schaub, "Advanced EHF Overview," presentation, 20 May 2005.)

The Milstar satellite extends 51 feet across its payload axis, and the massive solar arrays generate nearly 5,000 watts of power (fig. 14-5).[52] Its payloads have onboard computers that perform resource monitoring and control functions supporting worldwide voice, data, video, teletype, and facsimile communications.[53] The Milstar II also has "a nulling antenna that nullifies enemy jamming attempts."[54]

Milstar provides interoperable communications capabilities to terminals located on submarines, ships, land-based systems, and mobile systems.[55] Today over 1,000 fielded terminals meet service-specific platform requirements while also supporting joint communications to all US military users with antenna diameters "from 14 centimeters for submarine terminals to 3 meters for fixed command-post terminals."[56] The terminal segment of Milstar "consists of a family of multi-Service ground, shipborne, submarine,

Figure 14-5. Milstar satellite. (USAF photo)

and airborne terminals functionally interoperable. . . . These terminals consist of the Air Force air and ground command post terminals, the Navy Extremely High Frequency Satellite Program (NESP) ship, shore, and submarine terminals, and the Army's Single-Channel Anti-jam Man-Portable (SCAMP) terminal and Secure, Mobile, Anti-jam, Reliable, Tactical Terminal (SMART-T)."[57]

The 4th Space Operations Squadron (4 SOPS), a component of the 50th Operations Group, 50th Space Wing, Schriever AFB, Colorado, is responsible for overall command and control and payload management of the Milstar constellation.[58] The control segment is controlled through the Milstar Satellite Operations Center (MSOC), which performs "satellite command and control, communications resource management, systems engineering support, mission planning, user support and anomaly resolution."[59] The MSOC utilizes two distinct command and control resources to operate the Milstar system, depending on mission requirements. The majority of satellite contacts are completed using three fixed constellation control stations (CCS)—two located at Schriever AFB, and one located at Vandenberg AFB, California, and operated by the 148 SOPS, California Air National Guard. Additionally, mobile CCSs execute satellite command and control and enhance mission survivability in support of the US Northern Command and contingency operations with operators from 4 SOPS.[60]

Commercial SATCOM Systems

As mentioned earlier, most operational SATCOM is provided by commercial SATCOM, which is consistent with US national space policy:

> It is in the interest of the United States to foster the use of U.S. commercial space capabilities around the globe and to enable a dynamic, domestic commercial space sector. To this end, departments and agencies shall: Use U.S. commercial space capabilities and services to the maximum practical extent; purchase commercial capabilities and services when they are available in the commercial marketplace and meet United States Government requirements; and modify commercially available capabilities and services to meet those United States Government requirements when the modification is cost effective.[61]

SATCOM requirements are determined by USSTRATCOM in its role as SATCOM operational manager of both MILSATCOM and commercial SATCOM for DOD. Meanwhile, DISA serves as the contracting authority for commercial SATCOM services. DISA describes the Enhanced Mobile Satellite Services (EMSS) as follows:

> EMSS is a satellite-based telephone and data communication service, utilizing a commercial satellite infrastructure to provide voice and low data rate services from a mobile, lightweight terminal through a DoD dedicated gateway which accesses the Defense Information System Network (DISN). It is capable of providing . . . secure voice service and non-secure access to commercial and DSN [Defense Switch Network] telephone services. . . . EMSS also provides the following special features: Broadcast Service, Protected Paging, Unclassified but Sensitive Internet Protocol Router Network (NIPRNet) Connectivity, Short Burst Messaging, Conference Calling and Secret Internet Protocol Router Network (SIPRNet) Connectivity (2008)."[62]

The typical end terminal utilized with EMSS is the Iridium commercial satellite phone, which can be secured with "a removable National Security Agency (NSA) approved . . . Communications Security (COMSEC) sleeve. EMSS is available through DISA to DOD, other federal departments and agencies, state and local governments, and Joint Staff (J-6) approved foreign and allied government users."[63]

Future Military SATCOM Systems

New military SATCOM systems are under development. These future systems will give DOD a greater capacity for transmitting data, higher transmission speed, and increased user access to data.

Mobile User Objective System

The Mobile User Objective System (MUOS) is the next generation of US military tactical UHF SATCOM developed by the US Navy for DOD. The MUOS constellation will replace the UFO satellite constellation currently in operation and will significantly increase both the capability of users and the number of potential users. When fully fielded, MUOS will provide an aggregate of 40.216 Mbps for the war fighter, compared to the legacy UFO system's aggregate of 2.666 Mbps. The increase means future war fighters will have more than 16,332 simultaneous accesses (voice, video, data) at 2.4 kilobits per second (kbps), compared to 1,111 accesses provided by the present UFO satellite system at the same data rate.[64] Consequently, more terminals will be used for mobile connectivity at the lowest tactical level.

The war fighter's MUOS terminals will be available in a couple of different types. The Army is currently scheduled to employ the Joint Tactical Radio System (JTRS) as its satellite terminal. Meanwhile, other users will use portable receivers that are approximately the "same size as today's Iridium satellite handheld phones."[65] Currently, the US Army is projected to be the largest user of MUOS. Additionally, MUOS will operate in several network configurations for internet routing.

With four satellites and one spare planned for geostationary orbits, MUOS will be fully compatible with the legacy UFO system and its associated terminals. Additionally, MUOS will employ four Earth stations as its main hubs: Italy, Australia, Hawaii, and Virginia.

This next-generation UHF satellite system provides the war fighter 10 times more capacity with higher data rates than today's UHF military system. It supports hand-held terminals, which will enable the war fighter, whether mobile or static, to access the GIG.[66]

Advanced Extremely High Frequency

The joint-service Advanced Extremely High Frequency (AEHF) system "is the follow-on to the Milstar system, augmenting and improving on the capabilities of Milstar, and expanding the MILSATCOM architecture. AEHF will provide connectivity across the spectrum of mission areas, including land, air, and naval warfare; special operations; strategic nuclear operations; strategic defense; theater missile defense; and space operations and intelligence."[67] As of this publication, the first AEHF system is scheduled to be launched in September 2010.[68]

According to the Air Force Space Command, "On-board signal processing will provide protection and ensure optimum resource utilization and system flexibility among the Armed Forces and other users who operate terminals on land, sea, and air."[69] The AEHF system will be backward compatible with the LDR and MDR capabilities of legacy Milstar satellites and terminals, while providing extended data rate (XDR) and other improved functionality at less cost than the previous system.[70] XDR replaces both LDR and MDR. XDR improves LDR missions for national/nuclear command and control with a 75 bps to 19.2 kbps highly survivable waveform. XDR improves MDR missions by extending the data rate to 8.192 Mbps. Additionally, AEHF significantly improves on Milstar's MDR by providing full Earth coverage. Milstar's MDR coverage was provided with eight small-footprint steerable antennas—Earth coverage was not available on MDR (Earth coverage was LDR only).

Each satellite in the constellation will weigh approximately 9,000 lb. when in geosynchronous orbit. The satellite utilizes a commercial infrastructure "based on Lockheed Martin's flight-proven A2100 geosynchronous spacecraft series"[71] (fig. 14-6). It will use cross-banded EHF communications and communicate via SHF downlinks and EHF uplinks.[72] Three satellites were originally ordered. Recently, a fourth satellite was requested by the Pentagon "to ensure continuity of service to commanders around the globe until TSAT becomes operational."[73]

The system will serve a terminal segment comprised of terminals used by all the services and international partners. The AEHF satellites "will respond directly to service requests from operational commanders and user terminals, providing real-time point-to-point connectivity and network services on a priority basis."[74] The XDR capability has also been successfully tested with the international variant of the Secure

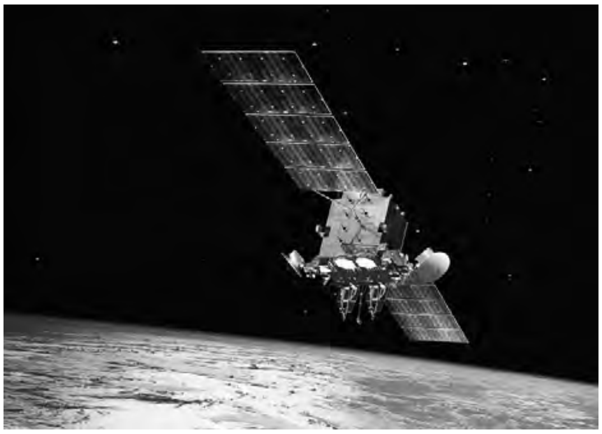

Figure 14-6. AEHF satellite. (USAF photo)

Mobile Antijam Reliable Tactical Terminal (SMART-T), and Lincoln Laboratory's Advanced Universal System Test Terminal (AUST-T).[75]

The AEHF program is currently on contract with Lockheed Martin Space Systems to develop and field the three satellites and the mission control segment (MCS). The new MCS will be used for both Milstar and the AEHF systems. The MILSATCOM Program Office is the contract manager of the AEHF program.[76]

Transformational Satellite

Transformational Satellite (TSAT) will provide further enhancement of AEHF satellites to include integrated Internet-like networking functionality. TSAT extends the ground-based GIG to deployed and mobile users. The system will also employ IP networks and onboard network routing to significantly increase and automate connectivity for the war fighter. TSAT increases bandwidth capacity up to 2 Gbps per satellite compared with 450 Mbps for AEHF. User RF data rates up to 45 Mbps are planned, while future laser communication links are capable of 1–10 Gbps. Higher throughput translates to faster download speeds, which means the war fighter can make decisions faster and act faster. As an example, an 8 x 10 image with a size of 24 megabytes (MB) can be transmitted in less than a second by TSAT, compared to a Milstar II communications satellite, which can transfer that same image in about two minutes. See figure 14-4 above for additional details.

The TSAT program is comprised of three segments: space, terminal, and TSAT Mission Operations System (TMOS). TMOS encompasses overall TSAT mission planning capability, network management, network services, and GIG border functions and interoperability. It will provide circuit and packet mission planning and policy management, external network coordination, network operations, key management, and a common operational picture.[77]

Currently, the space segment baseline consists of five satellites connected via crosslinks. The TSAT terminals will use at least one of the TSAT waveforms, and they may be backwards compatible with AEHF terminals.[78]

Five TSAT satellites are scheduled for launch beginning in 2019 to provide a wideband survivable network-centric capability to service the GIG in support of strategic and tactical war fighters. TSAT will employ packet switching with bulk and packet encryption/decryption to support secure information dissemination. TSAT's IP routing capability will connect thousands of users through interconnected networks rather than limited point-to-point connections. Initially TSAT satellites will use traditional RF cross-links to AEHF satellites to achieve integration and support transition from circuit-switched to packet-switched service delivery. Eventually TSAT satellites are intended to be interconnected by highly secure wideband laser cross-links.[79] (Note: As of April 2009, it is very likely that TSAT will suffer from major funding cuts, causing either an extremely long delay in fielding or possibly cancelation of the program.)

As a summary, figure 14-7 provides a timeline of key developments in military SATCOM systems.

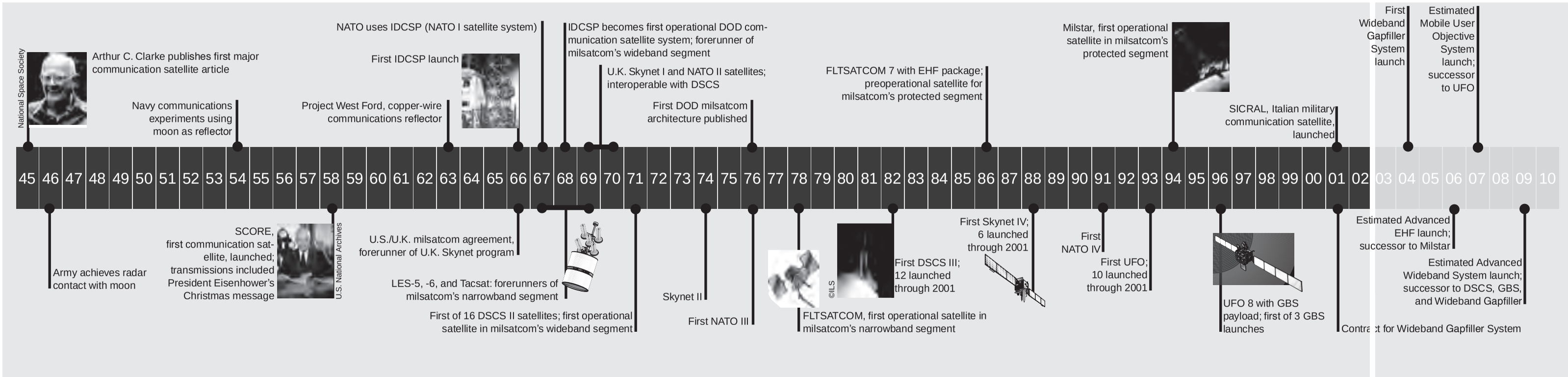

Figure 14-7. SATCOM timeline. (*Reprinted from* Donald H. Martin, "A History of U.S. Military Satellite Communication Systems," Crosslink 3, no. 1 [Winter 2001/2002], 56. Used by permission of The Aerospace Corporation, http://www.aero.org/.)

Notes

1. August E. Grant and Jennifer H. Meadows, eds., *Community Technology Update*, 8th ed. (St. Louis, MO: Focal Press, 2002), 274.

2. Joe Leland and Isaac Porche, *Future Army Bandwidth Needs and Capabilities* (Santa Monica, CA: RAND Corporation, 2004), 21.

3. Lt Col Roy Snodgrass, "Commercial SATCOM Support—Current/Future," presentation, LandWarNet 2007, Annual Armed Forces Communications and Electronics Association Conference, Ft. Lauderdale, FL, 21 August 2007.

4. "U.S. Stealth Bombers to Use EHF SatCom from Northrop Grumman," *MilsatMagazine* 1, no. 1 (First Quarter 2007): 7–8.

5. Leland and Porche, *Future Army Bandwidth Needs and Capabilities*, 11.

6. K. V. Prasad, *Principles of Digital Communication Systems and Computer Networks* (Boston, MA: Charles River Books, 2004), 41.

7. Chairman of the Joint Chiefs of Staff (CJCS) Instruction 6250.01, *Satellite Communications*, 30 April 2007, A-3.

8. AFDD 2-2, *Space Operations*, 2.

9. Sandra I. Erwin, "High Frequency: Navy Upbeat about Communications Spacecraft, Despite Radio Troubles," *National Defense*, July 2007.

10. Navy, "UHF Follow-On Program," Navy Fact Sheet, http://www.spaceflightnow.com/atlas/ac203/031211uhfprogram.html (accessed 2 April 2008).

11. Ibid.

12. Navy, "UHF Follow-On Program."

13. Ibid.

14. Boeing, "Successful Launch Orbits the 11th Boeing-Built UHF Follow-On Naval Satellite," http://www.boeing.com/news/releases/2003/q4/nr_031217o.html (accessed 7 April 2008).

15. Navy, "UHF Follow-On Program."

16. Ibid.

17. Air Force, "Defense Satellite Communications System," Air Force Fact Sheet, http://www.losangeles.af.mil/library/factsheets/factsheet.asp?id=5322 (accessed 21 January 2007).

18. Donald H. Martin, "A History of U.S. Military Satellite Communication Systems," *Crosslink* 3, no. 1 (Winter 2001/2002): 8–13.

19. Air Force, "Defense Satellite Communications System."

20. "DSCS-3," GlobalSecurity.org, http://www.globalsecurity.org/space/systems/dscs_3.htm (accessed 11 February 2008).

21. Mark R. Chartrand, *Satellite Communications for the Nonspecialist* (Bellingham, WA: SPIE: The International Society for Optical Engineering, 2004), 160.

22. "DSCS-3."

23. Air Force, "Defense Satellite Communications System."

24. Kostas Liopiros and Edward Lam, "Extremely High Frequency Satellites Offer Flexibility," *Signal* 44, no. 11 (July 1990): 77.

25. "DSCS-3."

26. Ibid.

27. Air Force, "Defense Satellite Communications System."

28. CW2 Garth R. Hahn, CW2 Anthony Kellar, and CW2 Steven Stubblefield, "Satellite Communications: Operating Together for National Defense," *Army Space Journal* 3, no. 1 (Winter/Spring 2004): 25.

29. Air Force, "3rd Space Operations Squadron," Fact Sheet, http://www.schriever.af.mil/library/factsheets/factsheet.asp?id=3914 (accessed 13 February 2008).

30. "Ft. Detrick Base Guide: 53rd Signal Battalion," dcmilitary.com, http://www.dcmilitary.com/special_sections/sw/082807_Detrick/ss_140741_31958.shtml (accessed 13 February 2008).

31. Hahn, Kellar, and Stubblefield, "Satellite Communications," 26.

32. "Boeing Completes On-Orbit Handover of Wideband Global SATCOM Satellite to USAF," Space War, http://www.spacewar.com/reports/Boeing_Completes_On_Orbit_Handover_Of_Wideband_Global_SATCOM_Satellite_To_USAF_999.html (accessed 14 February 2008).

33. Turner Brinton, "Longer Life Expected for First WGS Satellite," *Space News*, https://halfway.peterson.af.mil/NSSI/NSSISpaceNewsArchives/20080201_NSSISpaceNews.doc (accessed 14 February 2008).

34. Peter A. Buxbaum, "Wideband Comms: Change Is in the Air," *Defense Systems*, December 2007.

35. Air Force Space Command (AFSPC), "Wideband Global SATCOM Satellite," http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=5582 (accessed 14 February 2008).

36. Boeing, "Wideband Global SATCOM Backgrounder," http://www.boeing.com/defense-space/space/bss/factsheets/702/wgs/docs/WGS_overview.pdf (accessed 14 February 2008).

37. Boeing, "Integrated Defense Systems: Boeing 702 Fleet," http://www.boeing.com/defense-space/space/bss/factsheets/702/702fleet.html (accessed 20 March 2008).

38. "Wideband Gapfiller System: Satellite Design," GlobalSecurity.org, http://www.globalsecurity.org/space/systems/wgs-satdesign.htm (accessed 14 February 2008).

39. Boeing, "Integrated Defense Systems," http://www.boeing.com/defense-space/space/bss/factsheets/702/702fleet.html.

40. Buxbaum, "Wideband Comms."

41. Boeing, "Transformational Wideband Communication Capabilities for the Warfighter," http://www.boeing.com/defense-space/space/bss/factsheets/702/wgs/wgs_factsheet.html (accessed 14 February 2008).

42. DOD, *Unmanned Aerial Vehicles Roadmap 2002–2027* (Washington, DC: Office of the Secretary of Defense, December 2002), 107.

43. Boeing, "Transformational Wideband Communication."

44. "Boeing Completes On-Orbit Handover."

45. Boeing, "Transformational Wideband Communication."

46. AFSPC, "MILSTAR Satellite Communications," Fact Sheet, http://www.af.mil/factsheets/factsheet.asp?fsID=118 (accessed 12 February 2008).

47. Ibid.

48. Boeing, "Boeing Satellites: Milstar II," http://www.boeing.com/defense-space/space/bss/factsheets/government/milstar_ii/milstar_ii.html (accessed 19 February 2008).

49. Air Force, "MILSTAR," Fact Sheet, http://www.losangeles.af.mil/library/factsheets/factsheet.asp?id=5328 (accessed 25 November 2007).

50. "Milstar," Astronautix.com, http://www.astronautix.com/craft/milstar.htm (accessed 19 February 2008).

51. Air Force, "MILSTAR."

52. Lockheed Martin, "MILSTAR," http://www.lockheedmartin.com/products/Milstar/index.html (accessed 19 February 2008).

53. AFSPC, "MILSTAR Satellite Communications."

54. Muhammed El-Hasan, "Northrop Hopes for Satellite Bid," *Daily Breeze.com*, 26 October 2007.

55. Air Force, "MILSTAR."

56. Martin, "A History of U.S. Military Satellite Communication Systems," 12.

57. Director, Operational Test & Evaluation, DOD, "Military Strategic and Tactical Relay (MILSTAR) Satellite System," FY99 Annual Report, http://www.globalsecurity.org/military/library/budget/fy1999/dot-e/airforce/99milstar.html (accessed 29 February 2008).

58. AFSPC, "MILSTAR Satellite Communications."

59. Air Force, "4th Space Operations Squadron," Fact Sheet, http://www.schriever.af.mil/library/factsheets/factsheet.asp?id=3915 (accessed 29 February 2008).

60. Ibid.

61. White House Office of Science and Technology Policy, *U.S. National Space Policy*, 31 August 2006.

62. DISA, "Enhanced Mobile Satellite Services (EMSS)," http://www.disa.mil/services/emss.html (accessed 2 April 2008).

63. Ibid.

64. Keith Hollinger, "Narrowband SATCOM Support—Current/Future," presentation, 2006 LandWarNet Conference, 23 August 2006.

65. Ron Sherman, "MUOS: Milsatcom's Cutting Edge," *Avionics Magazine*, 1 June 2005, http://www.avtoday.com/av/categories/military/936.html (accessed 4 April 2008).

66. Virgil Labrador, "Military Satellite Market: Opportunities and Challenges," *MilsatMagazine* 1, no. 1 (First Quarter 2007): 16.

67. Air Force, "Advanced Extremely High Frequency (AEHF) System," Fact Sheet, http://www.losangeles.af.mil/library/factsheets/factsheet.asp?id=5319 (accessed 25 November 2007).

68. Amy Butler, "Fourth Satellite Busts Budget," *Aviation Week*, 4 March 2008, http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=space&id=news/AEHF03048.xml (accessed 15 March 2008).

69. AFSPC, "Advanced Extremely High Frequency System," Fact Sheet, http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=7758 (accessed 1 May 2009).

70. Ibid.

71. Steve Tatum, "Lockheed Martin Delivers Key Hardware for Third Advanced EHF Military Communication Satellite," Lockheed Martin press release, 22 December 2006.

72. Air Force, "Advanced Extremely High Frequency System."

73. Butler, "Fourth Satellite Busts Budget."

74. AFSPC, "Advanced Extremely High Frequency System."

75. "Northrop Grumman Demonstrates Compatibility of AEHF Satellite Interface with Terminals Using Extended-Data-Rate Waveform," *SpaceDaily*, 4 February 2008, http://www.spacedaily.com/reports/Northrop_Grumman_Demonstrates_Compatibility_Of_AEHF_Satellite_Interface_With_Terminals_Using_Extended_Data_Rate_Waveform_999.html (accessed 2 March 2008).

76. Air Force, "Advanced Extremely High Frequency."

77. Ibid.

78. Ibid.

79. Ibid.