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Standing in the Strategic Bandwidth Gap:

A View of Military Communications in 2012

by

David G. Ehrhard, Major, USAF

Acknowledgements

As a space operations officer, I wanted to do research involving satellites while learning something new. Thanks to my brother, Tom, I found both in this research. Ever full of ideas and opinions, he proposed the topic and suggested plenty of contacts, mostly experts helped me learn more. I have enjoyed it thoroughly.

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Abstract

The U.S. military enjoyed information superiority in the past, but a strategic bandwidth gap threatens that advantage in the future. In 2012, U.S. forces will likely meet an adversary that has fiber-networked his country, making it more survivable and linked with larger bandwidth than U.S. expeditionary forces that are linked by satellite communications. This presents a problem when the U.S. expects to achieve information superiority on foreign soil. The result will be loss of life in combat that lacks the benefits of surprise and initiative. The U.S. needs to overcome these deficits.

In this paper, communication technology is reviewed, showing that satellite technology is evolving while fiber optic technology can carry far more data and it is skyrocketing. Undersea fiber optic cables are gobbling up most of the international telephone and Internet markets, hindering many commercial satellite communications development plans. While the U.S. military foresees unmet demand for communication bandwidth, no overseas military bases are currently connected by fiber, a far less expensive solution than satellite communications when compared to bandwidth.

To bridge the strategic bandwidth gap, the U.S. should connect all overseas military sites with the growing worldwide fiber optic network, freeing up precious satellite communications bandwidth for tactical users. It should also develop faster ways to connect sites to fiber and find new ways to connect mobile users. Finally, satellite communications, especially laser communications, must continue improving to enable robust network-centric warfare in the future.

Introduction

> *The telecosm—the world enabled and defined by new communications technology—will make human communication universal, instantaneous, unlimited in capacity, and at the margins free.*
>
> —George Gilder

Worldwide communications have not yet reached Gilder's goals of unlimited, free capacity, but they are rapidly improving.[1] This will have a huge impact on the global economy, and it will also have strategic ramifications for the United States military.

The United States has enjoyed information superiority in recent military operations such as Desert Storm, Allied Force (in Kosovo), Enduring Freedom (in Afghanistan), and most recently, Operation Iraqi Freedom. The enemy has not enjoyed access to the same information, intelligence, and communications, allowing the U.S. military to have the advantage of surprise and initiative in each campaign. However, in a world with a significantly improved communications infrastructure via terrestrial fiber optics and satellite communications, future overseas operations could test the U.S. military's ability to fight without the same degree of information superiority or, worse yet, an information deficit—a "strategic bandwidth gap."[2]

To keep its information advantage, especially in expeditionary warfare, the U.S. military needs to improve its own communications capabilities. The warfighters' appetite for communication bandwidth is also on the rise, but that appetite is not matched by a correspondingly increasing supply of bandwidth. This mismatch in supply and demand of communications bandwidth in the U.S. military will not be overcome unless near-revolutionary changes can be made to improve the supply side of the equation, whether through space-, air-, or ground-based solutions.

This paper examines the potential strategic bandwidth gap at a high level. First, the current status of satellite and fiber optic communications systems and technologies are summarized to understand their respective capabilities, costs, and availability. Second, a likely communication-rich world of 2012 is described based on the projected evolution of satellite and fiber optic technologies. Third, the implications of an unfavorable bandwidth gap will be explained in terms of military strategic ramifications and financial costs to the United States. Finally, the paper concludes with recommendations and potential policy implications if the U.S. military is to avoid conducting expeditionary operations without the information superiority to which it is accustomed.

Satellite and Fiber Optic Communications

Information is power, but information that cannot be readily moved is gridlock on the World Wide Wait.

—George Gilder

Both space-based and ground-based communications play a key role in civilian communications today. While satellites pour hundreds of television channels into our households, fiber optic links increasingly connect our telephones and computers to counterparts around the globe. Each communication medium has unique capabilities, traits, and costs that make for interesting comparisons. Nevertheless, each mode can and must play a different part in future military operations than they do today. The question is, how?

One of the key features of any communication medium is bandwidth. Engineers refer to communications bandwidth as the range of frequencies over which a signal is passed from one user to another. Here, bandwidth will refer to data throughput, the number of data bits (binary digits, 1’s and 0’s) that can pass over a satellite link or fiber optic link in a given amount of time, usually in the period of one second. (The two terms are related, of course, but that discussion is beyond the scope of this paper.) This second definition is the primary means used by providers and users of communication systems to judge different systems’ relative capabilities. One bit per second is expressed as 1 bps. While 2,400 bps was once an acceptable capability level for a computer modem, users now speak in terms of megabits (million bits per second, Mbps) and gigabits (billion bits per second, Gbps) to satisfy current data flow appetites. The bandwidth of any system is a function of many things. For satellite systems, bandwidth is based on the frequency of transmission, transmitted power, and the size of the satellite dish or antenna, among other factors. Fiber optic bandwidth is based on the characteristics of the glass fibers and the capabilities of the transmitter that sends light waves through the fibers.

Satellite Communications

Satellite communication, or satcom, provides the bulk of overseas communications used for military operations today, and there are many systems that together make up the military satellite communication (MILSATCOM) network. These systems are run by the Army, Navy, and Air Force and transmit in different radio frequency ranges based on user needs. The three frequency ranges commonly used for satellite communications are Ultra-High Frequency (UHF, from 300 Megahertz to 3 Gigahertz), Super-High Frequency (SHF, from 3 to 30 Gigahertz), and Extremely-High Frequency (EHF, from 30 to 300 Gigahertz).

Ultra-High Frequency (UHF) Satellite Communications

Ultra High Frequency systems primarily support tactical users who use smaller satellite dishes and antennas.[3] These satellites were originally designed to connect navy ships, submarines, and ground stations, but now provide communications links to aircraft from all services and ground troops, among others.[4] UHF communication systems also penetrate foliage better than higher frequencies, requiring less power to use effectively, but they are also easier to jam.[5] These satellites are less expensive to build than their SHF and EHF counterparts and are more flexible.[6] In addition, although there are a variety of frequencies transmitted by all communication satellites, UHF satellites traditionally provide bandwidth that is negligible in comparison to the others.[7] The bandwidth limitations changed in 1998 and 1999 when three UHF Follow-on satellites, the newest in the UHF family of satellites, each were launched with a 96 Mbps EHF bandwidth capability for the new Global Broadcast Service, in addition to upgraded UHF capabilities.[8] Yet, like most communication satellites, the availability of UHF satellite services to military users is still not enough to meet demand. UHF Follow-on satellites were oversubscribed by 255% before Operation Enduring Freedom kicked off in Afghanistan, causing Naval Space Command to declare they had insufficient supply to meet U.S. Central Command's operations needs.[9]

Super-High Frequency Satellite Communications

Super High Frequency (SHF) satellites such as the Defense Satellite Communication System (DSCS) are the workhorses for military communications.[10] During Desert Shield and Desert Storm, DSCS satellites provided 80% of the satellite communications into and out of theater.[11] SHF operating frequencies are higher than UHF, they can carry more data, and they are more jam-resistant.[12] On the other hand, DSCS satellites are more costly to build than UHF satellites, and users need larger satellite dishes to receive and transmit on those high-bandwidth connections.[13] SHF frequencies are used to transmit phone conversations, military Internet data, and Global Command and Control System (GCCS) data, among other uses.[14] The newest DSCS IIIB satellite transmits an average capacity of 110 Mbps, the equivalent of about 2,600 phone lines simultaneously.[15] Yet even with a constellation of five DSCS satellites around the world with five on-orbit spares, the supply of bandwidth is not enough to meet the ever-growing demand. According to Greg Jaffe of the Wall Street Journal, the U.S. military supporting Operation Enduring Freedom in Afghanistan had insufficient bandwidth (primarily supplied by DSCS) to fly all of the available Predator and Global Hawk UAVs.[16]

Extremely-High Frequency Satellite Communications

EHF satellite communications were originally used to provide low bandwidth, secure, survivable communications for the National Command Authority and the military combatant commanders.[17] These Military Satellite Communications System (Milstar) satellites use the EHF spectrum because it is even more resistant to jamming than UHF or SHF, and the satellites can process data like a switchboard and cross-link to one another to avoid extra transmissions to the ground.[18] While their bandwidth is negligible, the cost of building these survivable, high-priority communication satellites is currently $800M, not including launch costs. This is higher than other communications satellite systems discussed here.[19] Still, there is another use for EHF satellite communications.

The Global Broadcasting System, introduced in the UHF section above because it was launched on three UHF Follow-on satellites, was built to provide a high-bandwidth (96 Gbps per satellite), one-way EHF broadcast, similar to commercial television satellites. Global Broadcasting System is used to transmit intelligence information, imagery, maps, and other large-data needs around the world.[20] Satellite dishes as small as one meter or less in diameter are required for receiving these high frequency, high-bandwidth signals, although the signal can be blocked by rain.[21]

Fiber Optic Communications

Fiber optics are changing the way the world is communicating. One glass strand smaller in diameter than a human hair can carry more data than many of the satellites discussed above...combined. One fiber using can carry 10 Gbps (10 billion bits per second) of data transmitted via one wavelength of laser light.[22] Additionally, because of a technology breakthrough called dense wave division multiplexing (DWDM), hundreds of different wavelengths of laser light can be carried simultaneously on the same fiber.[23] This directly multiplies the data each fiber can carry. America has an estimated 35 million miles of fiber optic cable in operation today.[24] That is enough cable to circle the earth more than 4,400 times or to stretch more than 10,000 times along highways from Seattle to Miami—not as the crow flies. Fiber is also reaching more areas of the world. New fiber cables continue to be laid on the ocean floor (submarine cable) and underground in foreign lands, better connecting communications between and within countries. Today, fiber optics carry 90 percent of the world's voice and data traffic.[25] This has caused a number of companies to scale back, postpone, or even cancel many new communications satellite launches.[26] Fiber optic cables connect more than 80 nations, yet major regions like Africa and South America have yet to be connected.[27] This leaves more than 100 countries that have yet to be connected, possibly in locations where the U.S. military may conduct its operations.[28] Still, despite the downturn in internet-related stocks, the main driver behind fiber optic proliferation worldwide, fiber optic suppliers continue to deploy networks.[29] In fact, the amount of purchased, transoceanic submarine bandwidth increased 196% in 2000 and 212% in 2001.[30] Figure 1 also shows the number of countries connected to fiber is growing, and the rate of growth does not appear to be slowing. The U.S. military, on the other hand, has not yet connected the U.S. to overseas bases, nor overseas bases to other overseas bases, choosing instead to use other means such as land-based communication systems and satellite communications.[31] In summary, fiber optics are capable of carrying huge amounts of data to an ever-growing number of locations worldwide. As of 2001, 42% of the world is now connected to one another via submarine fiber, but the U.S. military is not part of that trend.

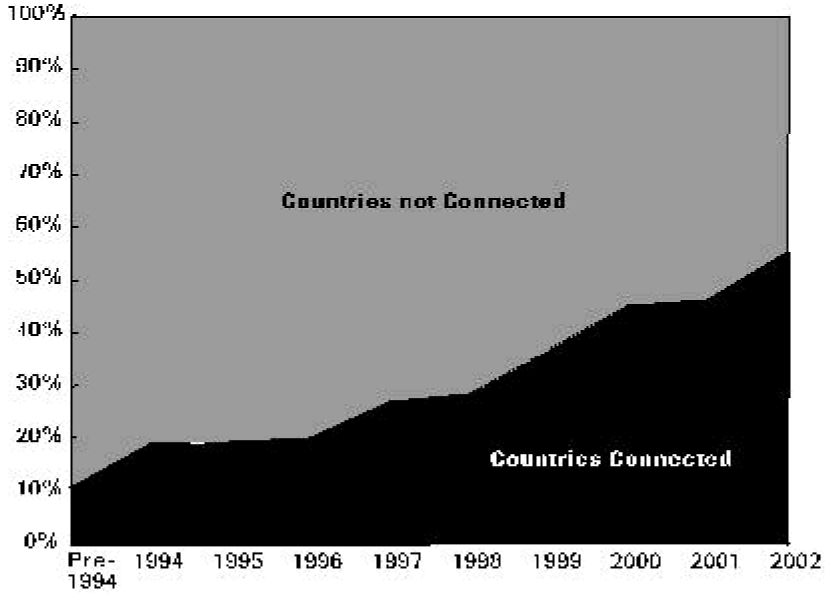

Figure 1. Multi Gigabit Submarine Cable Connectivity[32]

Communications in 2012

> *I am very skeptical that the right kinds and right amounts of commercial satcom bandwidth will be available to serve the U. S. military's ever-burgeoning requirements for connectivity. It wasn't there for Kosovo; it won't be there 10 years from now when our needs have further expanded an order of magnitude.*
>
> —Col. Dave Anhalt, OSD Office of Net Assessment, May 2001

The previous section reviewed satellite communications and fiber optic technologies in terms of the present, but what about the future? This section will present one possible view of the state of communication technology in the 2012 timeframe. In addition, estimates will be made about the demand for communications that will rely on satellites and fiber optic technologies.

In 2012, military satellite communications will not give way to commercial satellites. Commercial systems are already feeling the pressure of fiber optics in the marketplace, and assuming this will continue, it will result in little or no improvement in satellite bandwidth capacity available to the military. While there will be bandwidth available for lease, it will not approach the burgeoning demand of U.S. military forces. Therefore, the U.S. will continue to design and build military communications satellites.

Because the typical cycle length of military acquisitions is quite long, programs not yet underway have little chance of being fielded by 2012. So viewing the progress of military satellite communications optimistically, the DSCS system will be replaced by five fully operational Wideband Gapfiller Satellites (WGS). Each one will be able to downlink 2.4 Gbps of data to tactical users.[33] Then the Global Brocasting System III will be fully operational with upgraded capability, broadcasting 150 Mbps, for each of the system's five satellites.[34]

In addition to the radio frequency based satellite efforts, work is ongoing to create a capability using laser communications through space and air to communicate between satellites, aircraft, and ground sites. While this capability does not exist yet operationally, the National Reconnaissance Office launched a test satellite in 2001.[36] Finally, the Deputy Secretary of Defense proposed investing $2.5B in fiscal year 2003 and a total of $18.6B over the future years defense program to develop laser communications technology.[37] While the capability exists today to transmit 1Gbps in the laboratory, it could improve to as much as 10 Gbps and be operational by 2012.[38] The chances of success are high given the investment. Because the atmospheric effects of laser attenuation will be difficult to overcome, this remarkable capability will likely only exist between aircraft and satellites.[39] Still, linking satellites and aircraft with Gbps capability will greatly enhance overall capabilities of systems that need to be linked for improved network-centric warfare of the future.

In 2012, fiber optic cables will link half of the remaining 110 countries of the world, a conservative estimate based on Figure 1 (above). Thus, 135 of 191 countries will be connected through fiber optics that will carry increasingly greater amounts of data around the world. According to futurist George Gilder, 1,000 different wavelengths of light can now be used on a single fiber using DWDM.[40] When multiplied by 10 Gbps, the capacity of today's fiber optics, and up to 864 fibers per cable, data throughput will be larger than giga (billions) and tera (million millions), it will be 8.6 petabits per second (Pbps million billions, or 1 x 10^{15} bits per second).[41] According to Gilder, 8 petabits is the equivalent of the total international Internet traffic in one month during 1995. While improvements will be needed to make this astounding capacity available worldwide, including DWDM equipment control and optical switching improvements, the fiber optic industry has nearly 10 years to work them out, and they should. Table 1 below summarizes the current and future estimates for communication throughput capabilities based on the analysis given.

Table 1. Comparison of Current and Future Throughput

Technology	**2002**	**2012**
DSCS/Wideband Gapfiller	550 Mbps	12,000 Mbps
GBS/Advanced Wideband	288 Mbps	750 Mbps
Satellite Comm Total	838 Mbps	12,750 Mbps
Lasercom	N/A	10,000 Mbps
Fiber Optics	2,400,000 Mbps	8,600,000,000 Mbps

Finally, the U.S. military's insatiable appetite for data and bandwidth will continue to increase. In 2000, the Defense Science Board (DSB) concluded that in order to fight a major war in 2010, the U.S. military will need 16 Gbps of bandwidth.[42] In 2002, the National Security Space Architect, Brigadier General Stephen Ferrell, says that their forecast, [while classified,] is significantly higher than the DSB estimate.[43] The evolutionary satellite communications improvements summarized in Table 1 (above) will not meet these growing requirements. Meanwhile, potential adversaries will continue to improve their communication infrastructures with fiber optics.

In these times of U.S. expeditionary warfare, it is possible, if not reasonable, that adversaries who improve their internal lines of communications will have an advantage. Prior to Operation Iraqi Freedom, China had already helped Iraq to construct an internal fiber optic network to better integrate their communications and air defense systems.[44] Therefore, it is likely that any potential adversary in the 2012 timeframe will have well-engineered internal fiber optic networks.

Strategic and Financial Implications

> *Interior lines of operations are those adopted by one or two armies to oppose several hostile bodies. Their direction allows the general to concentrate the masses and maneuver with his whole force in a shorter time than the enemy would require to oppose to them a greater force.*
>
> —Antoine Henri Jomini
> *Art of War*

For the U.S., war in 2012 will likely be more challenging than in past. One should assume that future U.S. adversaries will take advantage of the worldwide fiber optic growth by constructing redundant, underground internal communications and possibly connecting to others externally as well. This will have ramifications to U.S. strategy and the overall cost of war.

It is unclear whether the U.S. will make significant gains in high bandwidth, fiber-based, network-centric warfare in the next decade. Nonetheless, if the U.S. enters war with a fiber-connected country, its goal of gaining and maintaining information superiority is severely at risk. No longer will a few well-placed bombs take away an enemy's eyes and ears. Many eyes and ears will be linked to a well-connected brain that will be difficult to restrain if the network is robust and protected underground. Knocking out an eye (e.g. a surface-to-air radar) or a communication node will result in automatic rerouting of information, much like the Internet does today. Bombing will need to be as extensive as the entire communications network to be successful, assuming the entire network architecture is known. If the bombing efforts leave any lines available to the enemy, then the enemy will continue to have information flowing at terabits, if not petabits per second. The same will not be the case for the U.S., since wars will primarily be expeditionary in nature, and non-fiber link capabilities cannot keep up. Thus, enemies will have the information version of Jomini's "interior lines," and America will be facing a strategic bandwidth gap.

Much like America feared the strategic missile gap in the mid-20th century, thinking the Soviet Union had more nuclear missiles and could therefore win a nuclear exchange, Americans should fear the strategic bandwidth gap. An enemy with robust sensors, weapons, and robust fiber-based communications will have a real strategic advantage—information superiority over the U.S. military. No more will surprise be easily gained. Military operations will involve increased loss of life and equipment, something Americans are not accustomed to experiencing. American warriors and weapons systems will be better connected than today, but the home team (the enemy) will be able to pass more information through fiber optic links than will the American visitors. As a result, the U.S. may choose instead not to get involved, which could lead to far less American influence overseas.

There are also long term financial implications for the strategic bandwidth gap. For the U.S. to bridge the gap, it must also consider the financial costs of fiber optics and satellite communications. While both technologies are likely to be part of a robust, long-term solution, investing in fiber optics can actually save money when considered on a bandwidth per dollar basis. Satellite and fiber communications have very different characteristics. Therefore, in the following analysis, choices and assumptions have been made more demanding toward fiber optics, and more lenient toward satellite communications in order to better assess the validity of fiber optic cost effectiveness. The results in Table 2 show that fiber optic communications are 1.7 million times less expensive than satellites for the same bandwidth. While one can surely find ways to indict each estimate, a 1.7-million-to-one ratio is hard to overcome. The financial implications of changing to fiber optic connections for long-haul communications are large and the margin is widening. Fiber optic technology and its demand are growing rapidly, while the satellite growth is evolving more slowly. Although fiber will not be suitable for communicating with mobile users, surely the U.S. military can follow the commercial world by pursuing a strategy of connecting fixed sites overseas to both the U.S. and to each other.

Table 2. Cost Comparison of Fiber Optic and Satellite Communications

	Satellite	**Fiber**
Farthest Distance From U.S.	12,451 mi.	12,451 mi.
Cost to Connect (1 undersea fiber, 2 WGS)	$ 600 M	$ 1,260 M
Bandwidth	2,400 Mbps	8,600,000,000 Mbps
Cost to Connect per Mbps	$ 250,000.00	$ 0.15
Comparison-Cost per Mbps (Satellite+Fiber)	Satcom costs are 1.7 million times higher	

Source: Distance from U.S. is half of the earth's circumference—worst case for fiber. Undersea fiber costs are two times that of Global Crossing's 1999 estimate to cross the Atlantic Ocean (www.globalcrossing.com/xml/news/1999/march/24.xml). Two Wideband Gapfiller Satellites (WGS) are required to connect around the world. Cost from Boeing website at www.hughespace.com/factsheets/702/wgs/wgs_factsheet.html for first two plus commercial launch cost of $50M for each (Watts, Barry D., Center for Strategic and Budgetary Assessments, Wash., D.C., Feb 2001, "The Military Use of Space: A Diagnostic Assessment." p. 123.) WGS bandwidth is maximum for one user using one ground hop between satellites. Fiber bandwidth explained in Chapter 2 is based on George Gilder, *Telecosm*, (Simon & Shuster, Inc. New York, NY. 2000.): p. 10.

Conclusions and Recommendations

> *The joint force of 2020 will use superior information and knowledge to achieve decision superiority, to support advanced command and control capabilities, and to reach the full potential of dominant maneuver, precision engagement, full dimensional protection, and focused logistics.*
>
> —Joint Vision 2020

The U.S. cannot allow the strategic bandwidth gap to widen abroad. U.S. satellite communications are improving in UHF, SHF, and EHF frequencies to better support military needs, but the demand for bandwidth greatly exceeds supply, which includes commercial satellite capabilities. Laser communications are receiving new funding that should energize the technology and allow for improved cross-linking between satellites and down to aircraft by 2012. Fiber optic technology, however, is improving much faster, as 42% of the world is connected today by faster links than satellites can reasonably achieve by 2012. With conservative growth compared to current trends, 71% of the world will be fiber-connected by 2012. Fiber already carries 90% of international telephone and data usage. Adversaries are laying fiber in order to transmit more data while surviving American attacks. As of 2002, no overseas American military sites are connected to the continental U.S., or each other, or anywhere by fiber optics. Current trends will present the U.S. military with a strategic bandwidth gap that will be insurmountable if we do not start making changes soon. From a strategic perspective, losing the information superiority battle, a key to enabling all military functions, will have serious consequences from loss of life, to lack of action, to lost world influence.

Finally, the financial implications of a tradeoff between fiber optics and satellite communications are staggering. Conservatively, fiber can replace satellite communications for many of its uses at a small fraction of the cost based on comparable bandwidth capability. That fraction is still shrinking as fiber technology continues to improve at a much faster rate than satellite technology. So, while the U.S. is surely staring at a strategic bandwidth gap in 2012, there are ways to bridge it.

The strategic bandwidth gap can be bridged by U.S. military pursuit of the following recommendations:

Connect Overseas Fixed Sites via Fiber Optics. In as much as the commercial world is connecting via fiber, so can the U.S. military. This effort should be aggressive. Every fixed site that is connected via fiber optics increases its own capabilities and frees up satellite bandwidth for other important functions. More UAVs can transmit video to operations centers and to other aircraft. Operations centers can communicate with more ground forces in or near the battle. Special Operations Forces can connect to ships, aircraft, and other ground forces to optimize the network-centric warfare of the future. Tactical users will benefit from fiber optic transmission for planning functions such as video teleconferencing, UAV videos, and Power Point presentations because satellite bandwidth will no longer be the limiting factor. To ensure redundancy, satellite communications can remain as a backup for planners.

Develop Quick Methods to Connect Fiber. The U.S. should use the growing worldwide fiber infrastructure to "plug into" overseas Points of Presence and connect them to operational sites. New undersea fibers should be unnecessary since sufficient bandwidth will be available in most regions. A Red Horse-like capability to set up or repair these fiber optic connections rapidly should be developed. These capabilities will greatly enhance U.S. expeditionary warfare efforts in new areas of the world.

Link Mobile Users to Fiber Optics. The U.S. should develop new ways to link traditional mobile satcom users such as submarines, ships, tanks, and aircraft to fiber-like bandwidth via laser communications or quick injects from fiber optic plug-ins, perhaps while being refueled, while in port, or while sitting on an airfield.

Continue Satellite Communication Advances. Satellites will still be needed for last-mile communications, but the rate of improvements needs to accelerate. Laser communications development will reap large benefits in this area as well, but these efforts need to be aggressive, allowing for reliable space-to-ground connections in addition to space-to-space, air-to-air, and space-to/from-air.

To minimize casualties, assure responsiveness, and maintain U.S. influence throughout the world, the American military can and must maintain the advantage of information superiority by bridging the strategic bandwidth gap confronting its forces. By pursuing efforts such as recommended here, the U.S. will be able to bring new sensors and shooters onto or near the battlefield, to connect them to each other and share data, and to realize the transformational network-centric warfare needed to promote peace and stability in the 21st Century.

Notes

1.George Gilder, *Telecosm* (New York, NY: Simon & Schuster, Inc., 2000), p. 2.

2. Lieutenant Colonel Thomas P. Ehrhard, School for Advanced Aerospace Power Studies, interviewed by author, 5 April 2002.

3. “UHF MILSATCOM,” Air University Space Education Series briefings, Air Command and Staff College, Maxwell Air Force Base, AL, Academic Year 2000.

4. Ibid.

5. Ibid.

6. “Introduction to MILSATCOM,” Air University Space Education Series briefings, Air Command and Staff College, Maxwell Air Force Base, AL, Academic Year 2000.

7. Ibid.

8. “UHF Follow-on Fact Sheet,” Boeing Corporation, n.p., on-line, Internet, 24 September 2003, available from http://www.boeing.com/defense-space/space/bss/factsheets/601/uhf_followon/uhf_followon.html.

9. Craig Covault, “Naval Space Ops Crucial to Afghan War,” *Aviation Week and Space Technology*, 8 April 2002, p. 86.

10. “Introduction to MILSATCOM.”

11. Ibid.

12. Ibid.

13. Ibid. p. 53.

14. Ibid. p. 33.

15. “Defense Satellite Communication System (DSCS),” Air University Space Education Series briefings, Air Command and Staff College, Maxwell Air Force Base, AL, Academic Year 2000.

16. Greg Jaffe, “Military Feels Bandwidth Squeeze As The Satellite Industry Sputters,” *The Wall Street Journal*, 10 April 2002.

17. “Introduction to MILSATCOM,” p. 36.

18. “Milstar Factsheet,” Lockheed Martin Corporation, 13 April 2002, n.p. on-line, Internet, 24 September 2003, available from http://www.lockheedmartin.com/factsheets/product395.html.

19. Craig Covault, “U.S. Military Wants Sweeping Satcom Changes,” *Aviation Week & Space Technology,* 21 January 2002, p. 27.

20. “Global Broadcast Service (GBS),” Air University Space Education Series briefings, Air Command and Staff College, Maxwell Air Force Base, AL, Academic Year 2000.

21. Ibid, p. 45.

22. Gilder, p. 10.

23. *Submarine Bandwidth 2002*, Executive Summary, Telegeography, Inc., March 2002, p. 2.

24. Thomas B. Allen, “The Future is Calling,” *National Geographic* 200, Issue 6 (December 2001): p. 76.

25. Allen, p. 76.

26. Jaffe, p. 1.

27. Allen, p. 76.

28. Office of The Geographer and Global Issues, Bureau of Intelligence and Research, U.S. Department of State, Washington, D.C., 9 April 2002, lists 191 independent states as of April 2002. Available online at www.state.gov/s/inr/rls/4250.htm.

29. *International Bandwidth 2001*, Executive Summary, Telegeography, Inc., 3 May 2001, p. 2.

30. *Submarine Bandwidth 2002*, p. 5.

31. Captain Adam Little, USAF, USCENTAF A-6, Communications Management and Maintenance officer, interviewed by author, 15 April 2002.

32. Colonel Dave Anhalt, OSD Office of Net Assessment briefing, “The Changing Nature of the Commercial Satcom Era and its Impact On U.S. Military Advantage,”cited in *International Bandwidth 2001*, p. 10.

33. “Wideband Gapfiller Satellite (WGS) Fact Sheet,” Boeing Corporation, April 2002, on-line, Internet, 29 September 2003, available from http://www.boeing.com/defense-space/space/bss/factsheets/702/wgs/wgs_factsheet.html. Only two WGS systems have been put on contract, but the optimistic approach includes buying another three to completely replace the entire existing DSCS constellation by 2012. The existing contract includes options for more than $1B.

34. “Introduction to MILSATCOM.” While plans are very loose on both GBS and WGS, this estimate is optimistic because the Joint Requirements Oversight Council approved requirement is

from 1997, and GBS one-way broadcasting appears complementary to fully duplex communications of the WGS system.

35. Craig Covault, “U.S. Military Wants Sweeping Satcom Changes,” *Aviation Week and Space Technology*, 8 April 2002.

36. Ibid.

37. Paul D. Wolfowitz, Deputy Secretary of Defense, “Testimony Delivered on Military Transformation,” U.S. Senate, 9 April 2002. Available on-line from www.defenselink.mil/speeches/2002/s20020409-depsecdef1.html.

38. Charles Niessen, MIT Lincoln Labs, Communication Division engineer, interviewed by author, 10 April 2002.

39. Ibid. Mr. Niessen agreed that the pointing of the laser and atmospheric attenuation are the most difficult problems to overcome. The unpredictable atmosphere can block too much light for the laser to be reliably effective. Pointing is being overcome today in many programs such as the Airborne Laser (ABL). Technology has not progressed as far on the attenuation problem. Thus much of the atmospheric effects can be avoided above the clouds at aircraft altitudes (40,000 ft.) and above.

40. Gilder, p. 10.

41. Ibid.

42. Jaffe.

43. Ibid.

44. Thomas E. Ricks and Vernon Loeb, “Rumsfeld: Iraq Has Rebuilt Air Defenses,” *Washington Post*, 4 August 2001.
