

NAVAL WAR COLLEGE
Newport, R. I.

COMMAND AND CONTROL IN THE INFORMATION AGE

by

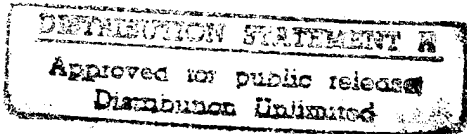
W. David Reese

Major, USA

A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of the Department of Joint Military Operations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

Signature: William D. Reese



14 June 1996

Paper directed by
Captain D. Watson
Chairman, Joint Military Operations Department

19960501 216

DEFINITION STATEMENT A

REPORT DOCUMENTATION PAGE

1. Report Security Classification: UNCLASSIFIED			
2. Security Classification Authority:			
3. Declassification/Downgrading Schedule:			
4. Distribution/Availability of Report: DISTRIBUTION STATEMENT A: APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.			
5. Name of Performing Organization: JOINT MILITARY OPERATIONS DEPARTMENT			
6. Office Symbol: C		7. Address: NAVAL WAR COLLEGE 686 CUSHING ROAD NEWPORT, RI 02841-1207	
8. Title (Include Security Classification): Command and Control in the Information Age (U)			
9. Personal Authors: William D. Reese, MAJ, USA			
10. Type of Report: FINAL		11. Date of Report: 14 JUN 1996	
12. Page Count: 19			
13. Supplementary Notation: A paper submitted to the Faculty of the NWC in partial satisfaction of the requirements of the JMO Department. The contents of this paper reflect my own personal views and are not necessarily endorsed by the NWC or the Department of the Navy.			
14. Ten key words that relate to your paper: Fiber Optics, Communication Satellites, Command and Control, Dominant Battlespace Awareness			
<p>15. Abstract: Effective military communications capabilities are not only essential for command and control of military forces but can also be used to achieve information dominance in the battlespace. The U.S. has historically applied its technological advantage to win at command and control warfare. As budget cuts slow the pace of research, development, and acquisition of military communications systems, civilian commercial systems are surpassing their military counterparts in many capabilities. It is important that our senior commanders are cognizant of new commercial communications technology and its applicability in a myriad of military situations.</p> <p>This paper describes recent advances in the commercial communications arena which have obvious command and control warfare applications. Fiber optic transmission systems, long known for their ability to transport huge volumes of information, have recently been improved to overcome a number of earlier shortfalls. A description of these refinements, along with a number of resulting new military applications is presented. Commercial communications satellites are discussed in the final part of the paper. A number of new multibillion dollar constellations are about to enter service just as military funding for such satellites dries up. Both technologies play key roles in achieving battlespace dominance in the information age.</p>			
16. Distribution / Availability of Abstract:	Unclassified X	Same As Rpt	DTIC Users
17. Abstract Security Classification: UNCLASSIFIED			
18. Name of Responsible Individual: CHAIRMAN, JOINT MILITARY OPERATIONS DEPARTMENT			
19. Telephone: 841- 6227 6461		20. Office Symbol: C	

Abstract

Effective military communications capabilities are not only essential for command and control of military forces but can also be used to achieve information dominance in the battlespace. The U.S. has historically applied its technological advantage to win at command and control warfare. As budget cuts slow the pace of research, development, and acquisition of military communications systems, civilian commercial systems are surpassing their military counterparts in many capabilities. It is important that our senior commanders are cognizant of new commercial communications technology and its applicability in a myriad of military situations.

This paper describes recent advances in the commercial communications arena which have obvious command and control warfare applications. Fiber optic transmission systems, long known for their ability to transport huge volumes of information, have recently been improved to overcome a number of earlier shortfalls. A description of these refinements, along with a number of resulting new military applications is presented. Commercial communications satellites are discussed in the final part of the paper. A number of new multibillion dollar constellations are about to enter service just as military funding for such satellites dries up. Both technologies play key roles in achieving battlespace dominance in the information age.

The rapid pace of technological evolution and the ever increasing value of information to all facets of our society have combined to thrust our generation into what has become known as the information age. Information dominates today's world. It has become as important as labor and capital during the industrial age or land during the agrarian age. It can translate into profits for commerce, power for political institutions, and, in the case of military organizations, dominant battlespace knowledge. The growing criticality of information has logically fueled the technological innovations related to its collection, transport, and processing. Innovative organizations which quickly capitalize on these new opportunities in the information arena will have a substantial advantage over their competitors. For our military, gaining information superiority can set the stage for victory at sea, in the air, and on the battlefield. Thus, our senior commanders and staffs need to stay apprised of how new technological developments can hinder or assist in achieving information superiority.

Command and control (C2) of modern military forces relies increasingly on information technology for success. Joint Pub 6-0, *Doctrine for Command, Control, Communications, and Computer (C4) Systems Support to Joint Operations*, lists the functions of C4 systems as collecting, transporting, processing, disseminating and protecting information. Today's communications capabilities enable us to transport, disseminate, and protect vital command and control data better than ever before. Further, current commercial capabilities rival or surpass even the best military telecommunication systems. This paper will focus on current communications technology developments and how they can be employed by military commanders to achieve or enhance information dominance.

Budget cuts have reduced not only the size of our military forces over the past decade, but have also slowed the procurement of the most modern and capable military equipment. Unfortunately, a corresponding reduction in the size, scope, or complexity of our military's missions has not occurred. Now, more than ever before, we are forced to rely on external resources to make up the resulting shortfalls. Reservists, allies and coalition partners routinely assist us both in combat and in military operations other than war. Civilian air and shipping assets have been called upon to transport troops and equipment to distant military operations because the military cannot afford the luxury of owning these assets on a full time basis. We rely, for similar reasons, on the world's commercial communications infrastructure to transport the vast majority of our military's information.¹ Perhaps most significantly, our future military technological capabilities are increasingly shaped by the efforts of *commercial* research and development programs which target their efforts at *civilian* applications.

Because so many of the world's leading edge technologies are targeted towards non-military applications, it is incumbent upon our military to make every effort to quickly employ appropriate technologies in innovative ways which can multiply our mission effectiveness. As the Pentagon's director for net assessments puts it, "Success lies not in the technologies themselves but in developing the right concepts of operations and organizational structures to best exploit them."² After all, nearly all of these technologies, packaged in commercial products, will quickly become available for purchase by potential adversaries throughout the world. Our failure to recognize innovative military applications could result in adversaries "outgunning" us in the information domain of future conflicts.

The Global Information Infrastructure (GII), a product of multiple national and regional telecommunication infrastructures, continuously grows larger and more sophisticated. These infrastructures are complex, expensive, and constantly changing. Even though they are vital to the success of many of our C4 systems, they are well beyond the ability of our military alone to build or maintain. Because of this dependence, our military leaders must be aware of changes in both the structure and capabilities of the GII.

Strategic and operational level commanders are particularly reliant on telecommunications support for their distant and mobile operations in sometimes remote regions of the world. These commanders usually have a number of redundant but limited communications capabilities available to help establish and maintain C2 in their areas of responsibility. Technological advances in the telecommunications area are about to result in an explosion of new commercial capabilities and services, many of which have obvious military applications. Commanders should be particularly interested in two areas of the current communications revolution. The first involves the improved capabilities of fiber optic transmission systems. The second relates to the new commercial communications satellite constellations about to come on line. Both hold exciting potential for the enhancement of C4 capabilities in both war and operations other than war. Both will also be available to our allies, coalition partners, and adversaries alike. For a number of these potential customers, these services will enable a tremendous increase in their C4 capabilities. In the case of allies, these new technologies could enhance interoperability with our own C4 systems. In the hands of adversaries, these enhanced capabilities will make winning the command and control warfare (C2W) battles increasingly challenging for our own forces.

Fiber Optics

With each passing day, the volume of information available to commanders and staffs continues to increase. It exists in every conceivable format from radio and telephone conversations to e-mail and television. To be of use, this information, once collected, normally needs to be rapidly transported to a location where it can be analyzed, acted upon, or forwarded. Modern military sensors and other intelligence collection products increasingly churn out information which is graphic in nature--often entailing real time video and requiring tremendous bandwidth to transport it. This transport function has become even more important as our forces are projected into far-flung missions throughout the globe--sometimes into areas where the existing telecommunications infrastructure is austere or altogether absent. Complicating the information transport mission is the fact that transmission of pictures and video signals can require 1,000 times the bandwidth of voice transmission (4 MHz vs. 4 KHz).³ The limited capacity of wire cables, radio, and even military communications satellites can quickly be overwhelmed with these volumes and types of information. In the past, much of this information simply wasn't passed through the C2 network because limited capacity would have prevented other important information from being sent. Commercial industry, seizing on the fact that a hair thin fiber optic cable has more than 8,000 times the bandwidth of a "twisted pair" of copper wires, has been working frantically to rewire the world with fiber. Today a commercial fiber optic global infrastructure which reaches most of the developed world is nearly in place.

While this fiber grid has obvious implications for relieving military networks of tremendous volumes of long-haul communications, both past military operations and many

existing C2W plans have incorporated cutting strategic enemy commercial long haul links during hostilities. Such vulnerability may call into question the wisdom of heavy reliance on commercial systems for just this reason. Nevertheless, recent advances in fiber optic transmission technology now have even broader applications for the warfighting CINC. Transmission schemes in commercial use two years ago, achieving 3.4 gigabits per second over a single fiber, are being rendered obsolete by 100+ gigabit per second schemes nearing fielding. Even these rates only achieve five percent of theoretical capacity.⁴ One can easily imagine how fiber could allow commanders and staffs to send nearly everything to everyone--letting users choose the information they want from that made available.

Besides the tremendous bandwidth of optical fiber, there are other qualities which make it an obvious candidate for use by the military. Optical transmission media has little susceptibility to external noise and electromagnetic interference (making jamming difficult) and signals traversing the fiber cannot be intercepted easily.⁵ Use of a tiny portion of its bandwidth for security monitoring allows for instant detection of any penetration, making encryption and its associated key management unnecessary.⁶ Further, they are immune to the destructive effects of high-energy electro magnetic pulse (EMP) and can survive a nuclear explosion. (Gamma radiation will cause the fiber to darken, impeding transmission, but only temporarily.)⁷ Fiber optic can not only withstand temperature extremes, but can withstand proof stresses of nearly 35,000 kg per square centimeter--a "tank can roll over fiber cable without causing damage."⁸ All of these features come in a cable which is a tiny fraction of the size and weight of copper cable. Until recently, however, fiber cable was very difficult to splice together, connect to, and repair. It had also been poorly suited for "short-hop"

applications.⁹ Additionally, it was limited in its ability to carry signals over long distances without the help of repeaters (devices used to amplify or regenerate a signal which has attenuated or faded with distance). Now that these shortfalls have been removed, potential warfighter applications have multiplied considerably.

Our joint doctrine has four fundamental objectives of C4 systems: 1) Produce unity of effort, 2) Exploit total force capabilities, 3) Properly position critical information, and 4) Information fusion.¹⁰ Optical fiber is uniquely suited to assist with all of these objectives by providing faster, improved, and more reliable communications capabilities to the operational commander. By more widely employing fiber optic transmission media and taking advantage of its tremendously increased information carrying capabilities, our military can better achieve its objectives.

Fiber optic technology has now improved sufficiently to allow ships and submarines to use it to communicate with each other and shore-based forces. One proposal under study would outfit ships with spools of fiber allowing them to communicate with the shore over a distance of about 200 kilometers.¹¹ Such communication links would enable huge quantities of all formats of information to pass back and forth in a secure mode without the possibility of giving away positions the way radio signals can.

Similarly, tanks on the battlefield could be tethered to command and control stations up to 50 kilometers behind them. This would allow real time audio and video intelligence updates in both directions and significantly contribute to the achievement of dominant battlefield awareness. This concept is not new--it was used during World War II with copper wire spooled from tanks.¹² Unlike earlier applications, fiber optic's bandwidth capabilities

could allow us to pass live images from tank mounted cameras to points anywhere in the world. Thus, live front-line images and reconnaissance could be passed to operational commanders while front line troops would be able to receive the latest data available on friendly and enemy positions and objectives. The secure nature of this jam-resistant media would simultaneously contribute to our own "C2 protect" aspects of C2W.

For especially fluid battlefield situations, missiles carrying spools of thin fiber optic cable could be fired (from command ships or ground locations) in the direction a commander wanted to extend communications to. Ground troops could rapidly splice the end of the arriving cable to a co-located tactical communications node for secure connectivity. Alternatively, helicopters could spool the cable nearly as rapidly if, for example, the cable had to terminate at a precise location such as a command ship or submarine.

Of course fiber-based networks alone will not solve every commander's communications problems. Rather, they will play an important role in providing redundancy and reliability, making C4 systems more responsive and flexible. Conversely, for counter C2 planning, we must be cognizant of this capability among adversaries. There is now no technical reason an enemy needs to rely heavily on commercial fiber optic lines alone when military versions can be quickly emplaced. The key point is, as one army general puts it, "You don't put all your communications in one basket."¹³ Another "basket" worth looking at contains commercial communications satellites.

Commercial Communications Satellites

Because of their ability to place a communications infrastructure over any land or sea mass on the globe, satellites have played an increasingly important role in C4 systems.

During the Gulf War, more than 90 percent of U.S. communications were supported by satellite.¹⁴ Because of limited military capacity, approximately one-quarter of satellite capacity used by the coalition was provided over commercial spacecraft.¹⁵ As funding for additional military satellites dries up, future military demand for such services will continue to increasingly overwhelm the capacity of our aging military satellites. One potential solution to this can be found in a number of commercial communications satellite constellations coming on line within the next few years. In addition to a number of foreign projects, at least seven U.S. companies have such multibillion dollar constellations under construction.¹⁶

Unlike previous generations of commercial satellites typically placed in geostationary (GEO) orbit 19,300 miles above sea level, many constellations now under construction will be placed in Low Earth Orbit (LEO). Orbiting as close as 420 miles above the Earth, these satellites will be able to offer Personal Communication Services (PCS) via small, cellular-like telephones. Large antennas and power supplies, necessary for connectivity with distant GEO satellites, will not be needed to place or receive calls via the much closer LEO satellite constellations. Unlike cellular phones, satellite telephones can also be operated from aircraft flying at high altitude. The LEO constellations are also capable of global coverage whereas a lone GEO satellite, positioned above the equator, is incapable of connectivity with latitudes beyond approximately 70 degrees nor the nearly 70 percent of the Earth which isn't within the satellite's line of sight.

The LEO constellations are commonly divided into two groups based on the frequency ranges used in their communication links. The first group, known as "little LEO"

systems, use the band of frequencies below 1 GHz. This frequency range is well suited for low data rate transmission and, accordingly, supplies services such as paging, remote sensor reading, cargo tracking, and e-mail. The "big LEO" systems operate in the 1-3 GHz portion of the electromagnetic spectrum, a range capable of supporting high data transmission rates. Although primarily designed to support voice traffic, services such as video teleconferencing would also be possible.

Little LEO systems would seem obvious candidates for tracking the current location of friendly force vehicles, ships or other mobile assets. Their ability to remotely monitor other sensors, measuring anything from water levels to temperatures, could also have military applications. The 36-satellite Orbcomm constellation will begin offering commercial service this month (February 1996). Service, however, will be intermittent until the complete constellation is in place in mid-1997.¹⁷

Big LEO constellations offer much more capability and tremendous potential for military use. They will offer the potential to assign units, commanders, and staffs with telephone numbers which will never need to change to be effective anywhere on or above the surface of the earth. As communications systems go, these commercial communications services arguably go further toward meeting many principles of C4 (interoperable, flexible, responsive, mobile, disciplined, survivable, and sustainable) than our myriad of military systems do. Satellite telephony would seem an ideal asset in immature theaters or for military operations other than war.

Most impressive of big LEO constellations, and nearest completion, is Motorola's Iridium system. The Iridium constellation, with full services available in mid-1998, will be

able to operate completely independently of ground stations. With 66 primary and 9 spare satellites, this constellation will be the most technologically advanced and expensive of the constellations nearing completion. On board switching and intersatellite links will enable two subscribers to communicate with each other from any location without the need for the circuit to pass through terrestrial links.¹⁸ Strategic connectivity would instantly be available for any operation.

Adding to redundancy and reducing costs through competition will be other new big LEO constellations. The 48-satellite Globalstar constellation will offer full services in mid-1998. Odyssey, a 12-satellite constellation in a slightly higher Medium Earth Orbit (MEO) will begin full service later that same year. Both of these services will also offer complete global coverage and expect to charge retail customers less than a dollar per minute.¹⁹

Complementing these constellations in 1998 will be additional GEO satellites providing regional coverage for much of Asia and Africa. Because of their high orbit, most of these systems will only be of use to those with links to ground stations powerful enough to communicate with these satellites. Nevertheless, they could provide tremendous additional C2 capability to those regions of the globe.

Further into the future, at least nine U.S. companies have applied to build satellites using a portion of the spectrum known as the Ka-band. Operating at frequencies above 28 GHz, these primarily GEO systems will be capable of much faster data rates. The sole non-GEO system will be an 840-satellite LEO constellation known as Teledesic. Backed by Microsoft's Bill Gates and cellular phone entrepreneur Craig McCaw, the system will focus on high data rate services between fixed Earth stations. Federal Communications

Commission (FCC) licenses for all of these systems will likely be granted in late 1996.²⁰ Services could possibly be offered within 2-5 years from license approval. Because of their orbits or design, they will not offer the convenience of hand-held communications devices. However, like all commercial GEO satellites, they have tremendous potential for economically transporting growing volumes of military communications traffic in the future.

Unlike military satellites, such as those in the Milstar program, this new generation of commercial communications satellites will be highly susceptible to Electronic CounterMeasures (ECM), ElectroMagnetic Pulse (EMP), and attack from anti-satellite satellites or high-energy lasers. Most will rely on vulnerable ground stations for completing circuits. Still, as our military satellites age, modern commercial systems may very well become relatively more capable.

Conclusion

As commercial telecommunications technology advances, it represents an increasingly valuable resource to theater commanders who are constrained in their organic ability to transport growing volumes of information. Commanders who deploy forces to immature theaters in remote regions can particularly benefit from commercial communications assets available today or in the very near future. In many cases, interoperability of key C2 networks will be enhanced between services, allies, and even ad-hoc coalition partners.

These new technologies not only impact how much one's own capabilities can be protected or improved upon, but also how much an enemy's information processes or systems can be degraded. These are, after all, commercial systems which adversaries can easily acquire. Even third-world adversaries, using inexpensive satellite telephony, will

significantly reduce the degree of relative information superiority our advanced C4 systems have traditionally provided. These near-future capabilities will impact our warfighting CINC's and need to be planned for now.

NOTES

1. William Matthews, "Susceptible to Sabotage," Army Times, February 5, 1996, p. 28.
2. John D. Morrocco, "U.S. Military Eyes Revolutionary Change," Aviation Week & Space Technology, May 1, 1995, 22.
3. William Stallings, Data and Computer Communications, 3rd ed. (New York: Macmillan, 1991), 45-48.
4. "The Last Frontier--Researchers Explore Fiber's Outer Reaches," Scientific American, March 1994, 105.
5. "Optical Transmission Media Stimulate High Growth Rate," Signal, February 1994, 53.
6. "Command Control Roadmap Begins With User Integration," Signal, May 1994, 59.
7. John McDermott, "Fiber Weaves New Thread in Battlefield Messaging," Signal, November 1991, 47.
8. Stefan Geisenheyner, "Fiber Optics in Military Communications," Armada International, August-September 1990, 12.
9. "Paving the Information Superhighway With Plastic," Science, March 31, 1995, 1921.
10. U.S. Joint Staff, Joint Pub 6-0, Doctrine for Command, Control, Communications, and Computer (C4) Systems Support to Joint Operations, (Washington, D. C., 1995) I-6.
11. Pat Cooper and Robert Holzer, "DoD Eyes Satellite Alternative," Space News, August 7-13, 1995, 28.
12. *ibid.*
13. Robert K. Ackerman, "Coordinated Modernizations Spur Army Communications," Signal, November 1993, 34.
14. Dale R. Hamilton and Walter G. Green, "Space and Power Projection," Military Review, November 1994, 64.

15. John Williamson, ed., Jane's Military Communications 1994-95, (Surrey, UK: Jane's Information Group, 1994), 3.

16. Joseph Kahn, "Chinese Choose Hughes to Build Satellite System," The Wall Street Journal, February 9, 1996, B3:4.

17. Patrick Seitz, "Orbcomm Resets Debut," Space News, October 9-15, 1995, 8.

18. Joseph C. Anselmo, "'Big LEO' Competitors Racing Toward Launch," Aviation Week & Space Technology, July 17, 1995, 61.

19. *ibid.*

20. James R. Asker, "Corporate Titans Vie for Satcom's Future," Aviation Week & Space Technology, October 9, 1995, 24-25.

Bibliography

- Ackerman, Robert K. "Coordinated Modernizations Spur Army Communications," Signal, November 1993, 31-35.
- Anselmo, Joseph C. "'Big LEO' Competitors Racing Toward Launch," Aviation Week & Space Technology, July 17, 1995, 61.
- Arquilla, John. "The Strategic Implications of Information Dominance," Strategic Review, Summer 1994, 24-30.
- Asker, James, R. "Commercial Growth Key to Space Sector," Aviation Week & Space Technology, March 13, 1995, 97.
- _____. "Corporate Titans Vie for Satcom's Future," Aviation Week & Space Technology, October 9, 1995, 24-26.
- _____. "U.S. to Seek More Spectrum," Aviation Week & Space Technology, May 22, 1995, 49.
- Canan, James W. "Forward into Outer Space," Sea Power, September 1995, 38-42.
- "Command, Control Roadmap Begins With User Integration," Signal, May 1994, 59-60.
- "Competitive Factors Sway World Optical Fiber Market," Signal, February 1994, 59.
- Cooper, Pat and Holzer, Robert. "DoD Eyes Satellite Alternative," Space News, August 7-13, 1995, 1, 28.
- deSelding, Peter B. "Military Officials Open to Using Civilian Links," Space News, August 7-13, 1995, 6.
- _____. "Mobile Phone Woes," Space News, July 3-9, 1995, 1.
- Fay, Kristin K. "Switch Could be Solution in Communications Crisis," Signal, January 1992, 42-45.
- Geisenheyner, Stefan. "Fiber Optics in Military Communications," Armada International, August-September 1990, 8-14.
- Hardy, Stephen M. "Should We Fear the Byte Bomb?," Journal of Electronic Defense, January 1996, 42-48.

- Hamon, Dale R. and Green, Walter G. "Space and Power Projection," Military Review, November 1994, 61-66.
- Harris, Larry. "Radio-frequency Spectrum is a Precious Resource," Army Communicator, Fall 1995, 48-49.
- "Information Dominance Edges Toward New Conflict Frontier," Signal, August 1994, 37-40.
- Johnson, Jerry D. "Fiber Optics Enhance Secure Telephone Use," Signal, April 1994, 60.
- Kahn, Joseph. "Chinese Choose Hughes to Build Satellite System." The Wall Street Journal, February 9, 1996, p. B3:4-5.
- LaPrade, Nicholas. "Communications," Aerospace America, December 1995, 38.
- "The Last Frontier--Researchers Explore Fiber's Outer Reaches," Scientific American, March 1994, 105-106.
- Laughridge, Gene. "Recent and Not-So-Recent Thinking on Information Operations and the Knowledge War," Army Communicator, Spring/Summer 1995, 32-38.
- Linton, Debbie. "The Army's Vision of Satellite Communications," Army Communicator, Fall 1995, 4.
- Matthews, William "Susceptible to Sabotage," Army Times, February 5, 1996, p. 28.
- McDermott, John. "Fiber Weaves New Thread in Battlefield Messaging," Signal, November 1991, 45-47.
- Morocco, John D. and Hughes, David. "Tight Budgets Force Innovative Strategies," Aviation Week & Space Technology, March 13, 1995, 56.
- Morocco, John D. "U.S. Military Eyes Revolutionary Change," Aviation Week & Space Technology, May 1, 1995, 22-23.
- Nordwall, Bruce D. "Mitre Study Favors Medium-Earth Orbits," Aviation Week & Space Technology, May 22, 1995, 53.
- "Optical Transmission Media Stimulate High Growth Rate," Signal, February 1994, 53-55.
- Owens, Admiral William A. "The Emerging System of Systems," Military Review, May-June 1995, 15-19.

- "Paving the Information Superhighway With Plastic," Science, March 31, 1995, 1921-1922.
- "Photonics Research Quests Imbue Myriad Service Uses," Signal, February 1992, 35-39.
- Robinson, Clarence A. "Defense Organization Safeguards War Fighters' Information Flow," Signal, October 1995, 15-18.
- Scott, William B. "Iridium on Track for First Launch in 1996," Aviation Week & Space Technology, April 3, 1995, 55.
- Seitz, Patrick. "Orbcomm Gets Scrutiny," Space News, April 24-30, 1995, 1.
- _____. "Orbcomm Resets Debut," Space News, October 9-15, 1995, 8.
- Stallings, William. Data and Computer Communications. 3rd ed. New York: Macmillan, 1991.
- Stewart, MG John F. "Command and Control Warfare and Intelligence on the Future Digital Battlefield," Army Research, Development and Acquisition Bulletin, November-December 1994, 14-15.
- Sullivan, General Gordon R. and Dubik, James M. "War in the Information Age," Military Review, April 1994, 46-62.
- U.S. Joint Staff, Joint Pub 6-0, Doctrine for Command, Control, Communications, and Computer (C4) Systems Support to Joint Operations, Washington, D. C., 30 May 1995.
- Walsh, Edward J. "The Copernican Revolution," Armed Forces Journal International, July 1995, 40-42.
- "'Weather' Forecasters Work on Higher Plane," Aviation Week & Space Technology, September 18, 1995, 49.
- Webb, R. C., and others. "The Commercial and Military Satellite Survivability Crisis," Defense Electronics, August 1995, 21-25.
- Williamson, John, ed. Jane's Military Communications 1994-95. Surrey, UK: Jane's Information Group, 1994.
- "Wireless Secure Electronic Mail Reaches the Warrior," Signal, December 1995, 33-36.