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NETWORKING REQUIREMENTS AND FUTURE ALTERNATIVES

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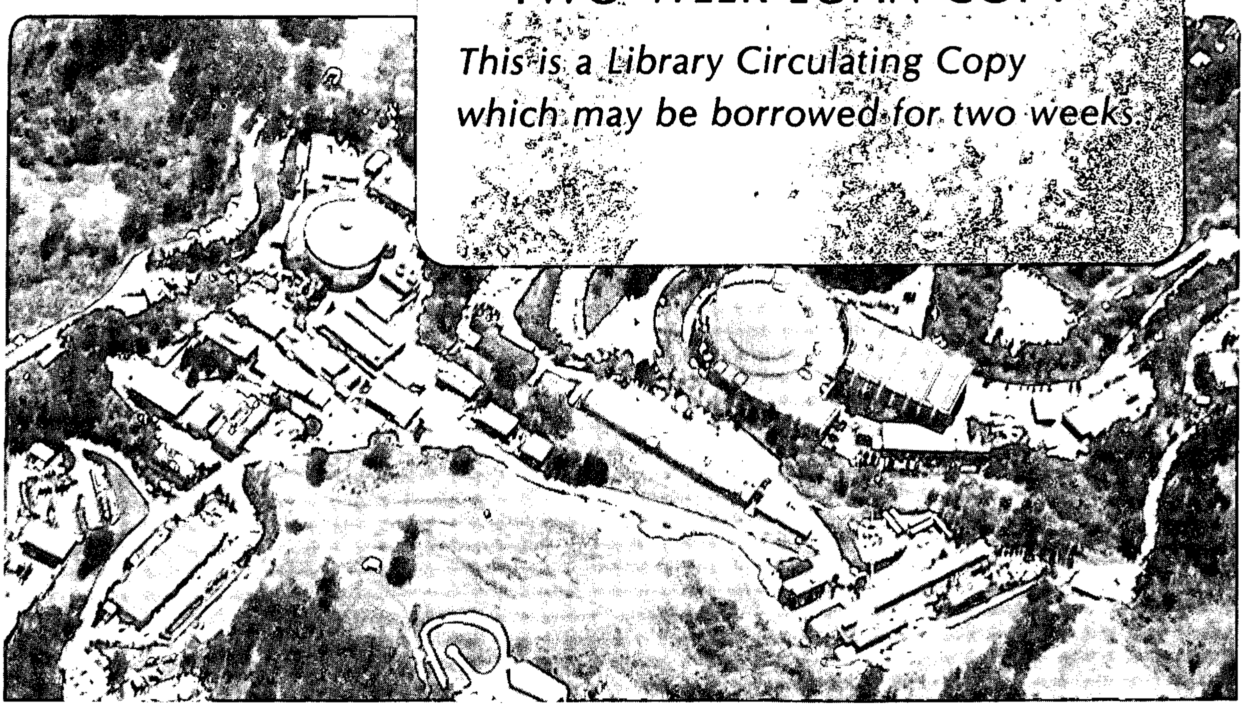
June 1987



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DISCLAIMER

NETWORKING REQUIREMENTS AND FUTURE ALTERNATIVES

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1. NETWORKING REQUIREMENTS AND FUTURE ALTERNATIVES

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Abstract

The Working Group on Networking Requirements and Future Alternatives recommends creation of an international, interagency networking facility for science, whose 15-year mission is

- *to ensure that U.S. scientists have available the most advanced wide area networking facilities in the world, and*
- *to ensure that U.S. wide area network technology maintains a position of world leadership.*

A minimum of 1.5-Mbit/s access to major government and academic research centers should be provided. Such a network would greatly benefit the competitive position of the United States in scientific research. It would also place the U.S. in a leadership position in utilization of high bandwidth, wide area networks. United States industries supporting wide area network technologies would gain a significant competitive advantage over other countries. An ongoing program of research and development into both wide area network technology and network management is necessary for this endeavor to be successful.

As part of the second year study, the Working Group recommends that an interagency coordinating committee be established to identify short-term implementation issues that can be investigated and resolved in parallel with long-term issues. This would provide immediate benefit to the nation's scientific community.

1.1. BACKGROUND

Many scientific research facilities in the U.S. consist of a single, large, and costly installation such as a synchrotron light source, a supercomputer, a wind tunnel, or a particle accelerator. These facilities provide the experimental apparatus for groups of scientific collaborators located throughout the country. The facilities cannot be duplicated in all states because of cost. Wide area networks are the primary mechanism for making such facilities available nationwide. Examples include government-supported wide area networks such as ARPANET, HEPnet, MFENET, MILNET, NASnet, NSFnet, SPAN, and so on, as well as commercial facilities such as Tymnet, BITNET, and AT&T leased lines. The cost of such networks is generally much less than the cost of the research facility.

Congress recently enacted legislation calling for an investigation of the future networking needs over the next 15 years for the nation's academic and federal research computer programs. The Federal Coordinating Council on Science, Engineering and Technology (FCCSET) formed a Network Study Group to coordinate investigation of the benefits, opportunities for improvements, and available options with particular attention to supercomputing. Within the Network Study Group, the Working Group on Network Requirements and Future Alternatives was formed to identify network demand during the next 5 years and to recommend a strategy for meeting that demand. This document is the Working Group's report.

1.2. APPROACH

The following approach was taken.

- The networking plans of the U.S. research community were analyzed, so that a 5-year network demand summary can be created.
- Corporations that provide telecommunications services were surveyed, with particular attention to the possible use of fiber optics and related cost/capacity gains.
- Issues related to interagency sharing of network facilities were identified.
- Alternative methodologies for meeting total network demand were considered.
- A 5-year networking strategy was developed and presented to the FCCSET Network Study Group.

1.3. NETWORK DEMAND SUMMARY

Four methods of estimating network demand were used.

- **Analysis of existing network utilization:** Wide area networks are used by scientists to access unique remote facilities (supercomputers, accelerators, analysis software, and databases) and as a critical mechanism for communication and coordination among the large geographically distributed U.S. and international scientific collaborations (Figure 1 and Section 1.9). High-speed local area networks are being connected to low-speed wide area networks throughout the research community. Communication speeds of 1.5 Mbit/s, digital data service (DDS), and packet networks have been introduced to wide area networks, and their use has become widespread. Nevertheless, wide area networking capacity has not kept up with the capacity of local area networks. Some wide area networks handle both high data volume and highly interactive traffic over the same communications links. This results in suboptimal performance. At the functional level, wide area network user interfaces have not kept up with their counterparts in local area networks.

  The Working Group heard presentations of current and planned networking in the Department of Defense, Department of Energy, National Aeronautics and Space Administration, and the National Science Foundation (NSF). Many scientific research centers funded by these agencies are physically connected to more than one network. The backbones for the major networks are similar in topology, and existing network links throughout the community are generally fully utilized. Some of these networks are severely overloaded, resulting in significant performance degradation. Additionally, more ubiquitous access is needed by the university research community, especially at smaller institutions. For example, there is a clear unmet need for nationwide, high-speed access to large scientific databases. The Working Group noted that in many cases demand for capacity seriously exceeded current supply.[1-3]

- **Estimation based on typical site:** A direct estimation of network demand was made using a major NSF university site as a basis. Network usage included wide area network facilities for supercomputer access as well as an extensive local area network. An absolute level of network demand for the next 5 years was estimated using three different models: task, user, and external flow. The task model focused on the network load generated by typical network tasks. The user model identified demand as a function of typical university network users. The external flow model centered on the university as an entity and estimated networking demand between it and other external locations. The three values of predicted network traffic were in agreement within an order of magnitude. They indicated a thousandfold increase in needed capacity over current network resources.[4]

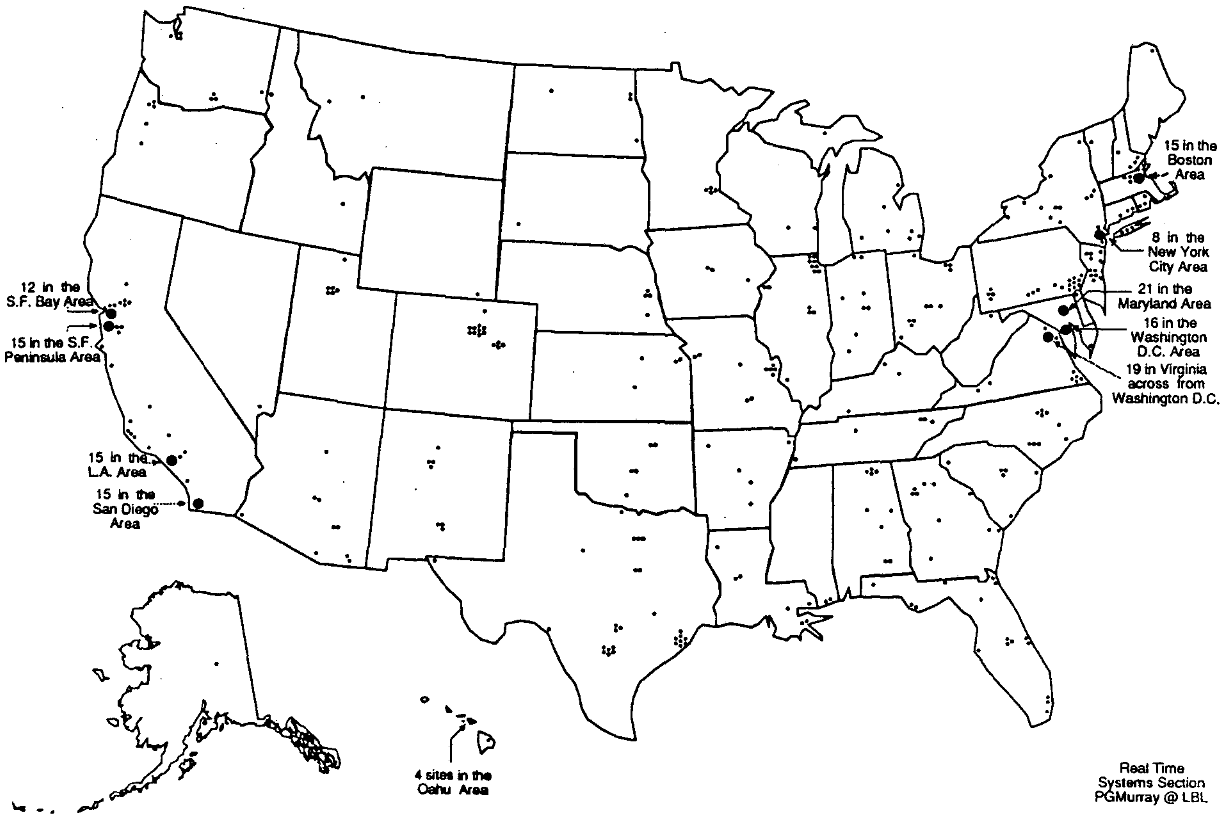


Figure 1. Principal networking sites - see Section 1.9 for a listing

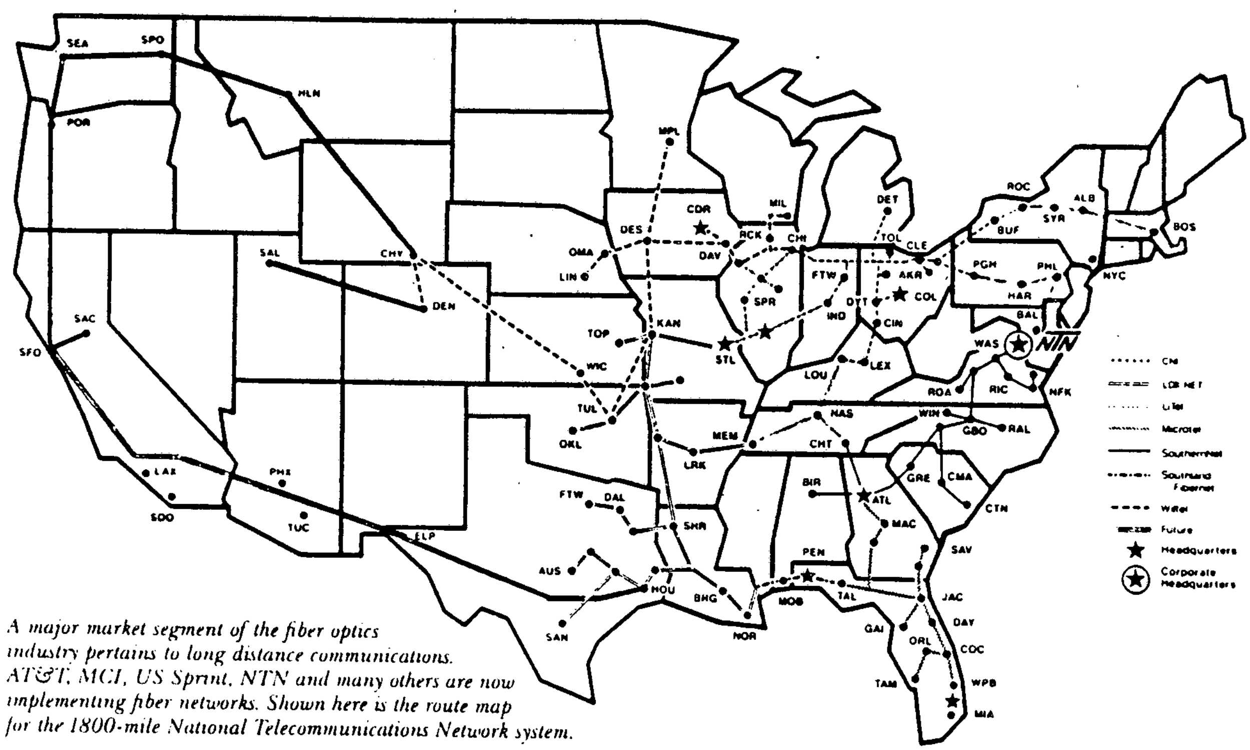
- **Extrapolation from experience with local area networks:** This method also projected need for a thousandfold increase in wide area network capacity over the next 5 years. A remote supercomputer access scenario was presented to demonstrate how network transparency can increase the speed and accuracy with which engineering decisions can be made. It was argued that one order of magnitude is needed to create a nationwide distributed file system on an existing 56-kbit/s network; another order of magnitude is needed to provide interactive monochrome graphics[5, 6] and a third order of magnitude is needed to accommodate expected increases in basic computer speeds. As more users are added, further increases in demand are anticipated.
- **Estimation based on expanded user community:** The above analyses estimate load increases for existing network topologies. There is an important additional need to extend network service to the smaller universities throughout the nation. This would add another factor of 2 to 3 to the above estimates. Since by definition these research sites are not currently connected to an existing wide area network, this represents a demand for more communications lines rather than an increase in line speeds.[1]

There is a further need to extend network service to international sites. Access to overseas scientific collaborations would significantly enhance the quality of U.S. science by providing researchers with access to remote experimental apparatus, data, and personnel. It would also enhance U.S. prestige in the scientific research community by providing overseas collaborators with access to U.S. facilities, data, and personnel. The effect on network traffic would be negligible, but network size would be increased dramatically.

1.4. SUPPLY

Several major U.S. telecommunications corporations were represented on the panel. They jointly provided a summary of expected industry-wide technological trends over the next 5 years.[7-10] Cost/capacity forecasts and opportunities for use of fiber optic technology in the U.S. scientific research community were also presented.

The leading trends in U.S. telecommunications technology are the decreasing cost of component materials and the widespread, though not ubiquitous, availability of fiber optics (Figure 2). The transport capabilities of the U.S. telecommunications industry will greatly increase during the next 5 years, as witnessed by the following observations. Packet switching rates are expected to rise to 10,000 packets per second (25 Mbit/s). Digital circuits are widely available at 56 kbit/s today. Within the next 5 years, Integrated Services Digital Network (ISDN) switched and nonswitched circuits ranging from 64 kbit/s to 1.5 Mbit/s will be available in the larger metropolitan areas of the U.S. The digital interexchange transmission rates available to users are at 1.5 Mbit/s in general and will rise to 45 Mbit/s between larger metropolitan areas. Services of 150 Mbit/s could be made available by special arrangement. ISDN 64-kbit/s service will be present in about 20% of the U.S. market by the end of the 5-year period. The ability of the user to customize service (such as time of day conversion and simultaneous coordinated voice and data), as well as the availability and general use of applications services (such as X.400 mail and electronic document interchange) will dramatically increase.



A major market segment of the fiber optics industry pertains to long distance communications. AT&T, MCI, US Sprint, NTN and many others are now implementing fiber networks. Shown here is the route map for the 1800-mile National Telecommunications Network system.

Figure 2. Fiber optic network links.[11]

Fiber optic technology is driving media costs downward. The cost of basic private line telecommunications services could fall by a factor of 20% to 50% during the upcoming 5 years. Any expectation that fiber would more dramatically reduce costs to the typical telecommunications user must be balanced by the recognition that the fiber itself is only one component of total transmission service cost.

It was recognized that the combination of fiber optic technology and the large amount of aggregate interagency demand may offer the scientific research community unique opportunities to acquire increasingly cost-effective bandwidth. This is only possible in the case of a long-term lease of very high bandwidth circuits. This ensures industry recovery of capital investment costs. If such a national network infrastructure were established as a long-term interagency goal, migration to such a topology is possible using existing standard telecommunications technologies, including satellite, microwave, copper, and fiber optic transmission media.

1.5. ALTERNATIVES

1.5.1. Supplying Capacity

The need to increase wide area network capacity by a thousandfold is justified both by increased opportunities for scientific breakthroughs and by the need to maintain the nation's position of world leadership in wide area network technology. Although industry projections indicate the necessary bandwidth will certainly be available as a national backbone, the required bandwidth will not be available all the way to the end user's site. The Working Group felt the most cost-effective way to proceed would be to provide the needed bandwidth in stages.

The Working Group recognized that a factor of 30 improvement could be achieved simply and cost effectively by:

(1) tuning existing protocol implementations and managing access,

(2) installing smarter congestion control algorithms,

(3) upgrading existing 56-bit/s trunks to 1.5- and 45-Mbit/s lines in a judicious manner, and

(4) providing type-of-service routing for efficient performance on high data volumes as well as highly interactive traffic.[3]

Beyond that, another factor of 30 is needed to meet the projected demand. The Working Group identified two promising approaches:

(1) develop more optimal distribution of network services between user systems and server systems to make more efficient use of the available bandwidth, and

(2) develop powerful gateway computers that compress data entering wide area networks and decompress the data at its destination. Such machines could also provide encryption without significant additional overhead.

The two approaches are entirely complementary. Thus, each might contribute a factor of 5 or 6, for a combined factor of 30. However, optimal distribution software is not available today, and data compression computers are only available for video compression. Therefore, applied research in these and other promising approaches is required.

1.5.2. Improved Usability

The Working Group agreed that an interagency, international network would significantly enhance the U.S. scientific research environment. To ensure ease of use, some peripheral issues must be addressed.

- **Global management and planning**: The ARPANET provides valuable experience in operating connected networks without global management. For example, ARPANET management reported that traffic generated by external networks created internal performance problems that are unmanageable. Similarly, inefficient protocol implementations cannot be prevented, since no central authority exits. This results in reduced network performance for all users. ARPANET management concluded that global management is essential to provide guaranteed performance. The Working Group agreed with this conclusion.
- **User services**: Consulting help and documentation are necessary for any facility accessed directly by end users. However, most scientists are not interested in networks per se, but only in the resources they make available. If a network could be made transparent or nearly so, the need for consulting help and documentation would be significantly reduced.
- **Reliability**: A wide area network in scientific research must be more reliable than many existing networks because of its critical role in supporting operation of remote experiments.
- **Extensibility**: The network will grow significantly in the next 15 years. It must be possible to expand it incrementally and to join it with other networks, both national and international.
- **Evolutionary**: To prevent obsolescence, the network must be tolerant of change. It must be designed in such a way that new protocols and services can be added without significantly disrupting existing services. This ensures the nation's scientists will keep a competitive edge in advanced networking technology. The rich environment for development of new products ensures that the technology itself maintains a competitive edge.

1.6. CONCLUSIONS

Five major conclusions about future networking requirements were drawn by the working group.

(1) An interagency scientific network facility should be created whose 15-year mission is

- to ensure that U.S. scientists have available the most advanced networking facilities in the world, and

- to ensure that U.S. wide area network technology maintains a position of world leadership.

(2) A phased implementation plan should be developed to provide these advanced network facilities to the nation's scientists. Rough guidelines should be to increase the effective capacity of existing networks tenfold in 3 years, a hundredfold in 5 years, and a thousandfold in 10 years.

- Existing wide area scientific networks should be overhauled to provide 56-kbit/s service to end users at about 30% of maximum load. Trunk lines of 1.5 to 45 Mbit/s would be necessary in some areas to provide the needed bandwidth to end users. Existing protocol implementations should be checked and tuned to eliminate unnecessary congestion from inefficient implementations. Networks from all U.S. government agencies funding academic and federal scientific research would be upgraded.

- Modern networking facilities such as wide area network file systems, distributed scientific databases, distributed window systems, and distributed operating systems should be developed and installed, along with facilities for users to find and use network resources from remote sites. Existing communications facilities should be upgraded tenfold to 1.5 Mbit/s to end users as necessary to handle anticipated increases in load. Very high bandwidth trunk lines may be necessary in some areas to provide the needed 1.5-Mbit/s service to end users.

• More advanced facilities such as wide area color graphics capabilities and remote control of experiments should be developed and introduced. Existing communications capacity should be upgraded tenfold to handle the load increase by using hardware and software technology developed as a result of applied research.

• To handle an anticipated increase in hardware speeds, existing communications links should be upgraded another tenfold as newer and faster computers become available in the mid 1990s.

• New local area network facilities should be tracked so that the more promising new products can be made available in wide area networks.

• Coverage should be expanded so that most colleges and universities in the U.S. will have access to the network in 5 years, with the remainder having access in 10 years.

(3) An applied research and development program in advanced communications and network techniques should be implemented to provide the following.

• Provide the technology needed to increase the effective bandwidth of communications links would involve

- more optimal distribution of functions between local hosts and remote hosts to minimize the need for raw network bandwidth,

- high-performance systems that compress data entering a wide area network and decompress it at its destination,

- development of gateway technology in general, and

- utilization of formal language theory and other innovative techniques to design components that fail in a diagnosable manner.

• Provide better ways to access remote resources that are needed to increase opportunities for scientific breakthroughs. Local area networks are the only cost-effective testbed for such facilities today. As capacity of wide area networks increases, a new source for network innovations can be expected to emerge.

• Provide better tools and techniques for management of networks as needed.

(4) An ongoing basic research program into future network architectures to ensure continued leadership in use of scientific networks, as well as national leadership in wide area network technology, is necessary.

(5) The panel recommends that issues of network design, cost analysis, management authority, and implementation be addressed by the second year study. Within this framework, an interagency coordinating committee should be established to identify issues that can be investigated and resolved in the short term. An important short-term issue is implementation of the first factor of 30 improvement to existing networks. This can provide immediate benefit to the nation's scientific community.

1.7. BENEFITS

Implementation of the above recommendations would provide the U.S. scientific research community with a significant competitive advantage. Modernization of the nation's wide area networks by increasing speed, functionality, and size increases opportunities for research advances significantly.[5, 6] Greater network speed can reduce the time required to perform a given experiment and increase both the volume of data and the amount of detail that can be seen. Scientists accessing supercomputers would benefit particularly, because access speed is often critical in this work. Improved functionality frees scientists to concentrate directly on their experimental results rather than on operational details of the network. Increased network size extends these opportunities to tens of thousands of individuals located at smaller academic institutions throughout the nation. These modernization measures would significantly enhance the nation's competitive edge in scientific research.

The components of a shared network infrastructure would obviously benefit from global management, and the positive effects of such an approach would be widespread. Centralized administration of research in wide area networks would minimize duplication of effort and provide rapid resolution of identified high-priority problems. A global management structure would also allow a matrix approach to this distributed network expertise.

The U.S. communications industries would also gain a significant competitive advantage. Development of modern, low-cost distributed computing facilities for wide area networks would help maintain the United States position of world leadership in networking technology. Use of these products in support of science would accelerate the development of newer products by U.S. industry to meet challenges from both Europe and Japan. The United States would thus gain a position of world leadership in utilization of wide area, high bandwidth networks. This would increase the nation's competitive edge in communications technology as well as scientific research. As a spinoff, it would help maintain the U.S. leadership position in computer architectures, microprocessors, data management, software engineering, and innovative networking facilities.

1.8. WORKING GROUP PARTICIPANTS

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Stan Ruttenberg
University Corporation for Atmospheric Research

David Stevens
Lawrence Berkeley Laboratory

Bob Wilhelmson
National Center for Supercomputing Applications

1.9. PRINCIPAL NETWORKING SITES

This list was compiled by the Lawrence Berkeley Laboratory, Informations and Computing Science Division.

Alabama
- Anniston Army Depot
- Army Aeromedical Research Laboratory, Fort Racker
- Army Missile Command
- Army Safety Center
- George C. Marshall Space Flight Center
- Gunter Air Force Station
- Maxwell Air Force Base
- University of Alabama, Birmingham
- University of Alabama, Huntsville

Alaska
- University of Alaska, Anchorage
- University of Alaska, Fairbanks

Arizona
- Arizona State University, Tempe
- Davis Monthan Air Force Base
- Army Information Systems Command, Fort Huachuca
- Army Small Computer Engineering Center, Sierra Vista
- Army Yuma Proving Ground
- Kitt Peak Observatory
- Luke Air Force Base
- United States Geological Survey Astrogeology
- University of Arizona, Tucson

Arkansas
- Blytheville Air Force Base, Blytheville
- University of Arkansas, Fayetteville
- University of Arkansas, Little Rock
- University of Arkansas, Monticello
- University of Arkansas, Pine Bluff

California
- AMPC
- Advanced Computer Communications
- Advanced Decision Systems
- Aerospace Corporation
- Air Force Systems Command
- AMES Research Center
- Army DARCOM Logistic Control Activity
- Beale Air Force Base
- California Institute of Geology and Planetary Science
- California Institute of Technology
- Digital Equipment Corporation
- Dryden Flight Research Facility
- Eaton Corporation
- Edwards Air Force Base
- Electronic Data Systems
- Energy Applications & Systems
- Fleet Analysis Center
- FMC Corporation
- GA Technologies, Inc.
- George Air Force Base
- GTE TELENET Communication Corp.
- Headquarters, 6th Army, Presidio of San Francisco
- Institute for Advanced Studies
- IntelliCorp
- ITT/Federal Electric Corporation
- Jaycor
- Jet Propulsion Laboratory
- Kestrel Institute
- La Jolla Institute
- Lawrence Berkeley Laboratory (LBL)
- Lawrence Livermore National Laboratory (LLNL)
- Letterman Army Institute of Research
- Lockheed Palo Alto Research Laboratories
- Logicon, Inc.
- Los Angeles Air Force Station
- March Air Force Base
- Mare Island
- Mather Air Force Base
- McClellan Air Force Base
- McDonnel Douglas Computer Systems Company
- NAS North Island
- NASA Resident Office
- National Aeronautics and Space Administration
- Naval Air Station, Alameda
- Naval Ocean Systems Center
- Naval Personnel Research and Development Center
- Naval Post Graduate School
- Naval Sea Systems
- Naval Technical Training Center
- Naval Weapons Center
- Navy Elex Systems Engineering Center
- Navy Regional Automated Services Center
- Navy Supply Center
- Norton Air Force Base
- Presidio of San Francisco
- Rand Corporation
- Salk Institute
- San Diego State University
- San Diego Supercomputer Center
- Sandia National Laboratory - Livermore
- Schlumberger Caslab
- Science Applications Inc. - La Jolla
- Science Applications Inc. - Pleasanton
- Scripps Clinic and Research Foundation
- Scripps Institute of Oceanography
- Southwest Fisheries Center
- Stanford Research Institute International (SRI)
- Stanford Linear Accelerator Center
- Stanford University
- SUN Microsystems
- System Development Corporation
- Teknowledge, Incorporated
- Travis Air Force Base
- TRW Inc., Los Angeles
- University of California, Berkeley
- University of California, Davis
- University of California, Irvine
- University of California, San Diego
- University of California, San Francisco
- University of California, Santa Barbara
- University of California, Santa Cruz
- University of Southern California, Los Angeles
- University of Southern California, Marina Del Rey
- Vandenberg AFB
- Xerox Corporation

Colorado
- JILA
- Lowry Air Force Base

National Bureau of Standards
National Center for Atmospheric Research
Colorado State University
Ford Aerospace and Communications
Martin-Marietta Denver Aerospace
National Oceanic and Atmospheric Administration
Peterson Air Force Base
Science Applications Inc.
Solar Energy Research Institute (SERI)
University of Colorado
U.S. Air Force Academy
U.S. Army, Fort Carson

Connecticut
- Naval submarine School
- Naval Underwater systems Center
- Yale University, New Haven

Delaware
- University of Delaware

District of Columbia
- Andrews Air Force Base
- Bolling Air Force Base
- Defense communications Agency
- Defense Mapping Agency
- George Washington University
- NASA Headquarters
- National Bureau of Standards
- National Science Foundation
- Naval Electronics Systems Security Engineering Center
- Naval Research Laboratory
- Navy Regional Data Automation Center
- USAEASA
- U.S. Air Force, Pentagon
- U.S. Department of Energy
- U.S. Headquarters for the Department of the Army
- Walter Reed Army Institute of Research

Florida
- Eglin Air Force Base
- Fleet Training Center
- Florida State University, Tallahassee
- Homestead Air Force Base
- Internet Systems Corporation
- Interscience, Inc.
- John F. Kennedy Space Center
- MacDill Air Force Base
- Martin Marietta Corporation
- Naval Air Station
- Naval Coastal systems Center
- Naval Training Systems Center
- Patrick Air Force Base
- Service School Command
- Tyndall Air Force Base
- University of Florida, Gainsville
- University of Miami

Georgia
- Auburn University, Auburn
- Georgia Institute of Technology
- Marine Corps Logistics Base
- Robins Air Force Base
- Skidaway Institute of Oceanography
- University of Georgia, Athens
- U.S. Army, Fort Gillem
- U.S. Army, Fort Gordon
- U.S. Army, Fort McPherson
- U.S. Army, Fort Stewart

Hawaii
- Camp H. M. Smith
- Hickam Air Force Base
- NEEACTPAC, Pearl Harbor
- OINC NUWES, Hawaii Detachment
- University of Hawaii
- Wheeler Air Force Base

Idaho
- Idaho National Engineering Laboratory
- University of Idaho

Illinois
- Argonne National Laboratory
- Astronomy & Astrophysics Center
- Chanute Air Force Base
- Fermi National Accelerator Laboratory
- Gould Software Division
- Headquarters for AMCCOM
- Illinois Institute of Technology
- McDonnel-Douglas
- Naval Hospital
- Northwestern University, Chicago
- Rock Island Arsenal
- Scott Air Force Base
- University of Chicago
- University of Illinois
- U.S. Army, Fort Sheridan

Indiana
- Grissom Air Force Base
- Indiana University
- Naval Weapons Support Center
- Purdue University
- University of Indiana, Bloomington
- University of Notre Dame, South Bend
- U.S. Army, Fort Ben Harrison

Iowa
- Ames Laboratory
- Iowa State University
- University of Iowa

Kansas
- Kansas State University, Manhattan
- McConnell Air Force Base
- University of Kansas, Lawrence
- U.S. Army, Fort Leavenworth

Kentucky
- University of Kentucky
- U.S. Army, Fort Campbell
- U.S. Army, Fort Knox

Louisiana
- Barksdale Air Force Base
- England Air Force Base
- Louisiana State University, Baton Rouge
- Michoud Assembly Facility
- Navy Regional Data Automation Center
- Slidell Computer Complex
- U.S. Army, Fort Polk

Maine
- Loring Air Force Base

Maryland
- Aberdeen proving Ground
- Andrews Air Force Base
- David Taylor Naval Ship
- Federal Data Corporation
- Goddard Space Flight Center
- Johns Hopkins University
- NSSDC
- National Bureau of Standards - Gaithersburg
- National Computer Security Center
- National Institutes of Health
- National Security Agency, Fort George G. Meade
- Naval Air Logistical Center

Naval Electronics Systems Commnad
Naval Surface Weapons Center
Network Solutions
Sea Automated Data Systems
Space Telescope Institute
University of Maryland
U.S. Army, Fort Detrick
U.S. Naval Academy

Massachusetts
- Air Force Geophysics Laboratory
- Atmospheric & Environmental Research, Inc.
- Bolt Beranek and Newman Communications Corporation, Boston
- Boston University
- Computer Corporation of America
- Digital Equipment Corporation
- Dynamics Research Corporation
- GTE Government Systems
- Hanscom Air Force Base
- Harvard College Observatory
- Harvard University
- Honeywell Information Systems
- Intermetrics
- Massachusetts Institute of Technology
- MITRE Corporation
- Northeastern University
- Palladian Software, Inc.
- Research Institute of Environmental Medicine
- Thinking Machines Corporation
- U.S. Army, Fort Devens
- U.S. Army, Watertown
- Woods Hole Oceanographic Institute

Michigan
- Central Michigan University, Mount Pleasant
- K. L Sawyer Air Force Base
- Marine Corps Air Station
- Michigan State University, Lansing
- Oakland
- University of Michigan, Ann Arbor
- Wayne State, Detroit
- West Michigan University
- Wursmith Air Force Base

Minnesota
- Comten-NGR
- Honeywell, Inc.
- Sperry Corporation
- University of Minnesota

Mississippi
- National Space Technology Laboratories
- Navy Norda

Missouri
- Army Aviation Systems Command
- Automated Logistics Management Systems Activity
- Defense Mapping Agency
- Marine Corps Central Data Processing Activity
- McDonnell-Douglas Astronautics Corp.
- University of Missouri, Columbia
- University of Missouri, Kansas City
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- U.S. Army, Fort Leonard Wood
- Washington University, St. Louis

Montana
- Malstrom Air Force Base
- Montana State University

Nebraska
- Army Engineer Division
- Offutt Air Force Base
- Stanford Research Institute International (SRI)
- University of Nebraska, Lincoln

Nevada
- Nellis Air Force Base

New Hampshire
- Dartmouth College
- Frey Federal Systems
- Pease Air Force Base
- University of New Hampshire

New Jersey
- Army Armament Research Development and Engineering
- Army Armament Research
- Army Communications
- Army Information Systems
- AT&T Bell Laboratories
- Institute for Advanced Studies at Princeton University
- John von Neuman Center
- McGuire Air Force Base
- Military Ocean Terminal
- Princeton Plasma Physics Laboratory
- Princeton University
- Rutgers University, New Brunswick

New Mexico
- Holloman Air Force Base
- JSC White Sands Test Facility
- Kirtland Air Force Base
- Los Alamos National Laboratory
- Sandia National Laboratories - Albuquerque
- University of New Mexico
- White Sands Missile Range

New York
- Army Information Systems
- Brookhaven National Laboratory
- City University of New York
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- Cornell University
- European Command
- General Electric Corp.
- Goddard Institute for Space Studies
- Griffiss Air Force Base
- Grumman Aerospace
- Hazeltine Corporation
- Lamont-Doherty Oceanography
- New York University
- Plattsburg Air Force Base
- Polytechnic Institute of New York
- Rensselaer Polytechnic Institute
- Rockefeller University
- Rome Air Force Base
- Sembach GE
- State University of New York, Albany
- State University of New York, Binghamton
- State University of New York, Buffalo
- State University of New York, Stony Brook
- Syracuse University
- University of Rochester
- U.S. Military Academy

North Carolina
- Duke University
- Navy Regional Automated Services Center
- North Carolina State University
- Pope Air Force Base
- Seymour Johnson Air Force Base
- SRI Field Office
- Triangle Universities Computation
- University of North Carolina
- U.S. Army, Fort Bragg

North Dakota
- Minot Air Force Base, Minot
- North Dakota State University
- University of North Dakota
- U.S. Air Force, Grand Forks

Ohio
- Case Western University
- Consolidated Data Center
- Defense Construction Supply Center
- Defense Electronics Supply Center
- Defense Systems Automation
- Lewis Research Center
- Newark Air Force Station
- Ohio State University
- University of Cincinatti
- University of Toledo
- Wright-Patterson Air Force Base

Oklahoma
- Headquarters, Department of Army, Fort Sill
- Oklahoma State University
- Tinker Air Force Base
- University of Oklahoma
- University of Tulsa

Oregon
- Intel Corporation
- Oregon Graduate Center
- Oregon State University
- Portland State University
- University of Oregon

Pennsylvania
- Carnegie-Mellon University
- Defense Mapping Agency
- Electronic Data Systems Network Service Center
- Lehigh University
- Leterkenny Army Depot
- Millersville University
- Naval Air Development Center
- Naval Aviation Supply Office
- Navy Ships Parts Control Center
- New Cumberland Army Depot
- Pennsylvania State University
- Philadelphia Naval Ship Yard
- Pittsburgh Supercomputer Center
- Systems Development Corp.
- Temple University
- Unisys Corporation
- University of Pennsylvania
- University of Pittsburgh
- Westinghouse Electric Corporation

Rhode Island
- Brown University
- Naval Data Automation Command
- University of Rhode Island

South Carolina
- Charleston Air Force Base
- Clemson University
- Myrtle Beach Air Force Base
- NCR Corporation
- Shaw Air Force Base
- U.S. Army, Fort Jackson

South Dakota
- Ellsworth Air Force Base

Tennessee
- Maxima Corporation
- Naval Air Technical Training Center
- Oak Ridge National Laboratory
- University of Tennessee
- Vanderbilt University

Texas
- Baylor College of Medicine
- Baylor University
- Bergstrom Air Force Base
- Brooks Air Force Base
- Carswell Air Force Base
- Dyess Air Force Base
- Geo-Chem Research Associates, Inc.
- Institute for Fusion Studies
- Johnson Space Center
- Kelly Air Force Base
- Lackland Air Force Base
- Laughlin Air Force Base
- Lunar and Planetary Institute
- Lyndon B. Johnson Space Center
- Microelectronics and Computer Technology Corporation
- Randolph Air Force Base
- Rice University
- Rockwell International
- Sheppard Air Force Base
- Southwest Research Institute
- Texas A & M University
- Texas Accelerator Center
- Texas Southern University
- University of Houston
- University of Texas
- U.S. Army, Fort Bliss
- U.S. Army, Fort Sam Houston

Utah
- Clearfield Federal Depot
- Dugway Proving Ground
- Hill Air Force Base
- Tooele Army Depot
- Utah State University
- University of Utah

Vermont
- University of Vermont

Virginia
- Army Materiel Command
- BBN Communications Corporation
- Boeing Computer Services
- CEBAF
- Center for Seismic Studies
- College of William and Mary
- Computer Sciences Corporation
- Criminal Investigation Command
- Defense Advanced Research
- Defense Communications
- Defense Nuclear Agency
- Electronic Data Systems
- Goddard Space Flight Center
- Honeywell Corporation
- Langley Air Force Base
- Langley Research Center
- Linkabit Corporation
- M/A-COM Government Systems
- Marine Corp Design Center
- Naval Weapons Center
- Norfolk Naval Air Station
- Science Applications Inc. - McLean
- Tamdem Computers, Inc.
- Teledyne Geotech Center for Seismic Studies
- The MITRE Corporation
- U.S. Air Force, Pentagon
- U.S. Army, Fort Belvoir

U.S. Army, Fort Lewis
Virginia Polytechnic Institute
Wallops Flight Facility

Washington
Battelle Northwest
Flow Research Company
Hanford Engineering Development Laboratory
Stanford Research Institute International (SRI)
Trident Training Facility
University of Washington
Washington State University

West Virginia
University of West Virginia

Wisconsin
University of Wisconsin, Madison
University of Wisconsin, Milwaukee

Wyoming
F.E. Warren Air Force Base

1.10. REFERENCES

1. S. Ruttenberg, "Summary of Agency Network Plans," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States (June 1987).*
2. D. Stevens, "DOE Networking Requirements," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States (June 1987).*
3. A.F. Fath, "Networking Trends in Data Communications," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
4. G. Ricart, "Research University Bandwidths," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
5. D. Hall, W. Johnston, Hutchinson M., et al, "The Effect of Distributed Computing Technology on Wide Area Network Capacity Requirements," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
6. T.A. Lasinski, "Role of Graphics Workstations in Supercomputing," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
7. J. Haverty, "Networking: Some Observations on the Future," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
8. S.G. Munshi, "Industry and Technology Trends," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
9. R.T. Roca, "AT&T Presentation Graphics," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
10. P. McGregor, "Contel Presentation Graphics," *Volume III, A Report to the Congress on Computer Networks to Support Research in the United States* (June 1987).
11. "The Future of Fiber", *Telephone Engineering and Management*, p.52 (February 1, 1987).

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