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HIGH-PERFORMANCE COMPUTING

High-Speed Computer Networks in the United States, Europe, and Japan

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The Honorable Ernest F. Hollings
Chairman, Senate Committee on Commerce,
Science, and Transportation
United States Senate

The Honorable Albert Gore
Chairman, Subcommittee on Science,
Technology, and Space
Senate Committee on Commerce, Science,
and Transportation
United States Senate

The Honorable George E. Brown, Jr.
Chairman, House Committee on Science,
Space, and Technology
House of Representatives

The Honorable Robert S. Walker
Ranking Minority Member
House Committee on Science, Space,
and Technology
House of Representatives

The Honorable Tim Valentine
Chairman, Subcommittee on Technology
and Competitiveness
House Committee on Science, Space,
and Technology
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The Honorable Tom Lewis
Ranking Minority Member
Subcommittee on Technology
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House Committee on Science, Space,
and Technology
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In letters dated October 2, 1990, and March 11, 1991, you requested that we review United States and foreign efforts to develop high-speed computer networks. In response to your requests, this report provides information on United States, European, and Japanese efforts to develop high-speed computer networks. Because high-speed computer networks used for research and education are of primary interest in the United States, the report specifically focuses on these types of applications.

In conducting our review, we identified high-speed networks, or in cases where none existed, lower-speed networks that were considered to be important for research and education. We defined high-speed networks as those capable of transmitting data at, or greater than, T1 speeds of 1.544 megabits per second, or E1 speeds of 2.048 megabits per second.[1] European and Japanese networks were identified with the assistance of experts familiar with their use of computer and communications technology.[2] Detailed descriptions of the United States, European, and Japanese networking initiatives we observed are contained in appendixes I, II, and III, respectively. Appendix IV provides additional information on the objectives, scope, and methodology of our review, and appendixes V and VI identify the government entities and other organizations that we contacted in Europe and Japan.

Results in Brief

Currently, the United States leads Europe and Japan in the development of high-speed computer networks for research and education. Efforts to increase data transmission speeds on a major portion of the United States' Internet to 1.544 megabits per second (T1) and 45 megabits per second (T3), and plans to develop a National Research and Education Network (NREN) operating at gigabit speeds,[3] exceed most plans and initiatives occurring in Europe and Japan at this time. Although some questions concerning the development and operation of NREN must still be answered, federal and academic sponsors of this networking initiative are nonetheless moving aggressively on this effort.

Although their networks are generally less developed than those in the United States, Europe and Japan clearly recognize the importance of

[1] T1 is the term commonly used for the high-speed digital standard in the United States and other countries such as Japan and Korea. Europe has standardized on E1, which differs from T1 in speed, signalling methods, and number of voice circuits supported.

[2] We limited our review to five European countries—France, Germany, Italy, the Netherlands, and the United Kingdom.

[3] A gigabit equals one billion bits.

high-speed networks, and have plans and projects under way to enhance the speed and capability of these networks. Some European participants, in particular, believe the United States' proposed NREN represents the kind of network that is needed in Europe. Presently, however, Europe and Japan face a number of financial, organizational, and other issues, which if not addressed, could prevent the development or expansion of their network infrastructures. European and Japanese officials told us they are working to resolve these issues. If they are successful in these efforts, Europe and Japan may be able to strengthen their positions in advancing research and education through the use of high-speed computer networks.

Background

Computer networks enable both local and long-distance communication between computers, often over public telephone lines, but also via dedicated switching and transmission systems. Computer networks transmit data at various speeds to meet the needs of many different user communities throughout the world. Traditionally, computer networks transmitted data at relatively low speeds measured primarily in kilobits per second. The early 1980s, however, saw a growing demand for increasingly higher-speed computer networks. Currently, regional and wide-area national networks operate at T1 speeds of 1.544 megabits per second in the United States or E1 speeds of 2.048 megabits per second in some European countries. Local-area networks transmitting data at speeds of between 10 megabits per second and 100 megabits per second also exist. These higher-speed networks have fueled the market for a variety of applications, including electronic mail, distributed data base access, large file transfer, and graphics transmission.

Although regional and wide-area networks transmitting data at speeds of between 1 and 2 megabits per second are generally considered sufficient for many network applications, sophisticated advances in computer and communications technologies and increased volumes and complexity of data traffic have contributed to a growing demand for higher-capacity networks that are capable of transmitting data at T3 speeds of 45 megabits per second, and up to a gigabit per second. One sector of society expressing a need for the higher-speed networks is the research and education community. Scholars, researchers, executives, and politicians in both the United States and overseas recognize the importance of networking to access unique experimental data, share results and publications, and run models on remote supercomputers.

Networking in the United States

The United States research and education communities are served primarily by the Internet, a loosely organized system of interconnected, unclassified computer networks linking over 500,000 computers nationwide and overseas. The United States' portion of the Internet includes government-funded national backbone networks and publicly and privately funded regional networks operating at 1.544 megabits per second (T1), as well as private local-area networks transmitting data at speeds of 10 megabits per second to 100 megabits per second. One of the major backbone networks comprising the United States' portion of the Internet is the National Science Foundation Network (NSFNet).[4] NSFNet links more than 3,000 networks at university and college campuses, business and industrial research laboratories, and governmental research centers throughout the world.

Currently, the United States' portion of the Internet is experiencing rapid growth in the number of networks and host computers connected to it, and is unable to satisfy all requirements of the research and education community. Traffic on NSFNet, alone, has increased by more than 25 times in the last 2 years. Approximately 3 million researchers worldwide actively use the academic networks connected to the Internet. In addition, supercomputers and other sophisticated applications used by some organizations require higher speeds than are currently available on the existing networks.

To enhance network services for the research and education community, federal sponsors and academic participants plan to transform the United States' portion of the Internet into a higher-speed network with nationwide coverage. Toward this goal, the National Science Foundation (NSF) has upgraded most telecommunications links on the NSFNet backbone to transmit data at a speed of 1.544 megabits per second, and is further increasing data transmission speeds to 45 megabits per second for some agencies. On a broader scale, the Congress is considering legislation and plans for developing NREN operating at gigabit speeds. NREN is expected to emerge from and expand existing capabilities of the United States' portion of the Internet. As envisioned, this network ultimately will be capable of transmitting end-to-end at rates of between 1 and 3 billion bits of data per second—approximately 50,000 typed pages per second—and will connect researchers in industry and academia to supercomputers and other information resources around the country.

[4] Other federal agencies operating networks on the Internet include the Defense Advanced Research Projects Agency, the Department of Energy, the Department of Health and Human Services, and the National Aeronautics and Space Administration.

Plans for creating NREN are being led at the federal level by the White House Office of Science and Technology Policy and the Federal Networking Council, a collaboration of various agencies, including NSF, the Defense Advanced Research Projects Agency (DARPA), the Department of Energy, the Department of Health and Human Services, and the National Aeronautics and Space Administration. The President's fiscal year 1992 budget request seeks $92 million for work related to developing NREN. In addition, the Corporation for National Research Initiatives, a nonprofit organization created in 1986, has received a 3-year award of approximately $15.8 million from NSF and DARPA to lead research to determine the technology and possible structure of a gigabit network and identify possible end-user requirements for such a network. As NREN's infrastructure takes shape, however, its sponsors are being tasked to answer questions concerning how the network should be managed, funded, and secured. One central question, for example, is whether management of NREN should be decentralized among network researchers, users, and sponsors, or whether one organization should assume a dominant role in its management.

European Research and Education Networks

European research and education communities are supported by an infrastructure of national and pan-European networks. Generally, the European networks are slower than networks existing in the United States. Many of the national networks, such as the ones we reviewed in Germany, Italy, the Netherlands, and the United Kingdom, were created in the mid to late 1980s through government initiatives to provide scientific and technical research capabilities within individual countries. These networks connect universities and research institutions at data transmission speeds ranging from 64 kilobits per second to 2 megabits per second. Overall, the national networks provide good levels of connectivity and service within the countries they serve.

The pan-European networks, which enable cross-border communications between countries, provide slower and less extensive service than the national networks. Most of the existing pan-European networks, such as the European Academic Research Network and the High Energy Physics Network, are designed to meet the needs of specific user groups and do not provide a general-purpose backbone infrastructure to connect all of the national networks. The pan-European networks generally operate at relatively low speeds of 4.8 to 64 kilobits per second.

The Commission of the European Communities,[5] national network operators, and various associations of European networks and users believe that more capable, higher-speed research and education networks are needed in Europe. Moreover, some of these participants view the United States' proposed NREN as an example of what is needed. In response to increasing needs, national network operators in the countries we observed either have already begun upgrading existing networks or plan to develop high-speed networks over the next few years. In addition, European network organizations and the Commission of the European Communities told us that progress is being made toward establishing a pan-European backbone network linking the national networks. Some officials noted that higher speeds could be available on a pan-European network by the mid-1990s.

European officials told us that several issues, unless resolved, may slow or prevent progress on planned enhancements to the national research and education networks and implementation of a high-speed, pan-European backbone network. According to these officials, although much of the technology needed to implement a pan-European network is available, issues concerning how to organize and fund the network still need to be addressed. Some officials reported that Europe currently lacks a cohesive central organizational structure and a supportive regulatory environment to guide the pan-European initiatives. In the absence of central leadership, cross-border telecommunications services are difficult and expensive to obtain. Various organizations, such as the European Engineering Planning Group (EEPG) and the Réseaux Associés pour la Recherche Européenne (RARE), an association of networking organizations and users in Europe, are optimistic that these issues can be resolved and have taken steps toward this goal. RARE has sponsored networking symposiums to highlight user needs for high-speed networks and EEPG has proposed an organization structure and approaches for funding and implementing a pan-European backbone network.

[5]The Commission of the European Communities proposes and enforces policies and laws that apply to the 12 countries making up the European Community—Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom.

Japanese Research and Education Networks

In Japan, various government-funded and privately operated computer networks support research and education. However, some Japanese officials believe that fewer and less advanced networks exist in Japan than in the United States. The existing networks connect Japan's major universities, and enable communications between researchers at other laboratories and research facilities. Generally, these networks do not have high-speed data transmission capabilities. Among the networks that we observed, only one, the Science Information Network operated by the National Center for Science Information System, provided a high-speed (T1) backbone. Most of Japan's other research and education networks operate at relatively low speeds of 192 kilobits per second or less.

Japanese officials considered high-speed networks to be important for research and education and told us that government and privately sponsored initiatives are being actively pursued to enhance Japan's computer networking capabilities. One of Japan's most significant undertakings involves its recently announced plans to invest approximately $250 billion to equip businesses and homes with a broadband Integrated Services Digital Network (ISDN) by the year 2015. Under this plan, Nippon Telegraph and Telephone Corporation (NTT) will use fiber-optic cable to link Japanese homes and businesses, enabling the transmission of digitized voice, data, and video traffic, and providing a standard way for computers and other equipment to share information at high speeds. NTT envisions providing such advanced services as 3-D video communications and automatic translation communications.

Japan's success in developing a broadband ISDN and other high-speed computer networks may depend on factors such as its ability to obtain the necessary funding for these efforts and to gain coordinated support from the Japanese government ministries. Some network operators and representatives of the Japanese ministries believe that increasing the number and capability of computer networks will, in part, depend on how well the networks compete with other programs for government funding. In addition, successful implementation of the broadband ISDN may require more accurate definition of customer needs for this service.

The information in this report is based primarily on testimonial evidence. Although we did not independently verify its validity and accuracy, we did discuss the information with various government officials and representatives of European and Japanese networking organizations, and have included their comments where appropriate. Our work was performed from October 1990 to June 1991.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the date of this letter. At that time, we will send copies to interested congressional committees and others upon request. Should you have any questions concerning this report, please contact me at (202) 275-3195. The major contributors to this report are listed in appendix VII.

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Director
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Contents

Abbreviations

ATM	asynchronous transfer mode
BITnet	Because It's Time Network
CERN	Centre Europeenne pour la Recherche Nucleaire
COSINE	Cooperation of Open Systems Interconnection Networking in Europe
DARPA	Defense Advanced Research Projects Agency
DECNET	Digital Equipment Corporation Network
DFN	Deutsche Forschungsnetz
EARN	European Academic Research Network
EASInet	European Academic Supercomputer Initiative Network
ECU	European currency unit
EEPG	European Engineering Planning Group
GAO	General Accounting Office
GARR	Group for the Harmonization of Research Networks
HEPnet	High-Energy Physics Network
IBC	integrated broadband communication
IBM	International Business Machines Corporation
IMTEC	Information Management and Technology Division
ISDN	Integrated Services Digital Network
IXI	International X.25 Infrastructure
JANET	Joint Academic Network
JICST	Japan Information Center of Science and Technology
JUNET	Japanese University Network
KEK	National Laboratory for High-Energy Physics
MITI	Ministry of International Trade and Industry
NACSIS	National Center for Science Information System
NREN	National Research and Education Network
NSF	National Science Foundation
NSFNet	National Science Foundation Network
NTT	Nippon Telegraph and Telephone Corporation
OSI	Open Systems Interconnection
PACCOM	Pacific Area Computer Communication
PTM	packet transfer mode
PTT	Postal, Telegraph, and Telephone Administration
RACE	Research and Development in Advanced Communications Technologies in Europe
RARE	Reséaux Associés pour la Recherche Européenne
SURF	Samenwerkende Universitaire Rekenfaciliteiten
TCP/IP	transmission control protocol/internet protocol
WIDE	Widely Integrated Distributed Environment

United States Plans for Building the National Research and Education Network

To better support research and education in the United States, federal and academic sponsors have proposed developing the National Research and Education Network (NREN). As planned, NREN will provide a high-capacity, high-quality network infrastructure to ultimately transport digitized information at several billion bits per second between high-performance computational resources, such as supercomputers, and individual workstations. NREN will build on the United States' portion of the Internet, the existing system of loosely connected, unclassified networks that links computers nationwide and overseas. Currently, the number of networks and computers connected to the Internet is increasing rapidly, as are demands for greater network capacity to support researchers in conducting complex analyses combining local and remote resources. NREN supporters envision creating a network that will meet increased demands for a higher-speed computer network offering nationwide coverage.

Description of the Internet Infrastructure

The Internet consists of over 5,000 interconnected networks that link approximately 500,000 computers worldwide. The United States' portion of the Internet consists of government-funded national backbone networks, publicly and privately supported regional networks, and local-area campus networks. Some of the regional and backbone networks comprising the United States' portion of the Internet transmit data at a speed of 1.544 megabits per second (T1). Private local-area networks on the Internet operate at data transmission speeds of 10 to 100 megabits per second. One of the major backbone networks on the United States' portion of the Internet is the National Science Foundation network (NSFNet). NSFNet connects more than 3,000 networks at university and college campuses, businesses, industrial research laboratories, and governmental research centers worldwide.

Management of the Internet is decentralized. Each of the networks within the Internet is operated independently and has its own operations center that monitors and maintains its portion of the Internet. Funding for the United States' portion of the Internet comes from the five federal agencies operating national research networks and from universities, states, and private companies that operate and use the local and regional networks.[1] Participating institutions generally pay fixed annual fees to connect to the regional networks of between

[1]The five federal agencies operating research networks on the Internet are the Defense Advanced Research Projects Agency, the National Science Foundation, the Department of Energy, the National Aeronautics and Space Administration, and the Department of Health and Human Services.

$10,000 to $50,000 per year, depending on the size of the institution and the carrying capacity of the telecommunications channel connecting it to the network.

Researchers use the Internet for a variety of applications. For example, electronic mail provides a way of sending person-to-person messages almost instantaneously, enabling researchers separated by thousands of miles to collaborate. Other uses of the Internet include file transfer, access to software and document libraries, and remote access to computer data banks and supercomputers. Access to supercomputers, in particular, has had a dramatic impact on scientific endeavors. Experiments that took years to complete on an ordinary computer can be performed in days or weeks on a supercomputer.

Limitations of the Existing Infrastructure

Presently, the number of users of the Internet is growing, as is the need for more extensive high-speed data networking capacity. Approximately 3 million researchers worldwide actively use the academic networks connected to the Internet. Data traffic on the NSFnet backbone alone has increased by more than 25 times in the last 2 years. As a result of its continual growth, the United States' portion of the Internet is unable to satisfy all the requirements of the research and education community. In addition, supercomputers and other sophisticated applications used by some organizations require higher speeds than are currently available on the existing networks.

Creation of a National Research and Education Network

The President's fiscal year 1992 budget requests $92 million for development of NREN. In addition, the Congress is considering legislation supporting its development. The proposed High-Performance Computing and Communications Act of 1991, for example, would authorize the creation of a multi-gigabit-per-second computer network linking government, researchers, businesses, consumers, and schools in every state.

NREN is intended to dramatically expand and enhance the capabilities of the United States' Internet. As envisioned, NREN ultimately will be capable of transmitting end-to-end at rates of between 1 and 3 billion bits (gigabits) of data per second—the equivalent of about 50,000 typed pages every second. Such capacity is expected to greatly enhance the ability of researchers to perform complex analyses using remote resources. For example, users will be able to share libraries, data bases, supercomputers, and other scientific technologies to perform computational analyses and simulations that generate very large, complex data, graphics, or video files.

Development of NREN is planned to occur in three phases. The first phase, begun in 1988, involved upgrading all telecommunications links within the NSFNet backbone to 1.544 megabits per second (T1). This upgrade has been completed for most agencies. The second phase, which is now under way, will provide upgraded services for 200 to 300 research facilities, using a shared backbone network with a carrying capacity of 45 megabits per second (T3). The third phase, which will result in a gigabit-speed NREN operating at roughly 50 times T3 speeds, is expected to begin during the mid-1990s, if the necessary technology and funding are available.

Plans for creating NREN are being overseen at the federal level by the White House Office of Science and Technology Policy and the Federal Networking Council, a collaboration of NSF, DARPA, the National Aeronautics and Space Administration, the Department of Energy, and the Department of Health and Human Services. As provided for in the Office of Science and Technology Policy plan, NSF will serve as the lead agency for coordinating the deployment of the operational NREN, and DARPA will lead research and development on advanced networking technology.

Research and Development for a Gigabit Network

Various research efforts are being conducted to yield insights into the design and development of gigabit network technology. One major project is being led by the Corporation for National Research Initiatives, a nonprofit organization, which received a 3-year award of approximately $15.8 million from NSF and DARPA to lead the research on gigabit technology. This research, which involves collaborators from universities, national laboratories, supercomputer centers, and major industrial organizations, is intended to advance the technology and understanding of requirements for high-speed networking by (1) developing architectural alternatives for consideration in determining the possible structure of a wide-area gigabit network, and (2) exploring possible applications for such a network. Presently, gigabit testbed facilities are being developed, and work on the gigabit network applications has begun.

The gigabit research project revolves around a set of five testbeds, each with its own research objective and distinct research staff. For example, one testbed is exploring switching technology to determine whether packet transfer mode or asynchronous transfer mode[2] is best suited for NREN. Other testbeds are studying different applications, such as weather modeling, detection of earthquakes, and cancer research, to assess whether they can be supported on NREN. A mid-course review of the progress of these testbeds is scheduled for mid-September 1991.

Issues Need to Be Addressed to Implement NREN

As developers of NREN move to shape its infrastructure, they are being confronted with various policy issues concerning how the network should be developed and organized. These issues have raised questions about the technology, security, management, and funding of computer networks and resources that will be linked to NREN. As previously discussed, developing NREN is expected to require major departures from existing network technology to handle networks operating at gigabit speeds. Some experts have questioned whether existing computer architectures, operating systems, and protocols are able to respond to gigabit speeds. It is expected that in some cases, new computer interfaces, switches, and data communication protocols will be required.

In addition, questions remain concerning how the collection of networks comprising NREN should be managed. The collaboration among network researchers, users, and sponsors that has guided the growth of existing academic and research networks is considered by some to be inadequate for managing NREN. Currently, no single entity within the federal establishment, higher education, or industry is thought to be capable of ensuring the reliable and timely introduction of improved networking services, technology, and capacity.

Another issue concerns the privacy of information carried over NREN. Open access to NREN is an essential element in creating an electronic community of researchers with the broadest possible participation by individuals and organizations in government, education, and industry. Maintaining an open and easily accessible network that protects the privacy and valuable resources of its users will require a balance of legal and technological controls.

Realizing the benefits of NREN also will require major financial investments over the next decade; however, no decision on who will make

[2]Packet transfer mode (PTM) and asynchronous transfer mode (ATM) are two switching approaches. PTM is based on variable-sized packets and is a method being pursued within the data communications industry. ATM uses small, fixed-size data packets, and is the current proposal within the telephone carrier standards community for the next generation of network switching technology.

these investments has yet been reached. Although the federal government has thus far played a dominant role in financing research networks, questions remain as to whether it can and should be the sole provider for the development and deployment of a gigabit NREN, or whether financing should be a shared responsibility of federal research sponsors, educational agencies and institutions, and participating private sector organizations.

High-Speed Computer Networks Supporting Research and Education in Europe

European research and education is supported by an infrastructure of national and pan-European networks. Although the national networks generally provide good levels of connectivity and service within individual countries, the pan-European links, which enable cross-border communications between countries, are relatively slower and serve more limited numbers of users. Various European networking organizations, national network operators, and the Commission of the European Communities, which makes policies and laws that apply to the European Community members,[1] believe that the network infrastructures in place do not adequately support all research and education needs, and are acting to increase the speed and capability of the national networks and establish a reliable pan-European network infrastructure. While most officials are optimistic that higher-speed networking capabilities will emerge in Europe, they recognize that various funding and management issues must first be resolved. All of the national network operators told us that the high cost of telecommunications services in Europe limits their plans to upgrade networks.

National Networks Provide Connectivity and Service Within Their Respective Countries

In Germany, Italy, the Netherlands, and the United Kingdom, national networks connect universities and research institutions at speeds ranging from 64 kilobits per second to 2 megabits per second.[2] Some of the networks are based on the X.25 telecommunications protocol supporting other protocols at higher layers. Other networks support, or will soon support, multiple protocols, including the Internet Protocol.[3] All of these networks receive financial support from their national governments.

Germany's National Research Network

The German national research and education network, called the Deutsche Forschungsnetz (DFN), was established in 1984. This network is managed by the DFN Association, which has more than 250 institutional members, including universities, national research centers, and industrial companies. The DFN Association contracts with the Deutsche

[1]The European Community members are Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom.

[2]Other European countries such as Sweden, Denmark, Finland, and Norway also have computer networks operating at these speeds; however, these countries were not included in our review.

[3]X.25 is an International Standard protocol that the European Postal, Telegraph, and Telephone Administration have adopted for their public data networks. This protocol fits the International Organization for Standardization's Open Systems Interconnection (OSI) layering model. The Internet Protocol is a vendor-independent and widely available Department of Defense standard protocol used for the United States' Internet, but is not directly compatible with the OSI protocol suite.

Bundespost, Germany's Postal, Telegraph, and Telephone Administration (PTT), for the DFN network and related services. Currently, DFN links all of Germany's universities and research centers using an X.25 backbone service called WIN (Wissenschaftsnetz), with access speeds of 64 kilobits per second. Members pay a fixed fee, regardless of the extent of usage, to use the network.

The DFN Association has an annual budget of about 30 million deutsche marks and is funded through federal grants, membership fees, and service charges.[4] According to the director of this association, expenditures are split between research and development costs and the network's operating costs. German Ministry of Research and Technology officials told us their organization provides the association with about 15 million deutsche marks per year to support research in Open Systems Interconnection technology and new system development.

The DFN Association plans to offer an upgraded speed of 2 megabits per second on the DFN in the second half of 1991. However, the Director of the DFN Association stated that because of the high cost, only 20 to 25 users have expressed interest in a higher speed networking service; most users probably will continue to rely on the 64 kilobits per second speed presently available. The DFN Association is now monitoring the development and testing of networks with speeds higher than 2 megabits per second. Information gathered from this project will provide a basis for deciding whether Germany should implement a research and education network operating at speeds greater than 2 megabits per second. The Director of DFN expects that such a large-scale national project may be possible in about 2 years.

Italy's National Research Network

The Italian national network was created in 1989 to link several scientific research networks. The Ministry of Universities, Research, and Technology created the Gruppo Armonizzazione Reti di Ricerca (GARR), or Group for the Harmonization of Research Networks, to manage and supervise the connections of the various scientific research networks. A senior adviser to the Minister for Universities, Research, and Technology explained that, in 1988, the Italian parliament passed a one-time appropriation of 50 billion lire to establish the GARR network and purchase two supercomputers.[5] The GARR network subsequently brought

[4] In June 1991, one dollar equaled about 1.78 deutsche marks.

[5] In June 1991, one dollar equaled about 1,317 Italian lire.

together three other Italian research and education networks and three computer centers. To facilitate more effective resource sharing and increase service, the three networks agreed to consolidate their funds and eliminate duplicative administrative costs.

The GARR network currently links more than 280 research laboratories throughout Italy, including public and university laboratories and industrial research establishments. A technical executive committee is responsible for managing the network, which operates on lines leased from the Italian PTT. The network provides access speeds of 64 kilobits per second and 2 megabits per second. The network uses time-division multiplexing[6] to support four protocols—Internet Protocol, X.25, DECNET, and Systems Network Architecture.[7]

According to a senior adviser to the Minister for Universities, Research, and Technology, one-time funding for the GARR network will be exhausted in late 1991, and future funding arrangements needed to continue network operations are currently being considered. Italy plans to modify the GARR network in 1991, and again in 1992, to meet the growing needs of its users by adding more nodes and more links to avoid bottlenecks and to provide alternate routing possibilities. The Executive Manager of the GARR network stated that the network's users currently have a need for 140 megabits per second lines. However, there are no plans to provide network transmission speeds greater than 2 megabits per second, primarily because of the high cost of telecommunications services. After 1993, however, GARR network officials plan to take advantage of expected cost reductions resulting from the prospective liberalization of the European telecommunications industry to increase the network's speed.

The Netherlands' National Research Network

The Dutch national research and higher education network, called SURFnet, was proposed as part of a 1984 government initiative that established the Surf Foundation to better coordinate Dutch networking and

[6]Time-division multiplexing is a digital transmission technique that allows multiple channels to share a single line.

[7]DECNET is a set of proprietary protocols of the Digital Equipment Corporation. Systems Network Architecture is a set of proprietary protocols of International Business Machines (IBM).

stimulate information technology.[8] The network was not actually implemented until 1989, when SURFnet B.V., a nonprofit limited liability company, was formed to develop and operate the network. SURFnet B.V. has two shareholders—the SURF Foundation and the Dutch PTT.

SURFnet links a total of 85 organizations, including all Dutch universities, most government and private research institutions, and the Dutch national supercomputer site. The network's main infrastructure consists of an X.25 backbone based on 64 kilobits per second leased lines and equipment. To meet the needs of its users, SURFnet B.V. also supports the use of the Internet Protocol over the X.25 backbone.

SURFnet's organization is somewhat different than that of the other national research networks that we reviewed in that its operations are managed by a commercial entity separate from its policy-making body. In other words, the primary operator of the network is SURFnet B.V. However, the SURF Foundation, comprised primarily of the network's users, has overall policy-making authority and interacts with the Dutch Ministry of Education and Science.

SURFnet is operated on a not-for-profit basis. Its annual operating costs of about 4 million European Currency Units (ECUS)[9] are covered by service and transport fees paid by network users, the SURF Foundation, and the Ministry of Economic Affairs. SURFnet has an annual budget of about 1 million ECUS for research and development, paid by the Ministry of Economic Affairs.

SURFnet has undertaken a pilot project, called SURFnet 3, which uses 2 megabits per second leased lines to link the major Dutch universities, the national aerospace laboratory, and other academic computing services to the national supercomputer center. SURFnet's managing director stated that 2 megabits per second links were chosen as the upper limit for the pilot project solely on financial grounds, and that higher speeds would have been used had they been affordable. After 1992, the SURFnet 3 pilot is expected to evolve into an operational network offering both X.25 and Internet Protocols.

[8]The "SURF" acronym comes from the original name, "Samenwerkende Universitaire Rekenfaciliteiten," or Cooperating University Computing Facilities. SURF is a Dutch organization roughly equivalent to a foundation in the United States.

[9]The ECU is a composite currency unit based on the currencies of 9 of the 12 European Community members. In June 1991, an ECU equaled approximately $1.16.

The United Kingdom's National Research Network

The United Kingdom's national research network, called the Joint Academic Network (JANET), was launched in 1984 as a government and industry initiative to more efficiently use computer resources. JANET consolidated diverse regional and national networks, operating at approximately 48 kilobits per second, among universities and research institutions. JANET connects public institutions, including universities, government research labs, and private research facilities. The network is managed by the Joint Network Team, a centralized group that operates under the Department of Education and Science's Computer Board for Universities and Research.

Since 1989, the national network backbone has been based on the X.25 protocol running over 2 megabits per second trunk circuits leased from British public service companies. The Computer Board has promulgated a policy for the network to use international standard protocols. Therefore, the Joint Network Team requires network users to use prescribed protocols to enhance the network's interworking capabilities.

JANET is funded by a number of governmental organizations under the Department of Education and Science. The 1991 budget for JANET's recurring expenses is 3.9 million pounds sterling.[10] An additional 4.1 million pounds sterling are budgeted for capital expenditures over a 2-year period during 1991 and 1992.

In 1989, the United Kingdom began a major performance enhancement to upgrade JANET's access speed. This enhancement involves implementing 2 megabits per second site access lines supported by a trunk network composed of multiple 2 megabits per second lines. The long-term strategy is to create a SuperJANET broadband network employing optical fibers to complement the introduction of fiber-based local area networks. This network upgrade is scheduled to be completed by 1994.

France Planning to Implement a National Network

Currently, France does not have an integrated national research and education network; rather, various general-purpose and specific disciplinary networks have been developed to support the needs of French government agencies and other users. The French government does plan, however, to begin implementing a national research and education network by the end of 1991. Toward this goal, three French ministries[11]

[10]In June 1991, a pound sterling equaled about $1.66.

[11]The three French ministries involved in this effort are the Ministry of Posts, Telecommunications, and Space; the Ministry of Research and Technology; and the Ministry of National Education.

have established a partnership to build a national high-speed network that will link the entire French research and education community, and be available to industrial research and development centers. The intent in establishing this network is to pull together the fragmented French networks in a more cost-effective manner.

French officials told us that decisions regarding the network have not been finalized, although implementing a network that can be upgraded to speeds of hundreds of megabits per second will be a primary consideration. The officials estimated that the network will offer trunk line transmission speeds beginning at 2 megabits per second and, soon thereafter, increasing to 34 megabits per second. In addition, the new network will accommodate multiple protocols to meet various users' needs. Funding for this network will be provided by the three ministries, regional authorities, and network users.

Pan-European Networks Meet the Needs of Specific Groups

Cross-border communications between European countries are handled by various pan-European networks. Generally, these networks are geared to the needs of specific groups and operate at lower speeds of 4.8 to 64 kilobits per second. None of these networks serves as a general-purpose backbone to interconnect the existing national networks.

High-Energy Physics Network

The High-Energy Physics Network (HEPnet) is the largest and fastest pan-European network currently available. HEPnet connects European high-energy physics laboratories through the Centre Européenne pour la Recherche Nucléaire (CERN) in Geneva. HEPnet is managed by the HEPnet Technical Committee, which is composed of representatives from each participating country.

Although HEPnet's main focus is on meeting the needs of the high-energy physics community, some of its lines and funding are shared with other pan-European networks in order to lease higher-speed trunk lines. HEPnet's line speeds range from 4.8 kilobits per second to 2 megabits per second, with most of the lines operating below 512 kilobits per second. HEPnet supports the Internet Protocol, IBM's Systems Network Architecture, X.25, and DECNET protocols by using time-division multiplexers.

European Academic Research Network

The European Academic Research Network (EARN) is a cooperative network started in 1984 with funding from IBM. EARN is the European portion of the worldwide BITnet (Because It's Time Network), which covers North America, Europe, and parts of Africa, Asia, the Middle East, and South America. EARN, along with BITnet, connects over 2,000 host computers worldwide, offering mail, mailing list, and file transfer services. Each European country participating as an EARN member provides a line to one other European country and also pays dues to cover network management costs and the trans-Atlantic link to the United States. Most EARN links operate at speeds of 9.6 kilobits per second or less. EARN is based on the IBM Network Job Entry protocols.

European UNIX Network

The European UNIX Network is a cooperative research and development network for users of the UNIX operating system developed by AT&T Bell Laboratories. This user-funded network extends throughout western Europe and is used by both academia and industry. The network operates primarily on 64 kilobits per second leased lines using the Internet Protocol. According to a network official, UNIX line speeds may be upgraded several times beyond 64 kilobits per second in the near future, and then to 2 megabits per second by 1994 if funding is available.

International X.25 Infrastructure Network

The International X.25 Infrastructure (IXI) network is a 64 kilobits per second, pan-European backbone pilot network, which is being developed as part of the COSINE (Cooperation of Open Systems Interconnection Networking in Europe) project.[12] IXI links national research networks, public networks, and international networks, such as HEPnet and EARN. IXI service is implemented by the Netherlands' PTT, under contract with the Commission of the European Communities, and is currently paid for entirely by the COSINE project. However, after the COSINE project is completed in 1992, user charges will be phased in, resulting in a self-supporting network. The IXI manager hopes to upgrade line speed to 2 megabits per second in late 1991, when the network's pilot phase is projected to end and production service begins. The COSINE Policy Group estimates that 23 to 36 million ECUs will be budgeted for the 3-year COSINE implementation phase, which extends from 1990 through 1992. The IXI budget is estimated to be 10 to 15 million ECUs.

[12]COSINE is a project of EUREKA, an advanced research program of the European Economic Community and European Free Trade Association countries to raise the productivity and competitiveness of Europe in the fields of advanced technology. COSINE's main objective is to create a common Open Systems Interconnection networking infrastructure to serve the European academic, governmental, and industrial research communities.

European Academic Supercomputer Initiative Network

The European Academic Supercomputer Initiative Network (EASInet) is funded by IBM and links 18 sites operating IBM supercomputers that were purchased as a part of this initiative. EASInet also shares many of its lines with other pan-European networks to support the development of an improved European networking infrastructure. EASInet links operate at 64 kilobits per second or higher when the lines are shared with other networks such as HEPnet. The network supports multiple protocols, including X.25, Internet Protocol, and Systems Network Architecture. IBM is committed to funding the network through 1992.

Need for an Improved High-Speed Pan-European Research and Education Backbone Network

Currently, the major participants in European research and education networking, as well as officials of national governments and the Commission of the European Communities, agree on the need for a pan-European research and education backbone network. Some of the participants believe that a high-speed network similar to the United States' proposed National Research and Education Network should be developed in Europe. Network operators and users and officials of the Réseaux Associés pour la Recherche Européenne (RARE), an association of networking organizations and users in Europe, told us that at a minimum, a 2 megabits per second pan-European network capable of supporting multiple protocols is needed as soon as possible.[13] They stated that such a network would likely be used to capacity by supporting only current applications, and that higher speeds will be needed for newer applications, such as interactive use of supercomputer-based modeling and visualization systems or multimedia conferencing. Most of these officials also believe that any pan-European network should quickly progress to speeds of 34 megabits per second.[14]

In discussing the need for a high-speed, pan-European network, some networking experts believed that the requirements for a wide-area network, such as the pan-European network, are driven largely by the capabilities of local-area networks. Currently, most local-area networks in Europe operate at speeds ranging from 10 to 30 megabits per second, with an increasing number of 100 megabits per second networks being implemented. As users become accustomed to the speed and services

[13] RARE, which aims to cooperatively develop a harmonized communications infrastructure, consists of over 24 national network members and 8 international members. In addition, the Commission of the European Communities participates actively in RARE's work in view of the Commission's special responsibilities regarding information technology and the research infrastructure in Europe.

[14] Although the IXI pilot network provides a backbone service, it operates at only 64 kilobits per second and may not be able to operate at speeds higher than 2 megabits per second.

available on the local-area networks, they begin to want similar speed and services from wide-area networks.

Network operators and users also explained that, while national networks are progressing, a Europe-wide backbone infrastructure connecting existing national networks is needed to allow effective collaboration among European researchers. Without such a network, the network operators and users believe it will be impossible to bring together the needed expertise and resources from across Europe to meet large-scale technical challenges.

An official of the Commission of the European Communities stated that a high-speed, state-of-the-art, pan-European research and education network will be needed to support their Networks of Excellence program. This program is intended to bring together European research efforts in key areas of information technology. Whereas present research efforts are often spread among various national facilities and programs, the Networks of Excellence program creates the organizational structure to link top-level European researchers in related interdisciplinary fields.[15] At the time of our review, three pilot Networks of Excellence had been established to address the subject areas of Speech and Natural Language, Distributed Computing Systems Architecture, and Computational Logic. Although these Networks of Excellence rely on access to the national or international networks described earlier, a high-speed, pan-European telecommunications infrastructure is needed to allow the Networks of Excellence concept to reach its potential.

Officials of the Commission of the European Communities also stated that a pan-European research and education network is needed to help lessen the economic disparity between northern and southern Europe. The officials foresee that, without a pan-European infrastructure, southern European nations could fall further behind because they lack the capital to invest in an infrastructure to support research and education. According to one official, a pan-European network could give southern European research and education communities access to the expertise and resources of northern Europe.

[15]The scope of the Networks of Excellence program does not include providing a telecommunications network.

Efforts to Establish a Pan-European Backbone Network

Representatives of European networking organizations and the Commission of the European Communities told us that recent progress toward implementing a pan-European network has been good. Moreover, they were optimistic that organizational and funding problems will be resolved, resulting in implementation of a pan-European backbone network in the near future. Several officials noted that a higher-speed network could be offered by the mid-1990s.

RARE has been an active proponent of high-speed networking in Europe. In February 1989 and in January 1991, RARE sponsored networking symposiums to highlight user needs for high-speed communications. In May 1989, RARE's Working Group 6, which deals with medium- and high-speed communications, proposed initiating a high-speed, pan-European network. While these efforts did not result in a high-speed, pan-European backbone network, or even a firm plan for implementing one, they have resulted in a general agreement that such a network is needed and that impending organizational and funding obstacles must be addressed.

In March 1991, an official of the Dutch government organized the European Consultative Forum on Research Networking, which brought together the key players from the political and networking communities to discuss development of a high-speed, pan-European backbone network. Forum participants agreed that organizational and funding issues must be resolved so that new high-speed communications services can be developed.

In May 1991, the European Engineering Planning Group (EEPG), composed of network experts organized by RARE, and chartered to undertake specific activities aimed at establishing a high-speed, pan-European backbone network, proposed an organizational structure for operating such a network and raising funds. EEPG also proposed alternative technical approaches for implementing a pan-European backbone network.

Also in May 1991, at the Second Joint European Networking Conference sponsored by RARE, EEPG's proposals were presented to an international audience. Additionally, the president of RARE presented a description of the political actions, the organizational structures, the technical tasks, and other steps needed to implement a high-speed, pan-European backbone network. Officials representing the Commission of the European Communities stressed the need for such a network and their willingness to assist in its implementation.

The Technology Needed for High-Speed Networks Is Being Developed in Europe

European officials stated that much of the technology needed to improve national networks and create a high-speed, pan-European network already exists. In addition, efforts are under way to develop more advanced technology to implement even higher-speed research and education networks. For example, Germany's University of Stuttgart Computing Center, a large supercomputing facility, has conducted high-speed trials using the Forerunner Broadband Network service. This service is offered by Germany's PTT to about 250 users and provides video conferencing and data transfer at 140 megabits per second. The Stuttgart Computing Center has successfully operated long-distance links using 100 megabits per second of this capacity. An official of the Center told us that a high-speed, pan-European backbone network is technically possible by 1992.

Another effort based in Germany is the BERKOM project, which is intended to stimulate the development of high-speed communication services, end systems, and applications. The project is being undertaken by the German PTT and includes the participation of over 70 organizations, such as equipment suppliers, research institutes, and commercial users of high-speed communications. At the time of our review, the project had resulted in the installation of 30,000 kilometers of fiber-optic cables and switching equipment near Berlin, yielding a network that provides access speeds ranging from 64 kilobits per second to 140 megabits per second. A BERKOM official told us that pan-European research and education networks with operational speeds exceeding 100 megabits per second will soon be technically feasible, and that speeds approaching a gigabit per second will be needed in the foreseeable future.

Another initiative to stimulate development of communication technology is the Research and Development in Advanced Communications Technologies in Europe (RACE) program, sponsored by the Commission of the European Communities. This program is meant to facilitate the introduction of commercial Integrated Broadband Communication (IBC) services in Europe by 1995 by funding research in pre-competitive technology.[16] IBC services being developed could be used to support a pan-European research and education network, as well as meet the needs of industrial users. RACE, which is now entering its second phase, has 85 ongoing projects involving 300 participating organizations and 2,000

[16]Integrated Broadband Communication is the use of wide-area, high-capacity networks to simultaneously provide a variety of communication services such as voice, data transmission, and image transfer. RACE officials told us that these types of services should be generally available by the mid-1990s and would be very useful to research and education networks, even though development of such networks is not an explicit objective of the RACE program.

people. Funding for phases I and II is provided by the Commission of the European Communities and RACE participants. Phase I was budgeted at 1.1 billion ECUs for 1987 through 1991. Phase II, which partially overlaps phase I, is scheduled to run from 1990 through 1994, and is budgeted at 1 billion ECUs.

Organization and Funding Issues Must Be Resolved to Implement a Pan-European Backbone Network

Although much of the technology required to create a pan-European research and education backbone network is thought to be available, European officials told us that Europe faces significant issues in managing and funding such a network. European officials were generally optimistic that these issues will be resolved, and that a high-speed, pan-European backbone network will be implemented.

Many organizations in Europe actively support computer networking for European research and education communities. However, none has the charter to provide a pan-European backbone infrastructure to link national networks supporting multiple disciplines and needs. The lack of central leadership has led to unsatisfactory cross-border networking services in Europe. In May 1991, a group of networking experts reported that while Europe does not lack the technology, skills, and competence to implement a high-speed, pan-European network, a cohesive, central organizational force and a supportive regulatory environment are missing.[17] An official of the Commission of the European Communities told us that progress has been slow because consensus among the large number of countries and organizations involved is not easily achieved. Organizing the development of a pan-European network could potentially include the 12 European Community countries, 6 European Free Trade Area countries, and Poland, Hungary, and Czechoslovakia.

Most of the officials also told us that it is difficult and expensive to obtain cross-border telecommunications services because there is no pan-European service provider. Rather, service is provided by national PTTs, which generally operate as regulated monopolies within their respective countries. Therefore, instead of working with a single provider, network operators must coordinate with multiple PTTs to obtain a line from one country to another. For example, if a network operator wants to obtain a link between the Netherlands and France, it must coordinate with officials of the intervening nation—in this case, the Belgian PTT—as well as with the PTTs of France and the Netherlands. Network operators told us that obtaining cross-border lines is time-

[17]European Engineering Planning Group, Final Report, (May 2, 1991).

consuming and expensive. While telecommunications costs are different in each country, many European tariffs are reported to be 10 times higher than in the United States. The PTTs have implemented some changes to simplify matters; however, network operators stated that the situation is still far from satisfactory.

Pan-European networking is further complicated by the use of different telecommunications protocols among users and networks. Some European countries, as well as the Commission of the European Communities, actively encourage the use of protocols that comply with the Open Systems Interconnection model, such as X.25, to avoid reliance on vendor-specific network solutions. However, for various reasons, many researchers often use other protocols that do not comply with the model.

High-Speed Computer Networks Supporting Research and Education in Japan

In Japan, government-funded and private networks provide support for the major research and academic institutions. However, some Japanese officials believe that Japan's networks, overall, are less advanced than networks in the United States. Japanese officials told us that high-speed networks are an integral part of ongoing plans and initiatives to further the nation's telecommunications capability. For example, plans are being formulated to develop a fiber-optic digital network capable of transmitting digitized voice, data, and video traffic, and providing a standard way to share information at high speeds. However, some Japanese officials believe that successful expansion of Japan's computer network infrastructure may depend on whether adequate funding and government coordination exists to support these plans and initiatives.

Japanese Research and Education Networks Provide Relatively Low-Speed Capability

Japanese research and education networks provide nationwide connectivity to academic researchers at universities throughout Japan, and to other specialized groups of users, such as those serving the high-energy physics community. Most of these networks transmit data at relatively low speeds of 192 kilobits per second or less. Only one of the networks that we observed provided high-speed data transmission at a speed of 1.5 megabits per second. According to some Japanese officials, high-speed research and education networks in Japan may not be as widespread or advanced as United States networks because Japanese researchers tend to be located closer together and concentrated in fewer organizations.

Science Information Network

The Science Information Network is the only high-speed network that we identified in Japan.[1] The network was created in 1987 by the National Center for Science Information System (NACSIS), an inter-university research institute authorized by the Japan National University Chartering Law. NACSIS created the network to promote the exchange of scientific information among researchers, primarily at universities, national research institutes, and major libraries throughout Japan. The Science Information Network expanded the services of one of Japan's earliest computer networks, the N-1 Network, which began operation in 1981 to facilitate the sharing of computer resources. The Science Information Network is funded by the government, receiving approximately

[1] Although the Science Information Network was the only high-speed network that we identified, Japanese officials told us that high-speed links have been created by some private companies, such as Honda Motor Co., Ltd. We also were informed that an extensive local-area network connecting nine government laboratories and a supercomputer center over high-speed links exists in Tsukuba Science City.

400 million yen annually for circuits and an unspecified amount for maintenance fees from the Ministry of Education, Science, and Culture.[2]

According to NACSIS officials, the Science Information Network has a 1.5 megabits per second (T1) backbone, with trunk lines connecting to 40 nodes at speeds ranging from 64 to 512 kilobits per second. The network supports various protocols, including X.25, the Transmission Control Protocol/Internet Protocol (TCP/IP), and certain proprietary protocols.

The Science Information Network provides services of the N-1 network and also is used for library information exchange, electronic mail, and experimental projects. The network directly links 135 universities, and provides packet-switching or dial-up connections to an unspecified number of other universities. Among the members of this network are the seven inter-university computing centers throughout the main Japanese islands. Since 1989, the Science Information Network also has provided its users with international connections to the National Science Foundation in Washington, D.C., and since 1990, to the British Library in London. In addition, NACSIS encourages interconnections among local-area networks on university campuses in order to promote greater use of computers by a wider range of researchers for more advanced applications.

NACSIS officials told us that they want to upgrade the network to provide minimum trunk line speeds of 192 kilobits per second for all major locations, and to offer new services, such as video conferencing. Accomplishing these goals, however, will depend on whether funding required to install new circuits can be obtained from the Ministry of Education, Science, and Culture.

Widely Integrated Distributed Environment Internet

The Widely Integrated Distributed Environment (WIDE) Internet project was initiated in July 1987 by a professor at the University of Tokyo. The project was designed to provide a testbed for the development of large-scale distributed systems technologies, and was initially constructed by interconnecting several local-area networks. The network has since provided a basis for Japanese computer science researchers to gain practical experience in advanced networking. The WIDE project also sponsors a consortium to study various computer issues including computer security and protocols and home computing. The WIDE project operates as a nongovernment network with funding support from about

[2]In June 1991, one dollar equaled approximately 137.55 yen.

25 private companies. According to a WIDE project representative, the operating budget for this network totals about 82.5 million yen annually.

The WIDE Internet is composed of a variety of links, including dial-up voice grade lines, voice grade leased lines, 64 kilobits per second and 192 kilobits per second digital leased lines, a 64 kilobits per second link to the Science Information Network of NACSIS, and an integrated services digital network. Currently, 43 user organizations, including universities and private companies, are connected to five operation centers through lines operating at 9.6 to 192 kilobits per second. The WIDE project provides connectivity to other networks, such as the University of Tokyo International Science Network, and supports TCP/IP as the basic protocol.

WIDE operates in conjunction with the Pacific Area Computer Communication (PACCOM) project to provide international links for Japanese researchers. PACCOM began as a testbed project by the University of Hawaii in June 1988. PACCOM provides international connections for some users in Japan to the United States and several other countries by means of links between two Japanese universities and PACCOM's operation center at the University of Hawaii. Connections between Japan and Hawaii are provided by five 64 kilobits per second lines.

Japanese University Network

The Japanese University Network (JUNET) is an academic network offering electronic mail and electronic news services. JUNET was begun in 1984 by university students to provide a testing environment for computer network research, and promote information exchange among Japanese and other researchers. JUNET is the largest nationwide, noncommercial computer network in Japan. As of March 1991, the network connected approximately 450 universities and private companies throughout Japan. Two primary international gateways also provide connections to Europe, the United States, Australia, and Korea. JUNET is not a high-speed network; many of its links are 9.6 kilobits per second. The WIDE internet serves as a backbone link for JUNET, using the X.25 protocol and leased lines to process traffic.

JUNET is operated on a volunteer basis. Within Japan, each user organization is requested to fund and manage links between its neighboring organizations. In addition, users are charged according to the service they use on international links, which are expensive to support.

High-Energy Physics Network-Japan

The High-Energy Physics Network-Japan (HEPNET-Japan) is the Japanese portion of the international high-energy physics network. It was established in 1982 to enable researchers to access computing power at the National Laboratory for High-Energy Physics (KEK), which also operates the network.[3]

Presently, HEPNET-Japan connects researchers at more than 35 universities and other research facilities throughout Japan. The network uses leased lines and private network services operating at 9.6 to 64 kilobits per second, and supports the TCP/IP and DECnet protocols. The network also provides international connectivity to the Lawrence Berkeley Laboratories in California by a 56 kilobits per second line. HEPNET-Japan provides various services, including remote interactive computer access, data transfer, and electronic mail, and supports other uses, such as complex distributed computing applications.

KEK officials stated that they plan to upgrade HEPNET-Japan, and have requested funds to begin improving the speed of the network. As planned, the network will operate six hub sites serving users in the surrounding areas, and connect to KEK by means of 512 kilobits per second or higher-speed dedicated leased lines. Funding for the upgrade, which is estimated to cost about 100 million yen annually for leased lines, is being requested in 1991 from the Ministry of Education, Science, and Culture. Additional upgrades to increase the speed of the HEPNET-Japan backbone to 1.5 megabits per second (or higher speed) lines also are planned, but funds have not yet been requested.

Japan Information Center of Science and Technology Network

The Japan Information Center of Science and Technology (JICST) network provides users throughout Japan with access to a multitude of bibliographic and factual data bases to encourage scientific and technical research. Presently, JICST offers access to over 90 million citations on approximately 118 data bases, including data bases that exist outside of Japan. The network is operated by JICST, a quasi-governmental organization, which is financed by income from the Science and Technology Agency of the Japanese government and from service fees. About half of JICST's annual budget comes from the Agency and half comes from service fees.

[3]KEK is a national laboratory for high-energy physics research, which is funded by the Ministry of Education, Science, and Culture. The laboratory is located in Tsukuba Science City, near Tokyo.

Over three-quarters of the JICST network users are private companies; about one-fourth of the users are universities, the Japanese government, or other agencies. These users gain access to JICST's data bases on lines operating at between 300 and 2,400 bits per second, and connecting to 10 JICST branch offices located throughout Japan. The branch offices also have connections to the online data bases over lines operating at 14.4 to 64 kilobits per second. JICST officials estimated that network use has almost doubled over the past 5 years, with users currently making more than 100,000 inquiries into the data bases each month. JICST officials want to provide upgraded capability to improve online data base service and the transfer of large data files.

Plans for Future Networks in Japan

According to some officials, high-speed networks are recognized in Japan as being important and valuable, and efforts to enhance the speed and capability of the existing computer networking infrastructure are actively encouraged. The officials stated that Japanese ministries, as well as private sponsors, have proposed projects or initiated studies aimed at expanding Japan's networking capability to support research and education.

Plans to Build a Fiber-Optic Digital Network

One of Japan's most significant initiatives is a plan to develop a fiber-optic digital network that will provide service to all businesses and virtually all homes in Japan by the year 2015. This fiber-to-the-home project will support a broadband Integrated Services Digital Network (ISDN) that Japan's largest telephone company, Nippon Telegraph and Telephone Corporation (NTT), plans to build at an estimated cost of 34 to 40 trillion yen (approximately $250 billion) over 25 years. NTT receives guidance and supervision from Japan's Ministry of Posts and Telecommunications, which is responsible for regulating the telecommunications industry.

As part of the project, fiber-optic cable will be used to transmit digitized voice, data, and video traffic through a single line. NTT's goal is to provide services such as portable "pocket phones," communication of characters and images ("textmail") between any computer on any computer network, and a "visual phone" with picture quality comparable to that of television. NTT also envisions other advanced services such as 3-D video communications and automatic translation communications.

According to an NTT representative, certain factors may affect the timing and extent of the project's development. For example, NTT plans to fund the fiber-to-the-home project with corporate investment funds generated from operating revenues, rather than from direct Japanese government general funds. In the future, NTT also could receive some tax incentives. However, according to NTT's 1990 Annual Report, a large part of the corporation's stock is government-owned. Upon incorporation on April 1, 1985, all the assets and liabilities of NTT's predecessor, the Nippon Telegraph & Telephone Public Corporation, were transferred to the Japanese government. Since that time, the Japanese government has sold about one-third of these shares to the public. Eventually, the Japanese government could reduce its share of the remaining stock ownership by another one-third, in accordance with the relevant Japanese law.

Moreover, if the fiber-optic cable is to be funded out of NTT's operating revenues, the plan may proceed only to the extent that consumers will pay for the services. However, according to the NTT representative, possibly the least developed part of the project plan is the extent to which actual customer needs have been defined. In addition, at least one important regulatory issue needs to be clarified before NTT will implement its fiber-to-the-home plan. The NTT representative explained that a current law may prohibit NTT from obtaining a license to provide home cable television services. If this is determined to be the case, the law will have to be changed, or NTT will have to reevaluate further investment in the network.

A possible reorganization of the telephone industry in Japan also may affect NTT's plan. A Japanese government report in 1990 proposed dividing up NTT into smaller organizations, but no action was taken at that time. However, this issue may be reevaluated in 1995. The impact of this regulatory decision on NTT's plans is uncertain.

Initiatives Being Studied to Enhance Japan's Network Capabilities

At the time of our review, representatives of the Ministry of International Trade and Industry (MITI) told us that they were studying initiatives that could result in expanding the capability of Japanese research and education networks. These initiatives are intended to strengthen the infrastructure for research, expand knowledge in computer technology, and further international scientific cooperation.

As one initiative, MITI is considering whether to provide further funding to improve networks linking Japan's supercomputer centers. MITI officials explained that although the number of supercomputers is increasing in Japan, the linkages between supercomputer centers is limited. Moreover, researchers' access to these centers depends on how the centers are funded. MITI officials stated that currently, supercomputer centers are either (1) funded by the Ministry of Education, Science, and Culture and are limited to users at major universities, (2) funded by MITI for use by researchers at various national laboratories, or (3) privately funded for commercial business purposes. Under the initiative that MITI is considering, researchers would be allowed to access supercomputer centers regardless of the source of their funding. Although MITI recognizes that there is a need for faster networks, the officials knew of no Japanese government initiative to study computer networks faster than 1.5 megabits per second.

MITI officials told us that government funding has not yet been approved for this initiative. MITI representatives estimated that if approved, the first-year budget for this initiative will be about 600 million yen, which may include contributions from Japanese companies. MITI plans to have more discussions and request comments from interested parties on this matter.

Issues Affecting Japan's Future Development of Computer Networks

Representatives of various Japanese organizations told us that further development of computer networks to support research and education activities depends on how Japan responds to issues concerning its budget environment, coordination among Japanese government ministries, and a shrinking labor force.

Operators of existing networks and representatives of Japanese ministries told us that expanding the number and capability of research and education computer networks will require successfully competing with other high-priority programs for government funds. According to a United States Embassy official in Tokyo, some Japanese officials perceive that higher education, including academic research, has not been a top priority, and therefore, is not well-funded by the government. Moreover, planning, building, and operating future networks may require funding and support from several government ministries, such as MITI and the Ministry of Education, Science, and Culture, rather than from only one organization, as was previously done. This would require, in the opinion of various ministry representatives, more government coordination than now exists.

Another issue which may affect increased networking, and in particular the broadband ISDN project, is a forecasted shortage of workers to install the fiber-optic cables and other telecommunications equipment. According to United States Embassy officials in Tokyo, a declining birth rate trend threatens to shrink Japan's population, and consequently, the size of its labor force. An NTT representative added that finding sufficient numbers of workers also is difficult because many of the younger Japanese workers consider certain construction work, such as installing fiber-optic cables, to be dirty, difficult, and generally undesirable.

Objectives, Scope, and Methodology

At the request of the Senate Subcommittee on Science, Technology, and Space; Senate Committee on Commerce, Science, and Transportation; House Subcommittee on Technology and Competitiveness; and House Committee on Science, Space, and Technology, we studied the development of high-speed computer networks in the United States, Europe, and Japan. Because high-speed computer networks used for research and education are of primary interest in the United States, we specifically focused on networks that are used to facilitate these types of applications.

In conducting our review, we interviewed officials of various United States government agencies, including the National Science Foundation, the Defense Advanced Research Projects Agency, the National Aeronautics and Space Administration, and the Department of Commerce. In addition, we met with representatives of other organizations and agencies, such as the Corporation for National Research Initiatives, the Federal Networking Council, and EDUCOM, a nonprofit consortium of higher education institutions which facilitates the use and management of information resources in teaching, learning, and research.

To determine which European and Japanese networks to include in our review, we obtained and analyzed various documents describing each nation's network infrastructures, policies, and initiatives. We attended networking symposiums held in the United States and Europe during the time of our review; and consulted with numerous government and academic officials who were considered experts on European and Japanese computer and communication technologies, and officials of the United States Mission to the European Community and the United States Embassy in Tokyo.

On the basis of information obtained from these sources, we limited our review to those networks identified as providing high-speed communication capabilities, or if low-speed, as being important to European and Japanese research and education. Although high-speed is not formally or universally defined, various officials and symposium participants considered high-speed networks to be capable of operating at T1 speeds of 1.544 megabits per second in the United States and Japan, or E1 speeds of 2.048 megabits per second in Europe. We excluded from our review networks that were operated on a private, for-profit basis. In addition, because of the size of the European Community, we limited our review to national research and education networks in five countries—France, Germany, Italy, the Netherlands, and the United Kingdom—and five principal pan-European networks.

In the European countries and Japan, we interviewed government personnel, representatives of organizations responsible for research and development, members of the academic community, managers of key projects for enhancing the network infrastructure, and telecommunications industry officials. From these sources, we obtained information describing the present networking infrastructures, plans to upgrade or develop future infrastructures, and to the extent possible, the resources being applied to these efforts. We also obtained information regarding the challenges or concerns that Europe and Japan believe must be addressed before future plans can be fully realized.

To confirm our understanding of network development, we discussed the information in this report with various government officials and representatives of network organizations in the United States, Europe, and Japan, and have incorporated their views as appropriate. However, we did not independently verify the validity or accuracy of the information provided. Our work was conducted from October 1990 to June 1991, primarily in Washington, D.C., and the European and Japanese locations listed in appendixes V and VI, respectively.

Organizations and Entities Contacted Regarding European Networks

European Countries

France	Government Organizations Ministry of Research and Technology National Center for Scientific Research Network Operators and Users National Aerospace Research Center National Research Institute for Computer Science and Automation Postal, Telegraph, and Telephone Administration France Telecom
Germany	Government Organization Ministry for Research and Technology Network Operators and Users Deutsche Forschungsnetz (National Research Network Center) The German National Research Center for Computer Science Postal, Telegraph, and Telephone Administration Deutsche Bundespost
Italy	Government Organization Ministry of Universities and Scientific Research Network Operators and Users Group for the Harmonization of Research Networks National Institute of Nuclear Physics Postal, Telegraph, and Telephone Administration ItalCable (Italian International Telephone Agency) Italian Public Agency for Telephones
The Netherlands	Government Organization Ministry of Education

Network Operators and Users

SURFnet B.V.

Pan-European Representatives

Government Organizations

Commission of the European Communities, Directorate-General for Telecommunications

European Strategic Program for Research and Development in Information Technology (Esprit)

Research and Development in Advanced Communications Technologies in Europe (RACE) Program

Networking Organizations

Association of Internet Protocol Users in Europe (RIPE)

Réseaux Associés pour la Recherche Européenne (RARE)

Network Operators

European Academic Research Network

European UNIX Network

International X.25 Infrastructure Network

Organizations and Entities Contacted Regarding Japanese Networks

Japanese Ministries and Government Organizations

Ministry of Education, Science, and Culture
Ministry of Foreign Affairs
Ministry of International Trade and Industry
Ministry of Posts and Telecommunications
National Institute of Science and Technology Policy

Japanese Network Operators and Users

Electrotechnical Laboratory
Japan Information Center of Science and Technology
National Center for Science Information System
National Laboratory for High Energy Physics
Research Information Processing System
University of Tokyo Computer Center
Widely Integrated Distributed Environment Internet

Japanese Industry and Other Organizations

Institute for New Generation Computer Technology
Kawasaki Steel Systems R&D Corporation
Nec Corporation
Nippon Telegraph and Telephone Corporation
Sony Corporation

United States Government

Department of Defense, Office of Naval Research Asian Office (Tokyo)
United States Embassy, Tokyo

United States Industry and Other Organizations

American Chamber of Commerce (High Technology Committee), Japan
International Business Machines (IBM) World Trade Asia Corporation, IBM Asia Pacific
Pacific Area Computer Communication Testbed (University of Hawaii)

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