Chapter 3
Networks

Information is the lifeblood of science; communication of that information is crucial to the advance of research and its applications. Data communication networks enable scientists to talk with each other, access unique experimental data, share results and publications, and run models on remote supercomputers, all with a speed, capacity, and ease that makes possible the posing of new questions and the prospect for new answers. Networks ease research collaboration by removing geographic barriers. They have become an invaluable research tool, opening up new channels of communication and increasing access to research equipment and facilities. Most important networking is becoming the indispensable foundation for all other use of information technology in research.

Research networking is also pushing the frontiers of data communications and network technologies. Like electric power, highways, and the telephone, data communications is an infrastructure that will be crucial to all sectors of the economy. Businesses demand on-line transaction processing, and financial markets run on globally networked electronic trading. The evolution of telephony to digital technology allows merging of voice, data, and information services networking, although voice circuits still dominate the deployment of the technology. Promoting scientific research networking—dealing with data-intense outputs like satellite imaging and supercomputer modeling—should push networking technology that will find application far outside of science.

Policy action is needed, if Congress wishes to see the evolution of a full-scale national research and education network. The existing "internet" of scientific networks is a fledgling. As this conglomeration of networks evolves from an R&D enterprise to an operational network, users will demand round-the-clock, high-quality service. Academics, policy makers, and researchers around the world agree on the pressing need to transform it into a permanent infrastructure. This will entail grappling with difficult issues of public and private roles in funding, management, pricing/cost recovery, access, security, and international coordination as well as assuring adequate funding to carry out initiatives that are set by Congress.

Research networking faces two particular policy complications. First, since the network in its broadest form serves most disciplines, agencies, and many different groups of users, it has no obvious lead champion. As a common resource, its potential sponsors may each be pleased to use it but unlikely to give it the priority and funding required to bring it to its full potential. There is a need for clear central leadership, as well as coordination of governments, the private sector, and universities. A second complication is a mismatch between the concept of a national research network and the traditionally decentralized, subsidized, mixed public-private nature of higher education and science. The processes and priorities of mission agency-based Federal support may need some redesigning, as they are oriented towards supporting ongoing mission-oriented and basic research, and may work less well at fostering large-scale scientific facilities and infrastructure that cut across disciplines and agency missions.

In the near term, the most important step is getting a widely connected, operational network in place. But the "bare bones" networks are a small part of the picture. Information that flows over the network, and the scientific resources and data available through the network, are the important payoffs. Key long-term issues for the research community will be those that affect the sort of information available over the network, who has access to it, and how much it costs. The main issue areas for scientific data networking are outlined below:

- research-to develop the technology required to transmit and switch data at very high rates;
- private sector participation-role of the common carriers and telecommunication companies in developing and managing the network and of private information firms in offering services;
- scope—who the network is designed to serve will drive its structure and management;
- access—balancing open use against security and information control and determining who

will be able to gain access to the network for what purpose;

- standards-the role of government, industry, users, and international organizations in setting and maintaining technical standards;
- management-public and private roles; degree of decentralization;
- funding-an operational network will require significant, stable, continuing investment; the financial responsibilities demarcated must reflect the interests of various players, from individual colleges through States and the Federal Government, in their stake in network operations and policies;
- economics-pricing and cost recovery for network use, central to the evolution and management of any infrastructure. Economics will drive the use of the network;
- information services-who will decide what types of services are to be allowed over the network, who is allowed to offer them; and who will resolve information issues such as privacy, intellectual property, fair competition, and security;
- long-term science policy issues—the networks' impacts on the process of science, and on access to and dissemination of valuable scientific and technical information.

THE NATIONAL RESEARCH AND EDUCATION NETWORK (NREN)

"A universal communications network connected to national and international networks enables electronic communication among scholars anywhere in the world, as well as access to worldwide information sources, special experimental instruments, and computing resources. The network has sufficient bandwidth for scholarly resources to appear to be attached to a world local area network."

EDUCOM, 1988.

". . . **a** national research network to provide a distributed computing capability that links the govemment, industry, and higher education communities."

OSTP, 1987.

"The goal of the National Research and Education Network is to enhance national competitiveness and productivity through a high-speed, high-quality network infrasoucture which supports a broad set of applications and network services for the research **and** instructional community."

EDUCOM/NTTF March 1989.

"The NREN will provide high-speed communication access to over 1300 institutions across the United States within five years. It will offer sufficient capacity, performance, and functionality so that the physical distance between institutions is no longer a barrier to effective collaboration. It will support access to high-performance computing facilities and services . , . and advanced information sharing and exchange, including national file systems and online libraries . . . the NREN will evolve toward fully supported commercial facilities that support a broad range of applications and services."

FRICC, Program Plan for the NREN, May 23, 1989.

This chapter of the background paper reviews the status of and issues surrounding data networking for science, in particular the proposed NREN. It describes current Federal activities and plans, and identifies issues to be examined in the full report, to be completed in summer 1990.

The existing array of scientific networks consists of a hierarchy of local, regional and national networks, linked into a whole. In this paper, "NREN" will be used to describe the next generation of the national "backbone" that ties them together. The term "Internet" is used to describe a more specific set of interconnected major networks, all of which use the same data transmission protocols. The most important are NSFNET and its major regional subnetworks, ARPANET, and several other federally initiated networks such as ESNET and NASNET. The term internet is used fairly loosely. At its broadest, the more generic term internet can be used to describe the international conglomeration of networks, with a variety of protocols and capabilities, which have a gateway into Internet; which could include such things as BITNET and MCI Mail.

The Origins of Research Networking

Research users were among the first to link computers into networks, to share information and broaden remote access to computing resources. DARPA created ARPANET in the 1960s for two purposes: to advance networking and data communications R&D, and to develop a robust communications network that would support the data-rich conversations of computer scientists. Building on the resulting packet-switched network technology, other agencies developed specialized networks for their research communities (e.g., ESNET, CSNET NSFNET), Telecommunications and electronic industries provided technology and capacity for these networks, but they were not policy leaders or innovators of new systems. Meanwhile, other research-oriented networks, such as BITNET and Usenet, were developed in parallel by academic and industry users who, not being grantees or contractors of Federal agencies, were not served by the agency-sponsored networks. These university and lab-based networks serve a relatively small number of special - ized scientific users, a market that has been ignored by the traditional telecommunications industry. The networks sprang from the efforts of users—academic and other research scientists-and the Federal managers who were supporting them.[1]

The Growing Demand for Capability and Connectivity

Today there are thousands of computer networks in the United States. These networks range from tempoary linkages between modem-equipped[2] desktop computers linked via common carriers, to institution-wide area networks, to regional and national networks, Network traffic moves through different media, including copper wire and optical cables, signal processors and switches, satellites, and the vast common carrier system developed for voice communication. Much of this hodgepodge of networks has been linked (at least in terms of ability to interconnect) into the internet. The ability of any two systems to interconnect depends on their ability to recognize and deal with the form information flows take in each. These "protocols" are sets of technical standards that, in a sense, are the "languages" of communication systems. Networks with different protocols can often be linked together by computer-based "gateways" that translate the protocols between the networks.

National networks have partially coalesced, where technology allows cost savings without losing connectivity. Over the past years, several agencies have pooled funds and plans to support a shared national backbone. The primary driver for this interconnecting and coalescing of networks has been the need for connectivity *among* users. The power of the whole is vastly greater than the sum of the pieces. Substantial costs are saved by extending connectivity while reducing duplication of network coverage. The real payoff is in connecting people, information, and resources. Linking brings users in reach of each other. Just as telephones would be of little use if only a few people had them, a research and education network's connectivity is central to its usefulness, and this connectivity comes both from ability of each network to reach the desks, labs, and homes of its users and the extent to which various networks are, themselves, interconnected.

The Present NREN

The national research and education network can be viewed as four levels of increasingly complex and flexible capability:

- physical wire/fiberoptic common carrier ''highways";
- user-defined, packet-switched networks;
- basic network operations and services; and
- research, education, database, and information services accessible to network users

In a fully developed NREN, all of these levels of service must be integrated. Each level involves different technologies, services, policy issues, research opportunities, engineering requirements, clientele, providers, regulators, and policy issues. A more detailed look at the policy problems can be drawn by separating the NREN into its major components.

Level 1: Physical wire/fiber optic common carrier highways

The foundation of the network is the physical conduits that carry digital signals. These telephone wires, optical fibers, microwave links, and satellites are the physical highways and byways of data transit. They are invisible to the network user. To provide the physical skeleton for the intemet, government, industry, and university network man-

[1] John S. Quarterman and Josiah C. Hoskins, "Notable Computer Networks," *Communications of the ACM*, vol 29, No. 10, October 1986, pp. 932-971; John S. Quarterman, *The Matrix: Networks Around the World*, Digital Press, August 1989

[2] A "Modem" converts information in a computer to a form that a communication system can carry, and vice versa. It also automates SOme Simple functions, such as dialing and answering the phone, detecting and correcting transmission errors.

agers lease circuits from public switched common carriers, such as AT&T, MCI, GTE, and NTN. In doing so they take advantage of the large system of circuits already laid in place by the telecommunications common carriers for other telephony and data markets. A key issue at this level is to what extent broader Federal agency and national telecommunications policies will promote, discourage, or divert the evolution of a research-oriented data network.

Level 2: User-defined subnetworks

The internet is a conglomeration of smaller foreign, regional, State, local, topical, private, government, and agency networks. Generally, these separately managed networks, such as SURANET, BARRNET, BITNET, and EARN, evolved along naturally occurring geographic, topical, or user lines, or mission agency needs. Most of these logical networks emerged from Federal research agency (including the Department of Defense) initiatives. In addition, there are more and more commercial, State and private, regional, and university networks (such as Accunet, Telenet, and Usenet) at the same time specialized and interlined. Many have since linked through the Internet, while keeping to some extent their own technical and socioeconomic identity. This division into small, focused networks offers the advantage of keeping network management close to its users; but demands standardization and some central coordination to realize the benefits of interconnection.

Networks at this level of operations are distinguished by independent management and technical boundaries. Networks often have different standards and protocols, hardware, and software. They carry information of different sensitivity and value. The diversity of these logical subnetworks matters to institutional subscribers (who must choose among network offerings), to regional and national network managers (who must manage and coordinate these networks into an internet), and to users (who can find the variety of alternatives confusing and difficult to deal with). A key issue is the management relationship among these diverse networks; to what extent is standardization and centralization desirable?

Level 3: Basic network operations and services

A small number of basic maintenance tools keeps the network running and accessible by diverse, distributed users. These basic services are software-based, provided for the users by network operators and computer manufacture in operating systems. They include software for password recognition, electronic-mail, and file transfer. These are core services necessary to the operation of any network. These basic services are not consistent across the current range of computers used by research. A key issue is to what extent these services should be standardized, and as important, who should make those decisions.

Level 4: Value-added superstructure: **links to research, education, and information services**

The utility of the network lies in the information, services, and people that the user can access through the network. These value-added services provide specialized tools, information, and data for research and education. Today they include specialized computers and software, library catalogs and publication databases, archives of research data, conferencing systems, and electronic bulletin boards and publishing services that provide access to colleagues in the United States and abroad. These information resources are provided by volunteer scientists and by non-profit, for-profit, international, and government organizations. Some are amateur, poorly maintained bulletin boards; others are mature information organizations with well-developed services. Some are "free"; others recover costs through user charges.

Core policy issues are the appropriate roles for various information providers on the network. If the network is viewed as public infrastructure, what is "fair" use of this infrastructure? If the network eases access to sensitive scientific data (whether raw research data or government regulatory databases), how will this stress the policies that govern the relationships of industry, regulators, lobbyists, and experts? Should profit-seeking companies be allowed to market their services? How can we ensure that technologies needed for network maintenance, cost accounting, and monitoring will not be used inappropriately or intrusively? Who should set prices for various users and services? How will intellectual property rights be structured for electronically available information? Who is responsible for the quality and integrity of the data provided and used by researchers on the network?

Research Networking as a Strategic High Technology Infrastructure

Research networking has dual roles. First, networking is a strategic, high technology infrastructure for science. More broadly applied, data networking **enables** research, education, business, and manufacturing, and improves the Nation's knowledge competitiveness. Second, networking technologies and applications are themselves a substantial growth area, meriting focused R&D.

Knowledge is the commerce of education and research. Today networks are the highways for information and ideas. The y expand access to computing, data, instruments, the research community, and the knowledge they create. Data are expensive (relative to computing hardware) and are increasingly created in many widely distributed locations, by specialized instruments and enterprises, and then shared among many separate users. The more effectively that research information is disseminated to other researchers and to industry, the more effective is scientific progress and social application of technological knowledge. An internet of networks has become a strategic infrastructure for research.

The research networks are also a testbed for data communications technology. Technologies developed through the research networks are likely to enhance productivity of all economic sectors, not just university research. The federally supported Internet has not only sponsored frontier-breaking network research, but has pulled data-networking technology with it. ARPANET catalyzed the development of packet-switching technology, which has expanded rapidly from R&D networking to multibillion-dollar data handling for business and financial transactions. The generic technologies developed for the Internet-hardware (such as high-speed switches) and software for network management, routing, and user interface-will transfer readily into general data-networking applications. Government support for applied research can catalyze and integrate R&D, decrease risk, create markets for network technologies and services, transcend economic and regulatory barriers, and accelerate early technology development and deployment. This would not only bolster U.S. science and education, but would fuel industry R&D and help support the market and competitiveness of the U.S. network and information services industry,

Governments and private industries the world over are developing research networks, to enhance R&D productivity and to create testbeds for highly advanced communications services and technologies. Federal involvement in infrastructure is motivated by the need for coordination and nationally oriented investment, to spread financial burdens, and promote social policy goals (such as furthering basic research).[3] Nations that develop markets in network-based technologies and services will create information industry-based productivity growth.

Federal Coordination of the Evolving Internet

NREN plans have evolved rapidly. Congressional interest has grown; in 1986, Congress requested the Office of Science and Technology Policy (OSTP) to report on options for networking for research and supercomputing.[4] The resulting report, completed in 1987 by the interagency Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), called for a new Federal program to create an advanced national research network by the year 2000.[5] This vision incorporated two objectives: 1) providing vital computer-communications network services for the Nation academic research community, and 2) stimulating networking and communications R&D which would fuel U.S. industrial technology and commerce in the growing global data communications market.

The 1987 FCCSET report, building on ongoing Federal activities, addressed near-term questions over the national network scope, purposes, agency authority, performance targets, and budget. It did not resolve issues surrounding the long-term operation of a network, the role of commercial services in

[3] Congressional Budget Office, *New Directions for the Nation's Public Works*, September 1988, p. xi ii; CBO, *Federal Policies for Infrastructure Management*, June 1986,

[4] P.L. 99-383, Aug. 21, 1986.

[5] OSTP, *A Research and Development Strategy for High Performance Computing*, Nov 20, 1987

providing network operations and services, or interface with broader telecommunications policies.

A 1988 National Research Council report praised ongoing activities, emphasized the need for coordination, stable funding, broadened goals and design criteria, integrated management, and increased private sector involvement.[6]

FCCSET'S Subcommittee on Networking has since issued a plan to upgrade and expand the network.[7] In developing this plan, agencies have worked together to improve and interconnect several existing networks. Most regional networks were joint creations of NSF and regional consortia, and have been part of the NSFNET world since their inception. Other quasi-private, State, and regional networks (such as CICNET, Inc., and CERFNET) have been started.

Recently, legislation has been reintroduced to authorize and coordinate a national research network.[8] As now proposed, a National Research and Education Network would link universities, national laboratories, non-profit institutions and government research organizations, private companies doing government-supported research and education, and facilities such as supercomputers, experimental instruments, databases, and research libraries. Network research, as a joint endeavor with industry, would create and transfer technology for eventual commercial exploitation, and serve the data-networking needs of research and higher education into the next century.

Players in the NREN

The current Internet has been created by Federal leadership and funding, pulling together a wide base of university commitment, national lab and academic expertise, and industry interest and technology. The NREN involves many public and private actors. Their roles must be better delineated for effective policy. Each of these actors has vested interests and spheres of capabilities. Key players are:

- universities, which house most end users;
- networking industry, the telecommunications, data communications, computer, and information service companies that provide networking technologies and services;
- State enterprises devoted to economic development, research, and education;
- industrial R&D labs (network users); and
- the Federal Government, primarily the national labs and research-funding agencies

Federal funding and policy have stimulated the development of the Internet. Federal initiatives have been well complemented by States (through finding State networking and State universities' institutional and regional networking), universities (by funding campus networking), and industry (by contributing networking technology and physical circuits at sharply reduced rates). End users have experienced a highly subsidized service during this "experimental" stage. As the network moves to a bigger, more expensive, more established operation, how might these relative roles change?

Universities

Academic institutions house teachers, researchers, and students in all fields. Over the past few decades universities have invested heavily in libraries, local computing, campus networks, and regional network consortia. The money invested in campus networking far outweighs the investment in the NSFNET backbone. In general, academics view the NREN as fulfillment of a longstanding ambition to build a national system for the transport of information for research and education. EDUCOM has long labored from the "bottom" up, bringing together researchers and educators who used networks (or believed they could use them) for both research and teaching.

Networking Industry

There is no simple unified view of the NREN in the fragmented telecommunications "industry." The long-distance telecommunications common carriers generally see the academic market as too specialized and risky to offer much of a profit opportunity.

[6] National Research Council, *Toward a National Research Network* (Wash] ngton, DC, National Academy Press, 1988), especially pp. 25-37.

[7] FCCSET or Federal Coordinating Council for Science, Engineering, and Technology, The *Federal High Performance Computing Program*, Washington, DC, OSTP, Sept. 8, 1989.

[8] S. 1067, "The National High-Performance Computer Technology Act of 1989," May 1989, introduced by Mr. Gore, Hearings were held on June 21, 1989, H.R. 3131, "The National High-Performance Computer Technology Act of 1989," introduced by Mr. Walgren.

However, companies have gained early experience with new technologies and applications by participating in university R&D; it is for this reason that industry has jointly funded the creation and development of NSFNET.

Various specialized value-added common carriers offer packet-switched services. They could in principle provide some of the same services that the NREN would provide, such as electronic mail. They are not, however, designed to meet the capacity requirements of researchers, such as transferring vast files of supercomputer-generated visualizations of weather systems, simulated airplane test flights, or econometric models. Nor can common carriers provide the "reach" to all carriers.

States

The interests of States in research, education, and economic development parallel Federal concerns. Some States have also invested in information infrastructure development. Many States have invested heavily in education and research networking, usually based in the State university system and encompassing, to varying degrees, private universities, State government, and industry. The State is a "natural" political boundary for network financing. In some States, such as Alabama, New York, North Carolina, and Texas, special initiatives have helped create statewide networks.

Industry Users

There are relatively few industry users of the internet; most are very large R&D-intensive companies such as IBM and DEC, or small high-technology companies. Many large companies have internal business and research networks which link their offices and laboratories within the United States and overseas; many also subscribe to commercial services such as MCI Mail. However, these proprietary and commercial networks do not provide the internet's connectivity to scientists or the high bandwidth and services so useful for research communications. Like universities and national labs, companies are a part of the Nation's R&D endeavor; and being part of the research community today includes being "on" the internet. Appropriate industry use of the NREN should encourage interaction of industry, university, and government researchers, and foster technology transfer. Industry internet users bring with them their own set of concerns such as cost accounting, proper network use, and information security. Other non-R&D companies, such as business analysts, also are likely to seek direct network connectivity to universities, government laboratories, and R&D-intensive companies.

Federal

Three strong rationales-support of mission and basic science, coordinating a strategic national infrastructure, and promotion of data-networking technology and industrial productivity-drive a substantial, albeit changing, Federal involvement. Another more modest goal is to rationalize duplication of effort by integrating, extending, and modernizing existing research networks. That is in itself quite important in the present Federal budgetary environment. The international nature of the network also demands a coherent national voice in international telecommunications standardization. The Internet's integration with foreign networks also justifies Federal concern over the international flow of militarily or economically sensitive technical information. The same university-government-industry linkages on a domestic scale drive Federal interests in the flow of information.

Federal R&D agencies' interest in research networking is to enhance their external research support missions. (Research networking is a small, specialized part of agency telecommunications. It is designed to meet the needs of the research community, rather than agency operations and administrative telecommunications that are addressed in FTS 2000.) The hardware and software communications technologies involved should be of broad commercial importance. The NREN plans reflect national interest in bolstering a serious R&D base and a competitive industry in advanced computer communications.

The dominance of the Federal Government in network development means that Federal agency interests ha-e strongly influenced its form and shape. Policies can reflect Federal biases; for instance, the limitation of access to the early ARPANET to ARPA contractors left out many academics, who consequent y created their own grass-roots, lower-capability BITNET.

International actors are also important. As with the telephone system, the internet is inherently international. These links require coordination, for example for connectivity standards, higher level network management, and security. This requirement implies the need for Federal level management and policy.

The NREN in the International Telecommunications Environment

The nature and economics of an NREN will depend on the international telecommunications context in which it develops. Research networks are a leading edge of digital network technologies, but are only a tiny part of the communications and information services markets.

The 1990s will be a predominantly digital world; historically different computing, telephony, and business communications technologies are evolving into new information-intensive systems. Digital technologies are promoting systems and market integration. Telecommunications in the 1990s will revolve around flexible, powerful, "intelligent" networks. However, regulatory change and uncertainty, market turbulence, international competition, the explosion in information services, and significant changes in foreign telecommunications policies, all are making telecommunications services more turbulent. This will cloud the research network's long-term planning.

High-bandwidth, packet-switched networking is at persent a young market in comparison to commercial telecommunications. Voice overwhelmingly dominates other services (e.g. fax, e-mail, on-line data retrieval). While flexible, hybrid voice-data services are being introduced in response to business demand for data services, the technology base is optimized for voice telephony.

Voice communications brings to the world of computer telecommunications complex regulatory and economic baggage. Divestiture of the AT&T regulated monopoly opened the telecommunications market to new entrants, who have slowly gained long-haul market share and offered new technologies and information services. In general, however, **the** post-divestiture telecommunications industry remains dominated by the descendants of old AT&T, and most of the impetus for service innovations comes from the voice market. One reason is uncertainty about the legal limits, for providing information services, imposed on the newly divested companies. (In comparison, the computer industry has been unregulated. With the infancy of the technology, and open markets, computer R&D has been exceptionally productive,) **A crucial concern for long-range NREN planning is that scientific and educational needs might be ignored among the regulations, technology priorities, and economics of a telecommunications market geared toward the vast telephone customer base.**

POLICY ISSUES

The goal is clear; but the environment is complex, and the details will be debated as the network evolves

There is substantial agreement in the scientific and higher education community about the pressing national need for a broad-reaching, broad-bandwidth, state-of-the-art research network, The existing Internet provides vital communication, research, and information services, in addition to its concomitant role in pushing networking and data handling technology, Increasing demand on network capacity has quickly saturated each network upgrade. In addition, the fast-growing demand is overburdening the current informal administrative arrangements for running the Internet. Expanded capability and connectivity will require substantial budget increases. The current network is adequate for broad e-mail service and for more restricted file transfer, remote logon, and other sophisticated uses. Moving to gigabit bandwidth, with appropriate network services, will demand substantial technological innovation as well as investment.

There are areas of disagreement and even broader areas of uncertainty in planning the future national research network. There are several reasons for this: the immaturity of data network technology, services, and markets; the Internet's nature as strategic infrastructure for diverse users and institutions; and the uncertainties and complexities of overriding telecommunications policy and economics.

First, the current Internet is, to an extent, an experiment in progress, similar to the early days of the telephone system. Technologies, uses, and potential markets for network services are still nascent.

Patterns of use are still evolving; and a reliable network has reached barely half of the research community. Future uses of the network are difficult to identify; each upgrade over the past 15 years has brought increased value and use as improved network capacity and access have made new applications feasible.

The Internet is a conglomeration of networks that grew up ad hoc. Some, such as ARPANET, CSNET, and MFENET, were high-quality national networks supported by substantial Federal funding. Other smaller networks were built and maintained by the late-night labors of graduate students and computer centers operators. One of these, BITNET, has become a far-reaching and widely used university network, through the coordination of EDUCOM and support of IBM. The Internet has since become a more coherent whole, under Federal coordination led by NSF and DARPA and advised by the Internet Activities Board. Improvements in service and connectivity have been astounding. Yet the patchwork nature of the Internet still dominates; some campus and regional networks are high quality and well maintained; others are lower speed, less reliable, and reach only a few institutions in their region. Some small networks are gatewayed into the Internet; others are not. This patchwork nature limits the effectiveness of the Internet, and argues for better planning and stronger coordination.

Second, the network is a strategic infrastructure, with all the difficulties in capitalizing, planning, financing, and maintaining that seem to attend any infrastructure.[9] Infrastructures tend to suffer from a "commons" problem, leading to continuing underinvestment and conflict over centralized policy. By its nature the internet has many diverse users, with diverse interests in and demands on the network. The network's value is in linking and balancing the needs of these many users, whether they want advanced supercomputer services or merely e-mail. Some users are network-sophisticated, while many users want simple, user-friendly communications. This diversity of users complicates network planning and management. The scope and offerings of the network must be at least sketched out before a management structure appropriate to the desired mission is established.

Third, the network is part of the telecommunications world, rampant with policy and economic confusion. The research community is small, with specialized data needs that are subsidiary to larger markets. It is not clear that science's particular networking needs will be met.

Planning Amidst Uncertainty

Given these three large uncertainties, there is no straightforward or well-accepted model for the "best" way to design, manage, and upgrade the future national research network. Future network use will depend on cost recovery and charging practices, about which very little is understood. These uncertainties should be accommodated in the design of network management as well as the network itself.

One way to clarify NREN options might be to look at experiences with other infrastructures (e.g., waterways, telephones, highways) for lessons about how different financing and charging policies affect who develops and deploys technology, how fast technology develops, and who has access to the infrastructure. Additionally, some universities are beginning trials in charging for network services; these should provide experience in how various charging practices affect usage, technology deployment and upgrading, and the impacts of network use policies on research and education at the level of the institution.

Table 3-1 lists the major areas of agreement and disagreement in various "models" of the proper form of network evolution.

Network Scope and Access

Scope

Where should an NREN reach: beyond research-intensive government laboratories and universities to all institutions of higher education? high schools? nonprofit and corporate labs? Many believe that eventually— perhaps in 20 years-de facto data networking will provide universal linkage, akin to a sophisticated phone system.

[9] Congressional Budget Office, *New Directions for the Nation's Public Works,* September 1988; National Council on Public Works Improvement, *Fragile Foundation A Report on America's Public Works,* Washington, IX, February 1988.

Table 3-1-Principal Policy Issues in Network Development

Major areas of agreement	Major areas of disagreement and uncertainty
Scope and access	
1. The national need for a broad state-of-the-art research network that links basic research, government, and higher education.	Ia. The exact scope of the NREN; whether and how to control domestic and foreign access.
	Ib. Hierarchy of network capability. Cost and effort limit the reach of state-of-the-art networking; an "appropriate networking" scenario would have the most intensive users on a leading edge network and less demanding users on a lower-cost network that suffices for their needs. Where should those lines be drawn, and who should draw them? How can the Federal Government ensure that the gap between leading edge and casual is not too large, and that access is appropriate and equitable?
Policy and management structure	
2. The need for a more formal mechanism for planning and operating the NREN, to supersede and better coordinate informal interagency cooperation and ad hoc university and State participation, and for international coordination.	2a. The form and function of an NREN policy and management authority; the extent of centralization, particularly the role of Federal Government; the extent of participation of industry users, networking industry, common carriers, and universities in policy and operations; mechanisms for standard setting,
Financing and coat recovery	
3. The desirability of moving from the current "market-establishing" environment of Federal and State grants and subsidies, with services "free" to users, to more formal cost recovery, shifting more of the cost burden and financial incentives to end users.	3a. How the transition to commmercial operations and charging can and should be made; more generally, Federal-private sector roles in network policy and pricing; how pricing practices will shape access, use, and demand.
Network Use	
4. The desirability of realizing the potential of a network; the need for standards and policies to link to information services, databases, and nonresearch networks.	4a. Who should be able to use the network for what purposes, and at what entry rest; the process of guiding economic structure of services, subsidies, price of for multi-product services; intellectual property policies.

S0URCE: Office of Technology Assessment, 1989.

The appropriate breadth of the network is unlikely to be fully resolved until more user communities gain more experience with networking, and a better understanding is gained of the risks and benefits of various degrees of network coverage. A balance must be struck in network scope, which provides a small network optimized for special users (such as scientists doing full-time, computationally intensive research) and also a broader network serving more diverse users. The scope of the internet, and capabilities of the networks encompassed in the internet, will need to balance the needs of specialized users without diluting the value for top-end and low-end users. NREN plans, standards, and technology should take into account the possibility of later expansion and integration with other networks and other communities currently not linked up. After-the-fact technical patches are usually inefficient and expensive. This may require more government participation in standard-setting to make it feasible for currently separated communities, such as high schools and universities, to interconnect later on.

Industry-academic boundaries are of particular concern. Interconnection generally promotes research and innovation. Companies are dealing with risk of proprietary information release by maintaining independent corporate networks and by restricting access to open networks. How can funding and pricing be structured to ensure that for-profit companies bear an appropriate burden of network costs?

Access

Is it desirable to restrict access to the internet? Who should control access? Open access is desired by many, but there are privacy, security, and commercial arguments for restricting access. Restricting access is difficult, and is determined more by access controls (e.g., passwords and monitoring) on the computers that attach users to the network, than by the network itself. Study is needed on whether and how access can be controlled by technical fixes within the network, by computer centers attached to the network, informal codes of behavior, or laws,

Another approach is not to limit access, but minimize the vulnerability of the network—and its information resources and users-to accidents or malice. In comparison, essentially anyone who has a modest amount of money can install a phone, or use a public phone, or use a friend's phone, and access the national phone system. However, criminal, fraudulent, and harassing uses of the phone system are illegal. Access is unrestricted, but use is governed.

Controlling International Linkages

Science, business, and industry are international; their networks are inherently international. It is difficult to block private telecommunications links with foreign entities, and public telecommunications is already international. However, there is a fundamental conflict between the desire to capture information for national or corporate economic gain, and the inherent openness of a network. Scientists generally argue that open network access fosters scientifically valuable knowledge exchange, which in turn leads to commercially valuable innovation.

Hierarchy of Network Capability

Investment in expanded network access must be balanced continually with the upgrading of network performance, As the network is a significant competitive advantage in research and higher education, access to the "best" network possible is important. There are also technological considerations in linking networks of various performance levels and various architectures. There is already a consensus that there should be a separate testbed or research network for developing and testing new network technologies and services, which will truly be at the cutting edge (and therefore also have the weaknesses of cutting edge technology, particularly unreliability and difficulty of use).

Policy and Management Structure

Possible management models include: federally chartered nonprofit corporations, single lead agencies, interagency consortium, government-owned contractor operations, commercial operations; and Tennessee Valley Authority, Atomic Energy Commission, the NSF Antarctic Program, and Fannie Mae. What are the implications of various scenarios for the nature of traffic and users?

Degree of Centralization

What is the value of centralized, federally accountable management for network access control, traffic management and monitoring, and security, compared to the value of decentralized operations, open access and traffic? There are two key technical questions here: to what extent does **network** technology limit the amount of control that can be exerted over access and traffic content? To what extent does technology affect the strengths and weaknesses of centralized and decentralized management?

Mechanisms for Interagency Coordination

Interagency coordination has worked well so far, but with the scaling up of the network, more formal mechanisms are needed to deal with larger budgets and to more tightly coordinate further development.

Coordination With Other Networks

National-level resources allocation and planning must coordinate with interdependent institutional and mid-level networking (the other two legs of networking).

Mechanisms for Standard Setting

Who should set standards, when should they be set, and how overarching should they be? Standards at some common denominator level are absolutely necessary to make networks work. But excessive standardization may deter innovation in network technology, applications and services, and other standards.

Any one set of standards usually is optimal for some applications or users, but not for others. There are well-established international mechanisms for formal standards-setting, as well as strong international involvement in more informal standards development. These mechanisms have worked well, albeit slowly. Early standard-setting by agencies and their advisers accelerated the development of U.S. networks, In many cases the early established standards have become, with some modification, de facto national and even international standards. This is proving the case with ARPANET's protocol suite, TCP/IP. However, many have complained that agencies' relatively precipitous and closed standards determination has resulted in less-than-satisfactory standards. NREN policy should embrace standards-setting. Should it, however, encourage wider participation, especially by industry, than has been the case? U.S. policy must balance the need for international compatibility with the furthering of national interests.

Financing and Cost Recovery

How can the capital and operating costs of the NREN be met? Issues include subsidies, user or access charges, cost recovery policies, and cost accounting. As an infrastructure that spans disciplines and sectors, the NREN is outside the traditional grant mechanisms of science policy. How might NREN economics be structured to meet costs and achieve various policy goals, such as encouraging widespread yet efficient use, ensuring equity of access, pushing technological development while maintaining needed standards, protecting intellectual property and sensitive information while encouraging open communication, and attracting U.S. commercial involvement and third-party information services?

Creating a Market

One of the key issues centers around the extent to which deliberate creation of a market should be built into network policy, and into the surrounding science policy system. There are those who believe that it is important that the delivery of network access and services to academics eventually become a commercial operation, and that the current Federal subsidy and apparently "free" services will get academics so used to free services that there will never be a market. How do you gradually create an information market, for networks, or for network-accessible value-added services?

Funding and Charge Structures

Financing issues are akin to ones in more traditional infrastructures, such as highways and waterways. These issues, which continue to dominate infrastructure debates, are Federal private sector roles and the structure of Federal subsidies and incentives (usually to restructure payments and access to infrastructure services). Is there a continuing role for Federal subsidies? How can university accounting, OMB circular A-21, and cost recovery practices be accommodated?

User fees for network access are currently charged as membership/access fees to institutions. End users generally are not charged. In the future, user fees may combine access/connectivity fees, and use-related fees. They may be secured via a trust fund (as is the case with national highways, inland waterways, and airports), or be returned directly to operating authorities. A few regional networks (e.g., CICNET, Inc.) have set membership/connectivity fees to recover full costs. Many fear that user fees are not adequate for full funding/cost recovery.

Industry Participation

Industry has had a substantial financial role in network development. Industry participation has been motivated by a desire to stay abreast of data-networking technology as well as a desire to develop a niche in potential markets for research networking. It is thus desirable to have significant industry participation in the development of the NREN. Industry participation does several things: industry cost sharing makes the projects financially feasible; industry has the installed long-haul telecommunications base to build on; and industry involvement in R&D should foster technology transfer and, generally, the competitiveness of U.S. telecommunications industry. Industry in-kind contributions to NSFNET, primarily from MCI and IBM, are estimated at $40 million to $50 million compared to NSF's 5 year, $14 million budget. [10] It is anticipated that the value of industry cost sharing (e.g., donated switches, lines, or software) for NREN would be on the order of hundreds of millions of dollars.

[10] Eliot Marshal, "NSF Opens High-Speed Computer Network," *Science*, p. 22.

Network Use

Network service offerings (e.g., databases and database searching services, news, publication, and software) will need some policy treatment. There need to be incentives to encourage development of and access to network services, yet not unduly subsidize such services, or compete with private business, while maintaining quality control. Many network services used by scientists have been "free" to the end user.

Economic and legal policies will need to be clarified for reference services, commercial information industry, Federal data banks, university data resources, libraries, publishers, and generally all potential services offered over the network.[11] These policies should be designed to encourage use of services, while allowing developers to capture the potential benefits of network services and ensure legal and economic incentives to develop and market network services.

Longer Term Science Policy Issues

The near-term technical implementation of the NREN is well laid out. However, longer-term policy issues will arise as the national network affects more deeply the conduct of science, such as:

- patterns of collaboration, communication and information transfer, education, and apprenticeship;
- intellectual property, the value and ownership of information;
- export control of scientific information
- publishing of research results
- the "productivity" of research and attempts to measure it
- communication among scientists, particularly across disciplines and between university, government, and industry scientists.
- potential economic and national security risks of international scientific networking, collaboration, and scientific communication;
- equity of access to scientific resources, such as facilities, equipment, databases, research grants, conferences, and other scientists. (Will a fully implemented NREN change the concentration of academic science and Federal funding in a limited number of departments and research universities, and of corporate science in a few large, rich corporations; what might be the impacts of networks on traditional routes to scientific priority and prestige?)
- controlling scientific information flow. What technologies and authority to control network-resident scientific information? How might these controls affect misconduct, quality control, economic and corporate proprietary protection, national security, and preliminary release of tentative or confidential research information that is scientifically or medically sensitive?
- cost and capitalization of doing research; to what extent might networking reduce the need for facilities or equipment?
- oversight and regulation of science, such as quality control, investigations of misconduct, research monitoring, awarding and auditing of government grants and contracts, data collection, accountability, and regulation of research procedures.[12] Might national networking enable or encourage new oversight roles for governments?
- the access of various publics to scientists and research information;
- the dissemination of scientific information, from raw data, research results, drafts of papers through finished research reports and reviews; might some scientific journals be replaced by electronic reports?
- legal issues, data privacy, ownership of data, copyright. How might national networking interact with trends already underway in the scientific enterprise, such as changes in the nature of collaboration, sharing of data, and impacts of commercial potential on scientific research? Academic science traditionally has emphasized open and early communication, but some argue that pressures from competition for research grants and increasing potential for commercial value from basic research have

[11] OMB, Circular A-130, 50 Federal Register 52730 (Dec. 24, 1985); A. 130. H.R. 2381, The Information Policy Act of 1989, which restates the role of OMB and policies on government reformation dissemination.

[12] U.S. Congress, Office of Technology Assessment, *The Regulatory Environment for Science*, OTA-TM-SET-34 (Washington, DC: U.S. Government Printing Office, February 1986).

dampened free communication. Might networks counter, or strengthen, this trend?

Technical Questions

Several unresolved technical challenges are important to policy because they will help determine who has access to the network for what purposes. Such technical challenges include:

- standards for networks and network-accessible information services;
- requirements for interface to common carriers (local through international);
- requirements for interoperability across many different computes;
- improving user interfaces;
- reliability and bandwidth requirements;
- methods for measuring access and usage, to charge users that will determine who is most likely to pay for network operating costs; and
- methods to promote security, which will affect the balance-between network and information vulnerability, privacy, and open access.

Federal Agency Plans: FCCSET/FRICC

A recently released plan by the Federal Research Internet Coordinating Committee (FRICC) outlines a technical and management plan for NREN.[13] This plan has been incorporated into the broader FCCSET implementation plan. The technical plan is well thought through and represents further refinement of the NREN concept. The key stages are:

Stage 1: upgrade and interconnect existing agency networks into a jointly funded and managed T1 (1.5 Mb/s) National Networking Testbed.[14]

Stage *2:* integrate national networks into a T3 (45 Mb/s) backbone by 1993.

Stage 3: push a technological leap to a multigigabit NREN starting in the mid-1990s.

The proposal identifies two parts of an NREN, an operational network and networking R&D. A service network would connect about 1,500 labs and universities by 1995, providing reliable service and rapid transfer of very large data streams, such as are found in interactive computer graphics, in apparent real time. The currently operating agency networks would be integrated under this proposal, to create a shared 45Mb/s service net by 1992. The second part of the NREN would be R&D on a gigabit network, to be deployed in the latter 1990s. The first part is primarily an organizational and financial initiative, requiring little new technology. The second involves major new research activity in government and industry.

The "service" initiative extends present activities of Federal agencies, adding a governance structure which includes the non-Federal participants (regional and local networking institutions and industry), in a national networking council, It formalizes what are now ad-hoc arrangements of the FRICC, and expands its scale and scope. Under this effort, virtually all of the Nation's research and higher education communities will be interconnected. Traffic and traffic congestion will be managed via priority routing, with service for participating agencies guaranteed via "policy" routing techniques. The benefits will be in improving productivity for researchers and educators, and in creating and demonstrating the demand for networks and network services to the computing, telecommunications, and information industries.

The research initiative (called stage 3 in the FCCSET reports) is more ambitious, seeking support for new research on communications technologies capable of supporting a network that is at least a thousand times faster than the 45Mb/s net. Such a net could use the currently unused capabilities of optical fibers to vastly increase effective capability and capacity, which are congested by today's technology for switching and routing, and support the next generation of computers and communications applications. This effort would require a substantial Federal investment, but could invigorate the national communication technology base, and boost the long-term economic competitiveness of

[13] FRICC, *Program Plan for the National Research and Education Network,* May *23, 1989.* FRICC has members from DHHS, DOE, DARPA, USGS, NASA, NSF, NOAA, and observers from the Internet Activities Board. FRICC is an informal committee that grew out of agencies' shared interest in coordinating related network activities and avoiding duplication of resources. As the de facto interagency coordination forum, FRICC was asked by NSF to prepare the NREN program plan.

[14] See also *NYSERNET NOTE,* vol. 1, No. 1, Feb. 6, 1989. NYSERNET has been awarded a multimillion-dollar contract from DARPA to develop the National Networking Testbed.

the telecommunications and computing industries. The gigabit network demonstration can be considered similar to the Apollo project for communications technologies, albeit on a smaller and less spectacular scale. Technical research needed would involve media, switches, network design and control software, operating systems in connected computers, and applications.

There are several areas where the FRICC management plan-and other plans-is unclear. It calls for, but does not detail any transition to commercial operations. It does not outline potential structures for long-term financing or cost recovery. And the national network council's formal area of responsibility is limited to Federal agency operations. While this scope is appropriate for a Federal entity, and the private sector has participated influentially in past Federal FRICC plans, the proposed council does not encompass all the policy actors that need to participate in a coordinated national network. The growth of non-Federal networks demonstrates that some interests—such as smaller universities on the fringes of Federal-supported R&D-have not been served. The FRICC/FCCSET implementation plan for networking research focuses on the more near-term management problems of coordinated planning and management of the NREN. It does not deal with two extremely important and complex interfaces. At the most fundamental level, the common carriers, the network is part of the larger telecommunications labyrinth with all its attendant regulations, vested interests, and powerful policy combatants. At the top level, the network is a gateway into a global information supermarket. This marketplace of information services is immensely complex as well as potentially immensely profitable, and policy and regulation has not kept up with the many new opportunities created by technology.

The importance of institutional and mid-level networking to the performance of a national network, and the continuing fragmentation and regulatory and economic uncertainty of lower-level networking, signals a need for significant policy attention to coordinating and advancing lower-level networking. While there is a formal advisory role for universities, industry, and other users in the FRICC plan, it is difficult to say how and how well their interests would be represented in practice. It is not clear what form this may take, or whether it will necessitate some formal policy authority, but there is need to accommodate the interests of universities (or some set of universities), industry research labs, and States in parallel to a Federal effort. The concerns of universities and the private sector about their role in the national network are reflected in EDUCOM'S proposal for an overarching Federal-private nonprofit corporation, and to a lesser extent in NRI's vision. The FRICC plan does not exclude such a broader policy-setting body, but the current plan stops with Federal agency coordination.

Funding for the FRICC NREN, based on the analysis that went into the FCCSET report, is proposed at $400 million over 5 years, as shown below. This includes all national backbone Federal spending on hardware, software, and research, which would be funneled through DARPA and NSF and overseen by an interagency council. It includes some continued support for mid-level or institutional networking, but not the value of any cost sharing by industry, or specialized network R&D by various agencies. This budget is generally regarded as reasonable and, if anything, modest considering the potential benefits (see table 3-2).[15]

AREN Management Desiderata

All proposed initiatives share the policy goal of increasing the nation's research productivity and creating new opportunities for scientific collaboration. As a technological catalyst, an explicit national NREN initiative would reduce unacceptably high levels of risk for industry and help create new markets for advanced computer-communications services and technologies. What is needed now is a sustained Federal commitment to consolidate and fortify agency plans, and to catalyze broader national involvement. The relationship between science-oriented data networking and the broader telecommunications world will need to be better sorted out before the NREN can be made into a partly or fully commercial operation. As the engineering challenge of building a fully national data network is surmounted, management and user issues of economics, access, and control of scientific information will rise in importance.

15 For example, National Research Council, *Toward a National Research Network* (Washington, DC: National Academy Press, 1988), pp. 2~31

Table 3-2-Proposed NREN Budget ($ millions)

	FY90	FY91	FY92	FY93	FY94
FCCSET Stage 1 & 2 (upgrade; NSF)	14	23	55	50	50
FCCSET Stage 3 (gigabit+; DARPA)	16	27	40	55	60
Total	30	50	95	95	110
S. 1067 authorization	50	50	100	100	100
HR. 3131 authorization	50	50	100	100	100

SOURCE: Office of Technology Assessment, 1989.

The NREN is a strategic, complex infrastructure which requires long-term planning. Consequently, network management should be stable (insulated from too much politics and budget vagaries), yet allow for accountability, feedback, and course correction. It should be able to leverage funding, maximize cost effciency, and create incentives for commercial networks. Currently, there is no single entity that is big enough, risk-protected enough, and regulatory-free enough to make a proper national network happen. While there is a need to formalize current policy and management, there is concern that setting a strong federally focused structure in place might prevent a move to a more desirable, effective, appropriate management system in the long run.

There is need for greater stability in NREN policy. The primary vehicle has been a voluntary coordinating group, the FRICC, consisting of program officers from research-oriented agencies, working within agency missions with loose policy guidance from the FCCSET. The remarkable cooperation and progress made so far depends on a complex set of agency priorities and budget fortunes, and continued progress must be considered uncertain.

The pace of the resolution of these issues will be controlled initially by the Federal budget of each participating agency. While the bulk of the overall investment rests with midlevel and campus networks, it cannot be integrated without strong central coordination, given present national telecommunications policies and market conditions for the required network technology. The relatively modest investment proposed by the initiative can have major impact by providing a forum for public-private cooperation for the creation of new knowledge, and a robust and willing experimental market to test new ideas and technologies.

For the short term there is a clear need to maintain the Federal initiative, to sustain the present momentum, to improve the technology, and coordinate the expanding networks. The initiative should accelerate the aggregation of a sustainable domestic market for new information technologies and services. These goals are consistent with a primary purpose of improving the data communications infrastructure for U.S. science and engineering,