FEDERAL COORDINATING COUNCIL ON SCIENCE, ENGINEERING AND TECHNOLOGY

A Report to the Office of Science and Technology Policy on Computer Networks to Support Research In the United States

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A Study of Critical Problems and Future Options

Volume I
Recommendations

November 1987

TRANSMITTAL LETTER

Dr. Paul Huray
Chairman, Executive (Steering) Committee
Committee on Computer Research and Applications
Federal Coordinating Council on Science, Engineering and Technology

Dear Dr. Huray:

I am pleased to transmit to you this Computer Network Study which was done by the Federal Coordinating Council for Science, Engineering and Technology at the request of the Office of Science and Technology Policy. This study responds to a charge of the 99th Congress for "a study of critical problems and current and future options regarding communications networks for research computers, including supercomputers, at universities and Federal research facilities in the United States." (Public Law 99-383, August 21, 1986). The Congressional charge asked that requirements for supercomputers be addressed within one year and requirements for all research computers be addressed within two years. Requirements for both supercomputers and research computers are addressed in this report; therefore, no second year study is planned.

Our principal recommendation is that an advanced computer network be designed and developed to interconnect academic, industrial, and government research facilities in the U.S. This proposed network offers a challenging opportunity to enhance the research capabilities throughout this country and to improve the networking capabilities of U.S. industry. To support this innovative project, a vigorous and focused program of research and development is needed, starting immediately and continuing for a 15 year period, during which time the network will be developed.

In conducting this study, we called upon the help of many experts from government, industry, and academia. White papers were invited on networking trends, requirements, concepts, applications, and plans. A workshop involving nearly 100 researchers, network users, network suppliers, and policy officials was held to air ideas, gather information and develop the foundation for our recommendations.

I believe that this study points the way to future progress in many areas of high technology research in the U.S., and I thank all of the people who have contributed -- the workshop participants; the chairs of the workshop groups; the San Diego Supercomputer Center which hosted the workshop; authors of the white papers; the Department of Energy and the Los Alamos National Laboratory staff who edited and published the 3 volumes of the report; and the members of the FCCSET group that conducted the study.

Sincerely,

Gordon Bell
Chairman

Subcommittee on Computer Networking,
Infrastructure, and Digital Communications

Committee on Computer Research and Applications,
Federal Coordinating Council on Science,
Engineering and Technology

1. EXECUTIVE SUMMARY

A strong national effort, supported by the Federal government, is needed to improve computer networks in the U.S. and to improve the access of U.S. researchers to computing and research facilities. Today's technology is not adequate to support access to high performance computing or requirements for researchers to collaborate through computer networks. Over the next 15 years, there will be a need for a 100,000 times increase in national network capacity to enable researchers to exploit computer capabilities for representing complex data in visual form, for manipulating and interacting with this complex data and for sharing large data bases with other researchers.

The key to improving the ability of computers to serve U.S. science is better coordinated efforts of agencies that support research networks, and a new initiative to carry out engineering and research in improved data communications speeds, switching technology, network security, and interoperability standards. Rough estimates of the costs of carrying out this work are included with this study.

A plan of action is recommended to conduct a three stage program starting with the internetworking and upgrading of current agency networks and progressing to higher speed data communication services reaching virtually every university and industry research facility in the U.S.

- As the first step, the current Internet system developed by the Defense Advanced Research Projects Agency and the networks supported by agencies for researchers should be interconnected. These facilities, if coordinated and centrally managed, have the capability to interconnect many computer networks into a single virtual computer network.

- As the second step, the existing computer networks that support research programs should be expanded and upgraded to serve 200-400 research institutions with 1.5 million bits per second capabilities.

- As the third step, network service should be provided to every research institution in the U.S., with transmission speeds of three billion bits per second.

A staged program of research and development can achieve the networking capability that is needed for the third step. This research and development effort will result in support to the U.S. research community and in an enhanced ability of the U.S. computer and communications industry to compete in world markets.

This report was conducted by an interagency group of the Committee on Computer Research and Applications of FCCSET. The report was requested by the 99th Congress in Public Law 99-383.

2. COMPUTER NETWORK STUDY

2.1. BACKGROUND

In 1986, the 99th Congress charged the Office of Science and Technology Policy (OSTP) with conducting "a study of critical problems and current and future options regarding communications networks for research computers, including supercomputers, at universities and federal research facilities in the United States" (Public Law 99-383, August 21, 1986). AT OSTP's direction, an interagency group under the auspices of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) was formed to carry out the computer network study. Agencies participating were DARPA, DoD, DOE, NASA, NBS, NSF, and NIH.

The Congress asked that the following issues be included in the study:

- the networking needs of the nation's academic and federal research computer programs, including supercomputer programs, over the next 15 years, including requirements in terms of volume of data, reliability of transmission, software compatibility, graphics capabilities, and transmission security;
- the benefits and opportunities that an improved computer network would offer for electronic mail, file transfer, and remote access and communications; and
- the networking options available for linking academic and research computers, including supercomputers, with a particular emphasis on the advantages and disadvantages of fiber optic systems.

This charge conveys the concerns of the Congress that effective network services for scientists may be approaching limits while requirements for access to networks are increasing. Computer networks are a vital support component for modern science, engineering and technology. Computer networks allow the large, diverse, and geographically dispersed U.S. research community to share large scale computing resources, to access remote research facilities, and to exchange information across great distances. Computer networks have the potential to support instantaneous communication and remote collaboration on a national and international scale. However, computer networks today cannot adequately support this communication and collaboration because of limited capacity and capability as well as lack of access to networks by all of the nation's academic, industrial and government research institutions.

In June 1985, the House Science and Technology Committee highlighted the importance of access to supercomputers by researchers at universities and laboratories. In 1985 FCCSET established a Network Working Group to coordinate Federal agency networking activities. A report "Interagency Networking for Research Programs" was published in February 1986 recommending the interconnection of existing Federally supported telecommunications networks and the formation of an Interagency Research Internet Organization.

In conducting its study during late 1986 and early 1987, the FCCSET Network Study Group enlisted the help of many experts from government, industry, and academia. White papers were invited on networking trends, requirements, concepts, applications, and plans. The group reviewed the status of existing research networks, analyzed the requirements of researchers to access networks, and assessed the capabilities of current technology. A workshop involving nearly 100 researchers, network users, network suppliers, and policy officials was held in February 1987 to air ideas, gather information, and

develop the foundation for the report to the Congress. The workshop participants discussed access requirements and future alternatives; special requirements for supercomputer networks; internetwork concepts; future standards and services requirements; security issues; and the role of government in networking.

2.2. FINDINGS

The information available to the Computer Network Study Group indicated that a strong, focused effort, supported by the Federal government, is needed to allow for adequate access to computing and to research facilities, to improve the state-of-the-art of computer networking, and to meet the challenge of foreign competition in this critical area of technology.

Today access to computer networks by researchers is haphazard and dependent upon individual funding or location. There is a great redundancy in the links from various agencies to each campus. Much broader coverage and better facilities are needed throughout the nation. High performance computers are partially driving the need for improved networking capabilities. They are capable of generating data much faster than it can be communicated using today's networking technology. The development of improved networking facilities can be compared to the development of the interstate highway system. Just as the interstate highway system stimulated economic development throughout the nation, so can data communications highways stimulate U.S. research and provide equitable access to resources.

2.3. REQUIREMENTS

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

Today's networking resources are not adequate to support the needs of future U.S. researchers. Existing network links throughout the research community are generally low data rate (i.e., at most 56 kbit/s) and fully utilized. Some of these networks are severely overloaded, resulting in significant performance degradation. Additionally, more ubiquitous access is needed by the university research community, especially at smaller institutions. By 1990, U.S. researchers will need access to wide area networks that are one thousand times more capable than those available today. This estimate was based on analysis of existing network utilization, use of a typical site, experience with current local area networks, and expected future user populations. (See Volume II, Networking Requirements and Future Alternatives.) Remote high resolution interactive workstations will be essential for using computer graphics techniques which enable researchers to visualize and simulate two and three dimensional structures. Molecular biology, space exploration, cartography, ship and airplane design, and energy research applications are some of the research areas that would benefit from increased speed of data transfers. Higher speeds are also needed to allow sharing of large data bases produced by distributed research enterprises and to keep pace with future high performance computers.

Longer-range estimates vary (see volume II, Networking Requirements and Future Alternatives, and Internet Concepts), but it is clear that by the year 2000 the nation's research community will be able to make effective use of a high-capacity national network with speeds measured in billions of bits per second.

Without improved networks, speed of data transmission will be a limiting factor in the ability of future researchers to carry out complex analyses. Digital circuits are widely available today, at a transmission speed of 56 kilobits per second (kbit/s). For highly complex analyses such as examining molecular structures, investigating flows of gases and liquids, and conducting structural analyses, such speeds are impediments to productive work. Presenting computer generated images that appear to move requires 30 frames per second; each frame represents about 10 million bits per second (Mbit/s) of information. This presentation thus requires a transmission speed of 300 million bits per second of information. To support thousands of scientists simultaneously (even using advanced compression technology) would require backbone speeds of 300 billion bits per second (Gbit/s). See Appendix D for an example of collaborative research for which high speed networking is essential.

Within the next five years, Integrated Services Digital Network (ISDN) switched and non-switched circuits ranging from 64 kbit/s to 1.5 Mbit/s will be available in the larger metropolitan areas of the U.S. However, even these services will fall short of the requirements for computer networks. For example, by 1988 over 50 campus area networks (CANs) will be operational with advanced capabilities (100 Mbit/s). Wide area networks operating at a much slower data transmission rate (56 kbit/s to 1.5 Mbit/s) cannot handle the expected high data volume. See Figure 1.

Increased data communications capacity will be needed to support the effective use of supercomputers and high capacity work stations. While many scientists will have direct access to these facilities, networking will still be important for collaborative research that utilizes large programs and databases.

Other future requirements relate to interoperability and security. An individual scientist may find it necessary to interact with other scientists or machines on more than one network. Some of the networks are not compatible because they were developed according to design goals that did not include consideration of uses and technologies unrelated to the job at hand. Some of the networks are overloaded with traffic. Security is not uniformly good from network to network or from host to host.

2.4. RECOMMENDATIONS

The U.S. should undertake, as a national goal, the establishment of a National Research Network in a staged approach that supports the upgrade of current facilities, and development of needed new capabilities. Achievement of this goal would foster and enhance the U.S. position of world leadership in computer networking.

As rapidly as feasible, the National Research Network should be designed, deployed, and maintained as an advanced computer network. This network should interconnect substantially every academic, industrial and government research establishment and unique scientific resource to encourage scientific collaboration unhindered by distance and to permit the sharing of unique research facilities and resources. Since security of the network is a vital concern, appropriate policies should be adapted to protect the information in the network from threats, vulnerabilities and risks, and to assure a uniform level of security.

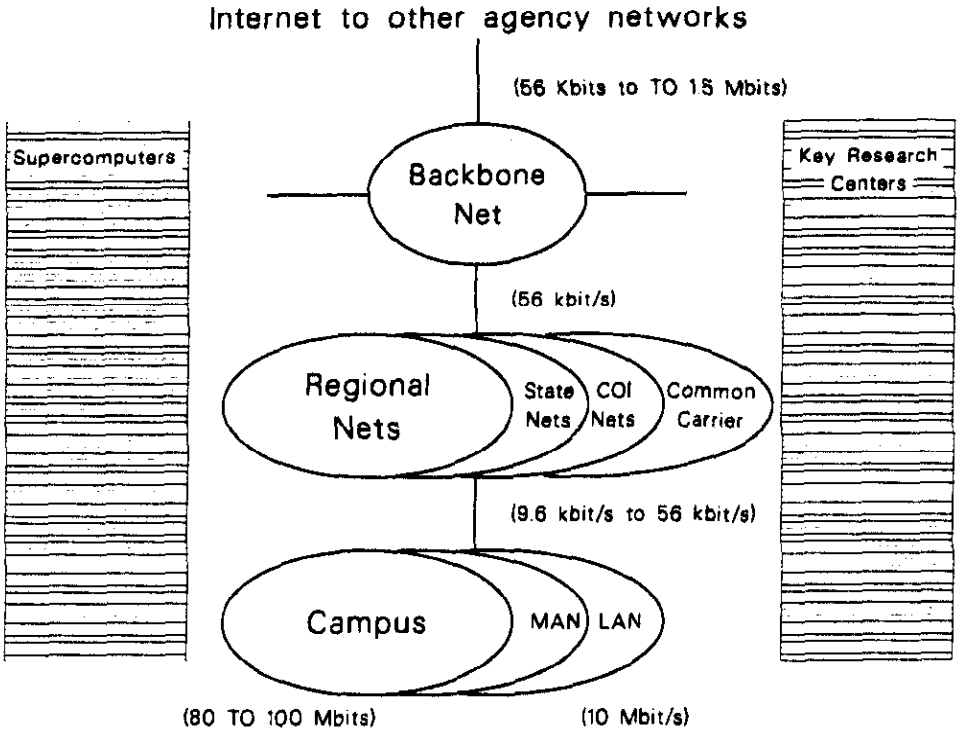

Figure 1. Research Network Hierarchy -- Today

Until the National Research Network can replace the current system, existing networks should be maintained and modified as they join the national network. Since supercomputer systems comprise a special and valuable national research resource with very high performance requirements, the responsibility for network access to supercomputers should be vested in the supercomputer centers themselves until the advanced computer network, capable of offering the requisite service level, is operational.

Industry should be encouraged through special incentives to participate in research, development, and deployment of the National Research Network. Tariff schedules which have been set for voice transmission should be re-examined in light of the requirements for transmission of data through computer networking.

To meet the goal for the National Research Network and to set an agenda for the future, the following actions are recommended:

- The Subcommittee on Computer Networking, Infrastructure and Digital Communications which was established by the Office of Science and Technology Policy on May 15, 1987, should oversee the first stage in the development and operation of the National Research Network, a coordinated internetwork that would include the Federal agencies that operate research supporting networks.
- The FCCSET Subcommittee on Computer Networking, Infrastructure and Digital Communications should identify a lead agency which would be responsible for requesting funds for the National Research Network, and eventually for selecting a contractor to manage the Network. *The manager would be responsible for* implementing Stages 2 and 3 of the National Research Network.

- As a first stage in the development of the National Research Network, the current Internet system developed by DARPA and networks supported by agencies should be interconnected over the next two years. These facilities, if coordinated and centrally managed, have the capability to interconnect many computer networks into a single virtual computer network. The Federal government should encourage and assist research facilities and academic institutions to establish local and campus area networks to connect to the Internet system. The estimated cost for this proposed upgraded service is $5 million per year and should be implemented through the shared resources of NSF, DOE, DARPA, NASA, and HHS.
- In the second stage, new funding for development should be requested at $5 million per year over the next five years to upgrade and expand the nation's existing computer networks, which support research programs, to achieve data communications at 1.5 Mbit/s to 200-400 U.S. research institutions. It is estimated that these expanded and upgraded facilities will require additional annual funding of approximately $50 million to operate.
- In the third stage, a vigorous and focused program of research and development for the National Research Network should be immediately established. A total of $400 million is needed over ten years to advance the knowledge base and technology of computer network capabilities in order to achieve data communications and switching capabilities to support transmission of three billion bits per second within fifteen years. These capabilities are 100,000 times more capable than currently available and will be essential to foster scientific collaboration and sharing of research resources. When fully deployed, the cost of operating this advanced network is estimated to be $400 million per year, given the current commercial tariffs for data communications.

Support should be given to the development of standards and their harmonization in the international arena. Aggressive action is needed to increase user participation in the standards development process, to get requirements for standards expressed early in the development process, and to speed the implementation of standards in commercial off-the-shelf products. It is essential that standards development be carried out within the framework of overall systems requirements to achieve interoperability, common user interfaces to systems, and enhanced security.

2.5. BENEFITS

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

The U.S. communications industries would also gain a significant competitive advantage. Development of modern, low-cost distributed computing facilities for wide area networks would help maintain the United States position of world leadership in utilization of wide area, high bandwidth networks. This would increase the nation's competitive edge in communications technology as well as scientific research. As a spinoff, it would help maintain the U.S. leadership position in computer architectures, microprocessors, data management, software engineering, and innovative networking facilities, and promote the development of international standards based on U.S. technology.

2.6. ACTION PLAN

The goal of the National Research Network interconnecting academic, industrial and government research organizations is reachable if we start now to support research and development on improved data communications speeds, to expand and upgrade existing networks, and to improve security and standards development.

This goal can be carried out in three stages, all of which must start immediately to achieve desired benefits. See Figure 2.

2.7. STAGE 1 THE INTERNET

This stage involves the internetworking and upgrade of existing agency networks. The various government networking activities touch a significant segment of the U.S. academic research community. The interlinking of some of these networks has already begun (e.g., NSFnet, the regional networks, the supercomputer networks, ARPANET, and other experimental defense networks). Most of these networks are adopting a common protocol suite to achieve interoperability. Through interagency collaboration, continued harmonization of protocols, and sharing of transmission facilities, these interlinked networks can be operational in two years. When these networks are in operation, performance will be 30 times that of today.

We recommend that each agency participating in the Internet (NSF, DOE, DARPA, NASA, and HHS) allocate $1 million per year to accomplish the internetwork and that the FCCSET Subcommittee on Computer Networking, Intrastructure, and Digital Communications coordinate the activity.

The 1986 Report on Interagency Networking for Research Programs by the FCCSET Committee on Very High Performance Computing recommended the establishment of an organization under the direction of a FCCSET committee to provide overall coordination of the management and operation of an interagency network. The activities recommended in the report to carry out this stage of the development of the National Research Network are:

- establish, promulgate, and coordinate protocol standards and functional standards for the interagency internetwork;
- address issues of documentation and information availability between the involved agencies;
- coordinate interagency internetworking research projects.

About $5 million per year spread over NSF, DOE, DARPA, NASA, and HHS is required to support this stage of development. Activities needed will be the purchase, installation, and operation of the major or 'core' network gateways between the existing and planned research networks; software development and maintenance, hardware maintenance, and operational monitoring and control of these gateways so that the interagency network is an available and reliable communications entity; installation of network routing, access control, and accounting procedures and tools, as these are developed; identification of the research and development projects necessary to create, maintain, and enhance the interagency network coordination of these projects with the constituent research network; implementation of standards.

2.8. STAGE 2 THE NATIONAL RESEARCH NETWORK

The goal of Stage 2 is to deliver network services of 1.5 Mbit/s to 200-300 research facilities. To provide this service, 45 Mbit/s speeds in optical fiber trunk lines must be achieved. This speed is needed to support computer graphics applications that enable users to visualize the results of calculations made on today's supercomputers and to provide the bulk capacity for thousands of users. This goal should be achievable through the application of sound development and engineering capabilities. About $5 million per year is required for development of this phase of the National Research Network and about $50 million per year to operate. A partnership with industry in the development of the National Research Network should be developed.

Private sector companies are offering an ever increasing array of communication services via satellite, recently installed optical fibers, microwave, and reorganized local service. Full advantage should be taken of these offerings as they change from time to time.

Fiber optic systems are most promising and are projected to operate at bandwidths which meet most of the requirements as defined by the U.S. research community. They also offer an additional advantage that, once installed, they should be able to accommodate more advanced, higher speed transmission equipment as it becomes available. However, lack of fiber optic ubiquity over the next decade may hinder its effectiveness to the end user or in reaching to the 'last mile'. In addition, satellite and digital microwave systems offer some economic and technical advantages which should not be overlooked for many requirements. For instance, satellite broadcast functionality may prove very beneficial to scientific collaborations and satellite transmission services may be the most cost effective approach for reaching less populated locations.

The limit of the current technology is very likely not bandwidth or connectivity. Researchers in the field suggest that the limitations will come first in gateways, routers, and switches and then later in the protocols and architectures of the networks. These issues must be addressed through a vigorous development effort to improve packet switching and protocols for networking.

2.9. STAGE 3 THE ENHANCED NATIONAL RESEARCH NETWORK

The goal of this stage is to deliver network services of 1.5 Mbit/s to every research facility in the U.S., and 1-3 Gbit/s to selected sites.

The technology to achieve this will require development and laboratory testing of new communications hardware, computer interfaces, transmission and routing protocols, and software design. The radically new designs that must result will require extensive laboratory and prototype testing.

The outcome of this process should be a design for a new national research network linking researchers and national support facilities such as supercomputer centers and research institutions. The first phase of deployment would involve settling the network design. Deployment of the trunks would follow, allowing interfaces to individual university campuses and research institutions. A national network to support research must be woven into the fabric of the national research infrastructure, and is as important as connecting major national research centers and facilities.

The estimated cost for research and development for this advanced facility is $400 million over a ten year period, and about $400 million per year may be needed to operate such a network. The cost of data communications will be a significant factor. Tariff structures created for voice communication are being imposed on data communication. The tariff structure should be reconsidered in light of the lower costs of high speed data communications using modern equipment.

The participation of industry in developing this network will be sought through the FCCSET Subcommittee on Networking, Infrastructure, and Digital Communications, the responsible agencies, and the contractor selected to operate the network. The participation of communication suppliers should be encouraged to provide low-cost fiber circuits during the critical ten-year research and development phase.

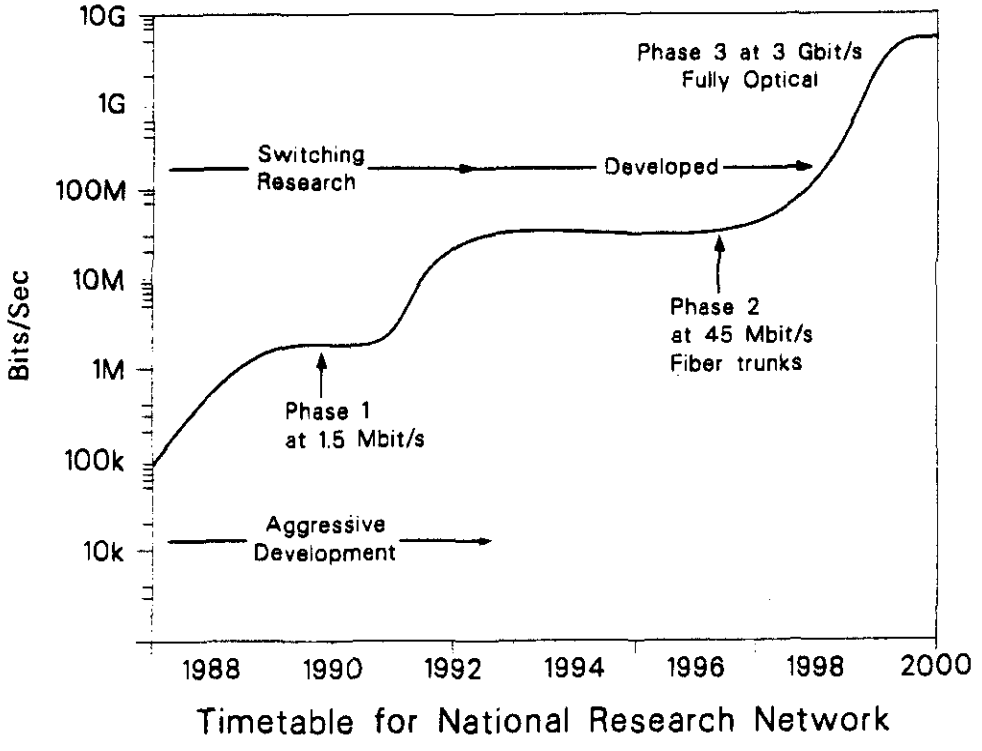

Figure 2. Timetable for a National Research Network.