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Advanced Networking Services:

Current Issues in Higher Education

Jack McCredie, University of California, Berkeley and ECAR

4772 Walnut Street, Suite 206 ◆ Boulder, Colorado 80301 ◆ www.educause.edu/ecar/

Overview

Providing a broad range of reliable computer networking services is certainly one of the key requirements—if not the most important—in the job description of a CIO at a modern college or university. Advanced high-performance networking services are rapidly becoming indispensable tools at leading universities and research organizations throughout the world. Currently the networking facilities provided to faculty, students, and staff are often adequate for the majority of their needs. Without significant investments during the next decade, however, these same organizations are in danger of falling behind the requirements of their leading researchers for using the services provided by many competitive institutions both in the United States and abroad.

The United States does not lead the world in the deployment of broadband computer networking. For example, the Organisation for Economic Co-operation and Development reported that the United States now ranks 15th of its 30 members in the number of broadband subscribers per 100 residents.[1] In 2001, the United States ranked 4th in this metric. In many other countries, the median speed at which customers are connected is significantly higher, and the cost per megabit per second significantly lower, than in the United States. These statistics reflect the present state of broadband access for individuals, not colleges and universities. U.S. higher education networks, however, are also in danger of falling behind the capabilities of those in other countries. Competition for superior facilities is very active in research and education as international research networks implement high-bandwidth capabilities and deploy application-driven services that can reconfigure worldwide networks based on the needs of specific research projects such as the Large Hadron Collider at CERN.

To help support the leadership role of the United States in science and engineering, the National Science Foundation formed the Office of Cyberinfrastructure with the following overall vision:

> NSF will play a leadership role in the development and support of a comprehensive cyberinfrastructure essential to 21st century advances in science and engineering research and education.[2]

NSF defines cyberinfrastructure as the

> comprehensive infrastructure needed to capitalize on the dramatic advances in information technology.…Cyberinfrastructure integrates hardware for computing, data and networks, digitally-enabled sensors, observatories and experimental facilities, and an interoperable suite of software and middleware services and tools. Investments in interdisciplinary teams and cyberinfrastructure professionals with expertise in algorithm development, system operations, and applications development are also essential to exploit the full power of cyberinfrastructure to create, disseminate, and preserve scientific data, information and knowledge.[3]

Cyberinfrastructure encompasses much more than advanced networking services. However, such networking resources are a necessary, albeit insufficient, condition for the support of the complex infrastructure required for world-class research and education. This research bulletin explores several of the advanced networking issues and investments that colleges and universities that aspire to support their faculty and students in leading edge research and education activities must face in the near future.

If current networking facilities in many colleges and universities are adequate for the present needs of most faculty, staff, and students, what is the issue? Networking advances during the past several years make many applications possible that were “blue sky” only a few years ago. Researchers quickly find ways of using such new capabilities to enhance their investigations. The networking innovations of our most demanding researchers soon become commonplace throughout our academic communities. Upgrading our networks and building the new coalitions required to finance, design, deploy, and support these new services require long lead times. We need to prepare now for the many advances that are just over the horizon. The following small sample of advanced applications illustrates the broad range of innovations emerging throughout our community.

The New World Symphony. Established in 1987, the mission of the New World Symphony is to prepare outstanding instrumentalists who are graduates of distinctive music programs for leadership roles in orchestras and ensembles throughout the world. It is a laboratory for music expression and education. The New World Symphony is now extending its relationships with guest conductors, coaches, and soloists through pioneering distance education projects using advanced networking services for live, interactive musical collaboration, coaching, and teaching. For example, it uses Internet2 facilities to enable its academy fellows to join in the remote exchange of master classes, seminars, rehearsals, and symposia with outstanding musicians around the globe. The organization is expanding its mission and developing a new forum for musical exchange by continuously experimenting with new uses for technology.[4]

The Large Hadron Collider. Planned to begin operations in May 2008, the Large Hadron Collider (LHC), an enormous particle accelerator and collider, is being constructed along the border between Switzerland and France near Geneva. When operational, it will become the most powerful experimental instrument ever constructed to study the smallest known particles, and it is designed to produce approximately 15 million gigabytes (or 15 petabytes) of data every year. At least 7,000 scientists from more than 80 countries will have access to the LHC, and petabytes of experimental data will flow through dozens of advanced networks for analysis throughout the world. For example, on October 1, 2003, scientists and engineers at CERN, the home of the LHC, and the California Institute of Technology set a new Internet Land Speed Record by transferring 1.1 terabytes of data in less than 30 minutes across 7000km of networks. Literally thousands of computers around the world will participate in analyzing the data produced at CERN.[5]

The Ocean Observatories Initiative. Scientists and engineers are now deploying what some are calling oceanography's third phase of research methodology (after ship-based oceanography and then satellites). This new research model is based on continuous power and data channel cables linked by networked observatories around the world. For example, in 2007 Congress gave NSF $5 million to begin the deployment of the more than $300 million Ocean Observatories Initiative. This initiative is a program that focuses the science, technology, education, and outreach of an emerging network of science-driven ocean observing systems. It will design and deploy a networked infrastructure of science-driven sensor systems to measure the physical, chemical, geological, and biological variables in the ocean and seafloor.[6]

The OptIPuter. The OptIPuter is a powerful distributed cyberinfrastructure designed to support data-intensive scientific research and collaboration. Its name is derived from its use of optical networking, Internet protocol, and computer storage, processing, and visualization technologies. The architectural element at the core of the OptiPuter is optical networking, not computers, which creates what its developers call "supernetworks." The goal of this new architecture is to enable scientists (such as those working on the LHC and the Ocean Observatories Initiative) who are generating terabytes and petabytes of data to interactively visualize, analyze, and correlate their data from multiple storage sites connected to optical networks.[7]

Highlights of Advanced Networking Services for Higher Education

Early in 2006, the University of California (UC) established the Information Technology Guidance Committee (ITGC) to study the information technology (IT) investments the UC system must make in the coming decade to maintain and enhance its strong competitive positions in research, education, and public service. The primary goal of the ITGC was to focus university-wide attention on the development of an IT infrastructure that supports and integrates the university's academic and administrative activities.

I served as chair of the Advanced Networking Services Work Group, one of six system-wide task forces charged to make recommendations in specific focus areas to the ITGC. This work group was asked to evaluate the current state of UC's networking infrastructure, identify best practices in global networking activities, and make recommendations to position UC for competitive advantage on a global basis by developing the recommended architecture for the next-generation UC network architecture. One of the members of the work group, Professor David Messerschmitt, previously served as a member of the NSF Blue Ribbon Panel on Cyberinfrastructure. In other words, the task of the six ITGC work groups was to understand the emerging role and importance of cyberinfrastructure as defined by the NSF and to develop recommendations and implementation plans about how UC should create its future IT infrastructure.[8]

Although the focus of the Advanced Networking Services Work Group was on specific issues and opportunities faced by the UC system, many of its observations, conclusions, and recommendations apply much more broadly. The intent of this research bulletin is to generalize and publicize the most important conclusions of these deliberations and to make them available to a wider audience. This bulletin is based to a large extent upon insights I gained as a participant in the year-long deliberations of the work group in addition to the background material and final report developed by the team during that process. However, the specific conclusions and recommendations presented below are my sole responsibility and do not necessarily represent the views of any of the other members of the work group or the ITGC.

For several years, computer networking capacity has doubled approximately every nine months. New services are becoming available on a regular basis, and faculty and other research personnel want to use these advances as soon as possible. For the purpose of this bulletin, “advanced networking services” means access to new circuit services based on switched Ethernet and switched optical capabilities, as well as access to traditional routed IP packet networks at substantially increased bandwidths. Such facilities are often called hybrid networks. An important example of an emerging service on such networks is the ability to provide scheduled (both static and dynamic), dedicated, end-to-end bandwidth for specialized demanding applications.[9]

The following sections illustrate some important challenges colleges and universities will have to deal with in the near future as they strive to make these new networking capabilities available not to just the “bleeding edge” of their constituents but also to a broad segment of faculty, students, and research personnel.

Enhanced Levels of End-to-End Support Personnel

Many campuses have done a much better job of bringing hardware and software to the campus than they have in providing a multi-tier, coordinated infrastructure of support professionals who can supply quality assistance to the entire university community in the use of IT resources. Departmental computing support professionals who are best situated to provide direct support are often so occupied with keeping their local technology functioning that they have little time to help their colleagues in the use of that technology, let alone the IT services offered by other departments within their campus or on other campuses.

The increased complexity and variety of choices inherent in advanced networking place escalating demands on both current and future users of the services required by their disciplines. Problems arise as a result of the distributed nature of the activities and the several different physical networks often required to establish needed end-to-end connections (e.g. departmental, campus, regional, national, and international networks). For example:

- End-to-end performance issues can be difficult to diagnose and to correct, especially when they arise from multiple causes that may exist on one or both end-hosts and some or all of the networks between them.

- Security measures such as firewalls and bandwidth resource controls can have significant negative impacts on performance. Firewalls and bandwidth-controlling devices are typically “invisible” to the end-user (although the effects are not!), especially when the device is located on a different campus. Even if your campus does not use any of these controls, a user on your campus collaborating with a colleague at a different campus may experience the detrimental effects of one of these devices at the other campus.
- Deployment of services such as dedicated optical waves requires special skills and significant coordination among distributed organizations.

Examples of important support services to help mitigate these issues include:

- Provide technical guidance about the networking technology choices that are available.
- Participate in end-to-end planning and technical coordination with campus, regional, national, and international networking organizations.
- Provide diagnostic and configuration documentation and tools to access the network and to understand performance capabilities and limits.
- Deploy and support local components that fit into larger network performance and diagnostic structures.
- Provide guidance about appropriate security technologies and architectures that can protect resources without impacting performance too severely.
- Provide documentation, coordination, and production support for distributed middleware such as directory and service location and authentication, authorization, and accounting facilities.
- Provide coordination and support for distributed collaboration tools.
- Provide directories of distributed applications and pointers to documentation about how to use them.
- Provide production support for communications activities such as large group video broadcasts.

Universities and colleges need support infrastructures that span different organizations and different networks. These support infrastructures should include departmental personnel to provide general support, as well as networking specialists at the campus and regional levels who have access to tools that provide visibility into relevant portions of the total network to resolve performance and connectivity issues. These infrastructures should also include specialists whose combined expertise covers the full range of network-based services, such as high-performance computing, video conferencing, and other forms of telecommunications.

Collaboration among Widely Distributed Virtual Organizations

Collaboration is fundamental to successful research and education. Many faculty members identify more closely with their research colleagues around the globe than with faculty in different disciplines on their own campus. Colleges and universities should enhance the ability of researchers and students to work more closely with colleagues across campus, at other campuses, and with other research organizations around the world by providing and supporting a sophisticated suite of real-time, networked collaboration applications and tools. Telephones, faxes, and e-mails are no longer adequate! Additionally, travel to meetings and conferences is being curtailed as faculty members are increasingly subjected to travel restrictions designed to cut costs and to reduce the institution's "carbon footprint."

According to the NSF,

> The convergence of information, grid, and networking technologies with contemporary communications now enables science and engineering communities to pursue their research and learning goals in real-time and without regard to geography. In fact, the creation of end-to-end cyberinfrastructure systems—comprehensive networked resources—by groups of individuals with common interests is permitting the establishment of Virtual Organizations (VOs) that are revolutionizing the conduct of science and engineering research and education.[10]

An important part of the cyberinfrastructure vision described by the NSF is the emergence of national and international groups of researchers focused on similar problems who share world-class resources through high-performance networks supporting advanced collaboration technologies. These VOs are sometimes called collaboratories, or science portals.

Today's technologies support a wide range of desktop videoconferencing capabilities, but often they are not widely deployed. One reason for the relatively slow adoption of some of these technologies is incompatible firewall settings on different campuses. However, several disciplines are successfully using advanced networking capabilities to experiment with video immersion and remote simulation laboratories. Chapter 4 of the NSF report referenced earlier outlines the initiatives the NSF plans to undertake to establish a flexible, open framework to support VOs, and Appendix E describes 56 such organizations that are currently operational.

The UC work group expects that in the coming 5 to 10 years, (1) several new modalities for distributed interactions will appear; (2) collaboration features will be integrated into all major computer applications; (3) there will be a migration to Internet-based integrated messaging services that offer voice, video, and graphics options; and (4) there will be dramatic reductions in the effort required to experiment with and implement these new ways of collaborating.

Colleges and universities should work together and with the NSF to establish the framework and standards that will support the collaborations that are fundamental to quality research and education.

Significant Additional Investment of Resources

During the budget process at UC Berkeley, senior university managers would often ask me to predict when the investments in our campus network would be complete. After wiring the dorms, classrooms, and labs, adding wireless and then upgrading speeds on everything, they were growing tired of the seemingly endless rounds of budget requests to extend, upgrade, secure, and improve this crucial element of our IT infrastructure. I always responded with the bad news that the campus network is not like a building; it will never stop growing and "eating money."

The process of building and sustaining a campus network appears to have two distinct kinds of phases: periods during which total investment in the network grows approximately linearly, as "standard" technologies are extended to more and more customers; and periods during which total investment has large, stepwise increases, as large investments are required to achieve a new level of capability. To move to the enhanced service levels promised by hybrid optical networking, significant investments must be made at the campus, regional, and national levels. One example of such an investment is the observation that current and emerging high-performance applications generally specify 10 Gbps campus connectivity between the lab and the campus border and, at the border, 10 Gbps redundant connectivity to regional and national networks.

As part of the follow-up to the work of the ITGC at UC, the standing Communications Planning Group was asked to undertake a preliminary analysis of the costs to the 10-campus system of implementing primary recommendations of the ad hoc Advanced Networking Services Work Group; for example, that each campus upgrade its connection to CalREN, the regional network, to redundant 10 Gbps connections. Their current estimates place the needed system-wide investments at approximately $80 million over the next five years.[11]

Another example is the eventual requirement to upgrade campus networks to Internet protocol version 6 (IPv6) from Internet protocol version 4 (IPv4). IPv6 is one of the newest networking standards on the horizon, and it promises vastly increased numbers of network addresses, built-in quality-of-service capabilities, much improved host auto-configuration, and potentially better routing performance. The U.S. government has specified that federal agencies should support IPv6 on their backbone networks by June 2008.[12] It is not a question of whether high-performance campus networks will have to deploy IPv6, but *when* they will have to do so.

These examples and rough cost approximations should not be taken as a model for what the costs may be for other campuses, but they illustrate the fact that upgrade expenses for emerging advanced networking services can be quite large.

The first links in the ARPANET became operational in October 1969. Beginning in 1985, NSF began sponsoring a set of coordinated activities (NSFNET) to support and promote advanced networking among U.S. research and educational institutions.[13] From these roots, U.S. higher education now finds itself in the midst of a complex and confusing web of networking organizations. For example, there are dozens of regional and statewide networking organizations and even coalitions of these organizations.[14] In addition, there are discipline-based networks such as the Energy Sciences Network, a high-speed network serving thousands of Department of Energy scientists and collaborators worldwide.[15]

Typically, a campus is a member of a regional networking organization, complete with staff, networking facilities, workshops and conferences, and purchasing arrangements with vendors. That regional organization (and/or the campus itself) is a member of one or more national networking organizations such as Internet2 or National LambdaRail (NLR). These national organizations also have staffs, national backbone networking facilities, workshops and conferences, and arrangements with vendors. All of these organizations have different peering arrangements with commercial Internet service providers. This multi-tiered national networking environment evolved over many years.

As we enter 2008, both Internet2 and NLR face serious challenges as a result of unhealthy competition, overlapping services, complex charging and membership agreements, and confusing and overlapping missions. The U.S. higher education networking environment is fragmented at just the time when we need more coherent leadership.

On and off negotiations to rationalize the national networking environment and merge the two organizations recently collapsed after more than two-and-a-half years of discussions and negotiations. Despite a tremendous amount of dedication and hard work from the merger teams from each organization, and positive support from many higher education organizations, new rounds of negotiations in 2007 once again failed to create a successful merger.

Both organizations are now pursuing their own agendas, while most observers fear that there are simply not enough resources available in the higher education community to support two competing national networking infrastructures and organizations. A year ago Polley McClure wrote an insightful Viewpoints article in *EDUCAUSE Review* in which she analyzed some of the reasons the earlier rounds of negotiations failed.[16] It is beyond the scope of this bulletin to analyze the present situation or the likely scenarios that may play out in the coming months and years. The current fragmented, competitive situation is unstable and unhealthy, however (see the cartoon below). Chancellors, presidents, and CIOs need to take an active role in trying to bring order out of the current chaos, or it will be very hard for U.S. colleges and universities to achieve the vision outlined in the NSF cyberinfrastructure report.

Internet2 and National Lambda Rail Merger Negotiations

New Policies, Procedures, and Governance Issues

Because many of the emerging services enabled by advanced hybrid networks require new forms of interinstitutional communication, cooperation, joint development, and operation, higher education and research institutions need to create new policies, procedures, and network governance models to deliver these services. In addition to these operational issues, state and national legislative bodies are passing laws requiring new levels of security to protect data and to restrict certain uses of networks. For example, they have proposed legislation that responds to demands from associations representing the entertainment industry, such as the Recording Industry Association of America (RIAA) and the Motion Picture Association of America (MPAA). Such legislation targeted at colleges and universities is intended to stop their constituents from using high-performance networking capabilities to download copyrighted material such as music, movies, and software. Most campuses now have privacy policies in place that do not allow administrators to inspect the contents of network communications without a subpoena. Technical solutions to this problem do not as yet seem feasible. Another example is the Communications Assistance for Law Enforcement Act (CALEA), which could potentially require campuses to install very expensive hardware and software to comply with its terms.

These examples illustrate the wide variety of policies and procedures that need to be discussed, developed, and then implemented across our campuses.

What It Means to Higher Education

Campus networks will continue to require attention and significant resource investments for the foreseeable future. The major issues facing the executive team of every campus boil down to two major questions:

- How much money should be invested in emerging networking capabilities?
- How soon do these investments need to occur?

Many campuses have adequate networking capabilities for the current requirements of their faculty, students, and staff. However, significant new demands are approaching quickly. They will be needed first by only a small percentage of the campus community. But these few individuals are likely to be the very scholars who are most likely to develop winning, innovative ideas that respond to proposals from major funding agencies. Many of these proposals will require advanced networking capabilities. History shows that in a relatively short time, the requirements of the most technically sophisticated researchers will become commonplace to a much larger community. Once again, it will not be a question of whether advanced network services are needed across the campus, but when.

Key Questions to Ask

- How would you describe your campus cyberinfrastructure strategy and the process for measuring and updating it as technology, economics, and politics evolve?
- To what degree do you have well-understood mechanisms to assess the long-term requirements of your faculty for advanced networking services?
- How do you assess whether your network funding model is scalable and sustainable?
- How confident are you that you have the people resources in place to support the increasingly complex technical issues arising from emerging advanced networking capabilities?
- What structures are in place for your faculty members to participate in virtual organizations (such as collaboratories, science gateways, etc.) that enable them to share world-class resources distributed throughout the world?
- To what extent does the executive leadership of your institution understand and participate in the governance processes for the national and regional networking organizations in which your campus is involved?
- What is your campus plan for migrating from IPv4 to IPv6?
- Which campus policies may have to change in response to potential new legislation regarding data security, individual privacy rights, and requirements to police the downloading activities of the campus community?

Where to Learn More

- NSF Cyberinfrastructure Council. *NSF 07-28, Cyberinfrastructure Vision for 21st Century Discovery*. National Science Foundation, March 2007, http://www.nsf.gov/pubs/2007/nsf0728/index.jsp.
- University of California Information Technology Guidance Committee. ITGC Final Report, December 2007, http://www.universityofcalifornia.edu/itgc/welcome.html.
- Internet2, http://www.internet2.edu.
- National LambdaRail, http://www.nlr.net/.

Endnotes

1. OECD Broadband Statistics, http://www.oecd.org/document/7/0,2340,en_2649_34223_38446855_1_1_1_1,00.html.
2. NSF Cyberinfrastructure Council, National Science Foundation, *NSF 07-28, Cyberinfrastructure Vision for 21st Century Discovery,* March 2007, p. 6, http://www.nsf.gov/pubs/2007/nsf0728/index.jsp.
3. Ibid., p. 5.
4. Internet2, http://www.nws.edu/AcademyInternet2.asp.
5. CERN, LHC—The Large Hadron Collider, http://lhc.web.cern.ch/lhc/.
6. Joint Oceanographic Institutions, Ocean Observing, http://www.joiscience.org/ocean_observing.
7. OptiPuter, http://www.optiputer.net.
8. The ITGC delivered its final report, *Creating a UC Cyberinfrastructure,* to the UC administration in December 2007 (http://www.universityofcalifornia.edu/itgc/ITGC_final%20report.pdf). The Advanced Networking Services Work Group used a public wiki to facilitate its year-long deliberations, to archive its working papers, and to communicate with the broad University of California community. In addition to the author, members of the work group were Mark Boolootian (UCSC), Cliff Frost (USB), John Haskins (UCSB), Jerry Keith (UCR), Ken Lindahl (UCB), Jim Madden (UCSD), David Messerschmitt (UCB), Michael Van Norman (UCLA), Michael Sinatra (UCB), David Walker (UCOP), and Jessica Yu (UCI). The work group's final report to the ITGC, background information, minutes of meetings, an assessment of the current status of networking at the university, white papers, and specific recommendations for the University of California are available at http://www.ucop.edu:8080/display/WGAN/Home.
9. A good reference to get the flavor of illustrative advanced services that are emerging internationally is the website of the Global Lambda Integrated Facility (GLIF) (http://www.glif.is/), an international virtual organization that promotes the paradigm of lambda optical networking. This site references many of the organizations throughout the world that are working with such networks, and its wiki has many entries about the technical and managerial issues faced by national research and education networks using these technologies.
10. NSF, *Cyberinfrastructure Vision*, p. 31.

11. These estimates were presented to the UC Information Technology Leadership Council on September 27, 2007, by Ken Lindahl and Cliff Frost. Their presentations are available at https://clue.berkeley.edu/nonsequitur/kenlindahl.
12. August 2, 2005, memorandum from the U.S. Office of Management and Budget to Chief Information Officers, http://www.whitehouse.gov/omb/memoranda/fy2005/m05-22.pdf.
13. On November 29–30, 2007, an event (http://www.nsfnet-legacy.org/) in Arlington, Virginia, celebrated the NSFNET, the many advances in networking it sponsored, and the extraordinary changes that networking developments have generated over the past few decades. The archive of this celebration contains a wealth of information about the history of academic networking from many of its pioneers as well as a vision of the future.
14. See, for example, the Quilt (http://www.thequilt.net/) and StateNets (http://www.educause.edu/StateNets/).
15. Energy Science Network (ESnet), http://www.esnet.net.
16. Polly Ann McClure, “Shame on Us,” *EDUCAUSE Review* 41, no. 6 (2006): 80–81, http://www.educause.edu/ir/library/pdf/erm06610.pdf.

About the Author

Jack McCredie (mccredie@berkeley.edu) is Associate Vice Chancellor Emeritus and CIO Emeritus at the University of California, Berkeley. He is also an ECAR Senior Fellow.

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