Report by the Subcommission on IT Infrastructure

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Table of Contents

Report and Recommendations 2-4

UPGRADING THE CAMPUS PHYSICAL INFRASTRUCTURE: 2-4
EXPERIMENTAL DEPLOYMENT AND EVALUATION OF EMERGING TECHNOLOGIES 2-5
UNBUNDLING OF SERVICES AND THE ESTABLISHMENT OF PRICING GUIDELINES 2-5
ORGANIZATIONAL STRUCTURE AND GOVERNANCE 2-6
CREATION OF A CAMPUS-WIDE SECURITY AND INFORMATION ASSURANCE FUNCTION 2-7
THE RECRUITMENT, TRAINING, AND RETAINING OF IT PROFESSIONAL STAFF 2-7

Appendices

APPENDIX A. VISION 2-8
APPENDIX B. UNIVERSITY OF MICHIGAN NETWORK INFRASTRUCTURE: ISSUES AND STATUS 2-11
Backbone Network Infrastructure 2-12
In-Building Network Infrastructure 2-13
Internet Connectivity 2-14
APPENDIX C. MAJOR RECOMMENDATIONS 2-15
Upgrading the Campus Physical Infrastructure 2-15
Experimental Deployment and Evaluation of Emerging Technologies 2-19
Unbundling Services and Pricing Guidelines 2-24
Organizational Structure and Governance 2-28
Campus-wide Security and Information Assurance Function 2-29
Recruiting, Training and Retaining IT Professional Staff 2-30
APPENDIX D. INFORMATION INFRASTRUCTURE AND SERVICES TAXONOMY 2-32

Report and Recommendations

A sound information technology (IT) infrastructure is essential to a healthy academic organization and its ability to fulfill its core missions of teaching, research, and service. Yet, maintaining a sound IT infrastructure poses interesting organizational challenges: the infrastructure is largely invisible when it is working; it has a high degree of complexity below the surface; and it must continually keep pace with new technologies. The Subcommission on IT Infrastructure believes that to meet these challenges, the "IT infrastructure" must be seen as more than wires, switches, and hubs. Included in its definition—and on the list of critical issues to be addressed—are the following: 1) Campus physical infrastructure, including, buildings, network backbone, and internet connectivity; 2) Advanced technologies and services for emerging technologies; 3) The unbundling of services and the establishment of pricing guidelines; 4) Organizational structure and governance; 5) Creation of a campus-wide security and information assurance function; and 6) Recruitment, training, and retaining of IT professional staff.

The University of Michigan IT infrastructure profoundly influences the culture of the institution and the potential for creativity in the academic enterprise. The IT infrastructure needs to evolve and adapt at an increasing pace to address changing user requirements and breathtaking advances in technology. If we keep pace in upgrading our infrastructure, we will also enable the emergence of new applications beneficial to our faculty and students, such as distributed modeling and simulation, three-dimensional biomedical imaging, trans-national high energy physics research, bioinformatics and computational biology, distance learning, digital arts and media, and large-scale data mining and trends analysis. The ongoing challenge will be to balance continually increasing demands for bandwidth—the available capacity to move information from point to point, both on-campus and across the Internet—with the levels of support needed by specific key University functions and institutional priorities.

This subcommission offers the following six major infrastructure recommendations to address the needs of the campus community in the coming decade:

Upgrading the Campus Physical Infrastructure

As the University's dependence on information technology has increased, demand has grown beyond the capabilities of the current infrastructure, and we find ourselves unable to provide acceptable "quality of service" to the University community. Our goal must be to successfully deploy a high-function, heterogeneous IT infrastructure that will support a high level of "end-to-end" performance, e.g., one that will permit faculty and students to move very large amounts of data very rapidly from their desktops and labs to other points on campus or off campus, seamlessly and reliably.

To meet this goal, we must do three things: a) upgrade in-building network infrastructure; b) upgrade campus backbone infrastructure; and c) upgrade external Internet connectivity.

Specific recommendations include:

- Upgrade building wiring as needed to provide the capacity to support up to one (1) Gigabit per second (Gbit/s) connectivity to end-user locations, with minimum desktop performance of 100

Megabits per second (Mbit/s). This upgrade will take several years to complete and should start soon and be sustained until completed.

- Upgrade the campus backbone network to provide backbone bandwidth capacity to support ten (10) Gbit/s of aggregate service. This upgrade, including fiber optic cable, electronics and necessary physical provisioning, should begin immediately.
- Upgrade our external connectivity to provide sufficient levels of commodity and Internet2 connectivity in light of anticipated traffic growth stemming from increased demand and removal of artificial bottlenecks as the preceding upgrades are realized.
- Coordinate efforts with the State of Michigan, telecommunications providers, peer universities, and the regional business community to locate a Network Access Point (NAP) in the southeast Michigan area, preferably in Ann Arbor.

Experimental Deployment and Evaluation of Emerging Technologies

As technology advances, what were once specialized services tend to become widespread and basic, i.e., they become part of the infrastructure. Institutions that foresee and effectively manage this cycle reap significant advantages over time: having experience with new technologies early in the life cycle greatly facilitates their widespread deployment later in the life cycle. Therefore, the University should support investment in pilot projects and experimental evaluations in order to continuously integrate new core and specialized services that address the teaching and research needs of the faculty and students. This report identifies three areas requiring focused investment and exploration in the near term:

Pilot Wireless Infrastructure Initiative: Start a focused Pilot Wireless Infrastructure Initiative to test the deployment of wireless networking on a large campus for planning and evaluation of a future pervasive campus installation.

Advanced Technologies and Services for Emerging Applications: Develop pilot projects and prototype demonstrations of services and technologies that support high performance research and instructional applications. This initiative is meant to exploit the full potential of emerging infrastructure and computing capabilities.

Voice over IP Initiative: Develop a plan to exploit the rapid convergence of voice and data networks into a "universal network" and to test the widespread deployment of Voice over IP technology to replace the University's legacy telephone system.

Unbundling of Services and the Establishment of Pricing Guidelines

A key principle held by this subcommission is that IT services should be "unbundled" to clearly separate unrelated services as well as basic services from specialized technology services. In terms of service availability and cost allocations, certain components of the network infrastructure should be offered and priced as unbundled services and not financially tied to or related to each other. This

action allows units to better plan and allocate their own resources in terms of their own missions and priorities. We endorse the University's early efforts in separating different technology services and establishing a pricing model for each service.

Specific recommendations include:

- The backbone network should be viewed as a strategic asset of the University. It should be provided to the campus as a commodity service with minimal bundling or tying with other services.
- The idea of unbundled services should be a framework for pricing and cost allocation decisions. This approach should balance those services that are provided in a "common good" manner through central funding and those specialized and/or advanced services that are cost-recovered via chargeback systems.
- A "Campus IT Pricing and Services Commission" should be formed at a senior strategic level to advise the University executive officers on IT service and pricing recommendations.
- A monitoring and measurement infrastructure should be deployed to aid in the collection and analysis of short-term and historical data for use in service measurement, pricing and allocation decisions.

Organizational Structure and Governance

The University executive officers must make timely, informed, strategic decisions for the campus as a whole—including decisions about which services are to be provided centrally and which should be of local responsibility. They need a mechanism that assures that campus-wide issues are brought to their attention in a timely and persuasive way. We are agnostic on what the right administrative and governance structure might be. We are sure that it involves coordination at a high level, where many of the key decisions should be made. We propose a simple test of whether the governance structure is minimally adequate:

Addressing the needs of the network infrastructure requires informed executive-level attention of a kind that has been missing for many years. If the Executive Officers have not approved an overall campus networking plan that addresses the recommendations of this subcommission within six months of the release of this report, including the identification of resources to support the needed upgrades, it is plain that our governance structure is inadequate to the task at hand.

Specific recommendations include:

- Executive and central IT leadership, with the cooperation of the campus IT organizations, must refocus to support the collaborative upgrade of the campus information infrastructure.
- Central IT administration and the Provost's Office must begin to negotiate and initiate a concerted campus-wide building infrastructure upgrade plan with Deans and Directors.
- IT administration must streamline and optimize key committees such as the Strategic Directions Group (SDG) and the IT Federation. These groups should be coordinated with IT leadership to insure that their input and counsel are provided to the Executive Officers.

- IT administration must extend working corporate partnerships in IT for key areas of infrastructure development at all levels. Some areas for increased corporate partnership include the Pilot Wireless Infrastructure Initiative, campus-wide software licenses, campus-wide high performance end-to-end networking, and Voice over IP telephony.

Creation of a Campus-wide Security and Information Assurance Function

The increasing reliance on information technology for teaching, research, and administrative functions has necessitated an explosive growth in size and complexity of the underlying IT infrastructure. This dependency on timely and reliable access to information and services is not without risk. University campuses especially face the dual challenge of protecting systems and services from outside attacks and protecting the Internet from attacks originating on campus, while at the same time ensuring appropriate access to University information assets. The subcommission endorses the recommendations made by the University Security Architecture Task Force and strongly recommends the establishment of a campus-wide security and information assurance function with appropriate representation from various IT administrative units.

Specific objectives of this effort include:

- Ensure the security and privacy of valuable digital records and assets across campus through rigorous and continuous assessment of policies and practices on an ongoing basis.
- Ensure implementation of baseline security in the University-wide IT infrastructure and services shared by both academic and administrative environments.
- Establish mechanisms to ensure that "preventative IT security measures are available" to the entire campus.
- Establish a "Crisis Response Team" representing campus IT service providers to coordinate a University-wide response to potential technology-based attacks or mishaps.

Recruitment, Training, and Retaining of IT Professional Staff

As the demand for IT professionals continues to exceed the supply, the University must develop a multi-faceted approach to address the IT support needs for instruction, research, and administration. The subcommission recognizes the need for an institutional response to the challenges of recruiting, developing, and retaining qualified IT staff in a highly competitive market. The subcommission strongly recommends that the University make a long-term commitment, starting immediately, to recruit and hire needed IT professional staff, and to further develop and maintain critically needed professional staff skills through ongoing training and retraining of IT personnel.

Specific recommendations include:

- The University must develop innovative compensation packages to reward excellence and to maintain a degree of parity with industry in recruiting and retaining professional IT staff.
- The University should create internship and training programs, partnership programs, and transition programs to move recent graduates and support staff into IT professional roles.

APPENDIX A. Vision

A sound information technology (IT) infrastructure is essential to a healthy academic organization and its ability to fulfill its core missions of teaching, research, and service. And yet, maintaining a sound IT infrastructure poses interesting organizational challenges: the infrastructure is largely invisible when it is working; it has a high degree of complexity that lies below the surface; and it must continually keep pace with new technologies. Think for a moment about the national electrical grid. All of us depend on electricity, but very few of us know the details behind its generation or distribution. If electrical service is disrupted or changes radically, we notice it, and questions are asked—just as they are now being asked in California. Electricity distribution and use is now standardized, but it wasn't always that way. In the late 19th century there were several different electrical grids and services, with some communities using AC and others using DC services. We are in a similar state of affairs with information technology infrastructure today: it is evolving rapidly and changing daily, and standards come and go. Development of IT infrastructure to support our research, education, and service missions could do more to change the institutional culture and the possibility for creativity in the academic enterprise than any single thing since the library. Consequently, the University's IT infrastructure must evolve at a rapid pace and continuously adapt to changing user requirements, emergence of new applications, and breathtaking advances in technology.

> As we approach the new millennium, it is clear that the "information infrastructure"—the interconnected networks of computers, devices, and software—may have a greater impact on worldwide social and economic structures than all networks that have preceded them. The advances in computing and communications technologies of the last decade have already transformed our society in many ways. These advances have transformed the ways in which we view ourselves, our relationships with each other and with other communities, and the ways in which we obtain services, ranging from entertainment and commerce to education and healthcare. Even so, we have only just begun to grasp the opportunities and experience the transformations that will occur as these technologies mature. *"Information Technology Research: Investing in Our Future," President's Information Technology Advisory Committee, February 1999.*

Demands upon the IT infrastructure, and expectations for service, are rising exponentially. Performance requirements are changing almost daily. Technology use at the University is growing very rapidly, but levels of general fund infrastructure support have remained relatively flat and auxiliary operating revenues have decreased. As a result, we now face tremendous pressures on our infrastruc-

ture capacity as well as rapidly rising costs. Some important indicators are apparent in comparing today's IT use on campus with that of 1994:

- The number of users of Information Technology Central Services (ITCS) core services has increased from under 20,000 to over 100,000.
- The percentage of students using a computer daily to read e-mail has increased from 17% to 92%.
- The size of the dial-in modem pool has increased from 500 to over 1,800 modems.
- The number of telephone lines at the University has increased by over 10,000 lines.
- University Internet usage is now doubling annually and Internet2 research experimentation is taking place.

A dramatic example of the increasing pressure on the IT infrastructure is the growth of Internet traffic, which is unprecedented and is not predicted to subside. The University of Michigan has seen a doubling of Internet network traffic each year for the last several years, consistent with similar patterns at other major academic institutions.

Another equally dramatic example is the increase of the power of the desktop computer. It is widely appreciated that the common desktop machine of today is more powerful that the mainframes of the past. What is less well appreciated is that by the end of the decade standard desktop workstations will be more powerful than the most powerful supercomputers of today, having Terahertz processors and Terabyte memory systems—a thousand-fold increase from the Gigahertz and Gigabyte systems of today. By 2020 another 1000-fold increase in computing and network capacity is predicted. IT infrastructure upgrades must keep pace with, and in some cases anticipate, these trends.

> Many of the studies of exponential growth of computational power based on Moore's Law focus on the doubling of the computational power every eighteen months. What has been more dramatic in the last decade is the doubling of magnetic densities every twelve months and doubling of optical network bandwidth every eight months. These advances portend transformations in societal use of information technology that will be far-reaching and revolutionary. *Raj Reddy, Herbert A. Simon University Professor of Computer Science and Robotics; School of Computer Science, Carnegie Mellon University; Co-chair of the President's Information Technology Advisory Committee.*

The University of Michigan has traditionally been a leader in IT infrastructure, providing powerful capabilities to faculty and students for research and education. In the MTS era (1965-1985), our faculty and students benefited tremendously from access to an innovative and world-leading campus system that was widely implemented as a standard in academic institutions. In the NSFnet era (1985-1995), the campus again benefited by being in a leadership position in the development and exploitation of national and worldwide connectivity. In these periods, the University realized great benefits by combining vision with bold initiative and ongoing, disciplined implementation of infrastructure, facilitated by critical partnerships with corporations and government.

In recent years, the ability of the University to offer its faculty and students the best computing environment has diminished. We are no longer in a clear position of leadership, and this has important implications for recruitment and retention of faculty and students and for the effectiveness of the members of our campus community.

We can learn from our own past. By acting boldly, the University can regain national leadership and visibility in Information Technology Infrastructure in three to five years, with measurable positive effects seen within a year. Implementing an information technology infrastructure that captures the spirit of the times will transform our research and education environments and re-establish our competitive advantage. We need a precision deployment of diverse, high-quality IT functions reflecting the varied needs of our community, all at the cutting edge. We need people to support these efforts who are the best available and paid a competitive wage. We need to seek and seize opportunities for key partnerships to facilitate this implementation.

The President's Information Revolution Commission (PIRC) report can help provide vision and give important meaning and value to this process, but it cannot deal with practical details of implementation or with the acute need for leadership. Empowered University executive leadership, in combination with a decisive action plan, is both warranted and necessary. The situation is simply too complex, too central to the core missions, and too expensive to treat in any other way.

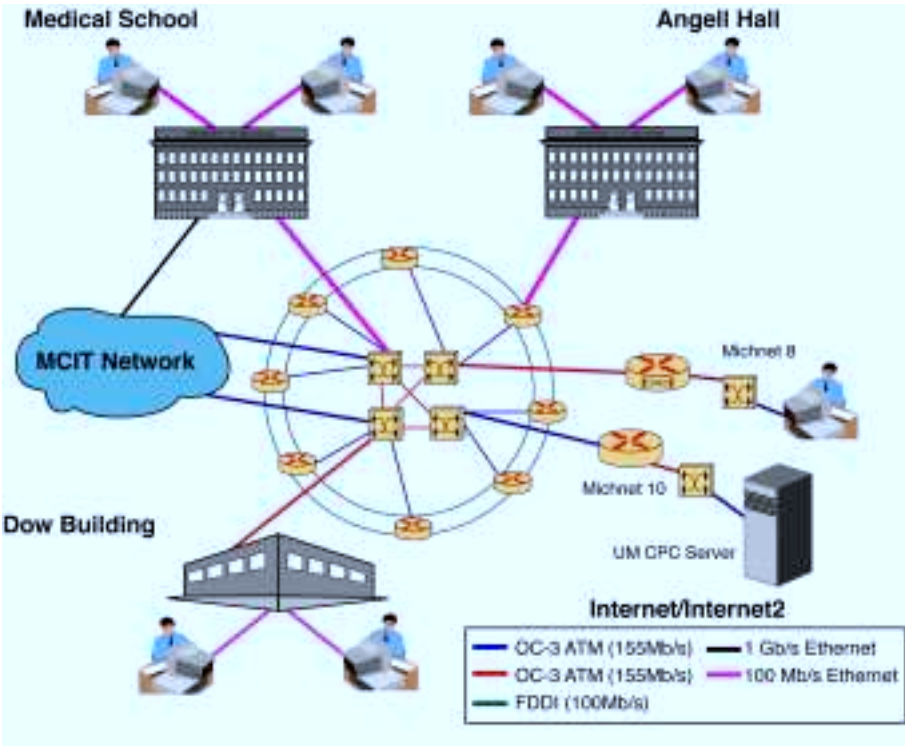


Figure 1: *The University of Michigan information infrastructure must link users in University buildings and facilities to those across campus and throughout the world.*

APPENDIX B. University of Michigan Network Infrastructure: Issues and Status

The IT Infrastructure Subcommittee finds the current status of the U-M network infrastructure unacceptable. The implementation of a University-wide network infrastructure upgrade plan for mission-critical components has been stalled and is most likely under-specified and under-funded. Key University-level committees—such as the IT Federation, the Strategic Directions Group (SDG), the Research Computing Advisory Committee, and several others—are not performing optimally or have disbanded. Many of our best IT managers and staff have departed the University, sometimes in frustration. The University is running close to capacity on several backbones, networks, and facilities. These problems are shared across centralized and college-based service providers and often "cascade" to magnify the individual problems. If we do not address this situation, the University will become increasingly vulnerable to IT and communications problems, seriously threatening the productivity of our faculty and students. For these reasons, the proposed IT infrastructure upgrades should start immediately, as this will take several years to complete and will be an ongoing process.

The IT infrastructure at U-M flourished in the MTS era (1965-1985) and the NSFnet era (1985-1995) by combining vision with disciplined implementation. Key corporate and government partnerships were critical to these success stories. We note that significant internal investments occurred to fund these initiatives and that some of these investments were taken from telephone system operating margins—no longer possible today. Also, in these earlier times the use of these capabilities were more limited to a small number of "early adapters"; today the use of, and need for, IT services is pervasive. As we establish another new era of IT, the University's IT infrastructure will require a precision deployment of a diverse set of high-quality IT services that reflect the varied needs of our community. These services range from the network infrastructure layer to highly specialized computational resources.

The University of Michigan maintains a very large and complex network and computing infrastructure. The Ann Arbor campus is served by a fully redundant ATM OC-12c[1] backbone to carry IP[2] traffic, three large 100Mbps FDDI[3] rings to carry legacy protocols such as Novell IPX and AppleTalk, and a Gigabit Ethernet backbone serving the Medical Center complex. Over 200 buildings are connected to this fiber optic backbone, and over 50,000 network Ethernet and ATM connections are supported by the network infrastructure. The three University of Michigan campuses are connected to the Internet via Merit Network Inc.,[4] of which the University is a founding member. Commodity Internet traffic[5] to and from the Ann Arbor campus averages over 70 Megabits per second. The University also maintains an OC-12c connection to the Internet2 Abilene network[6] for research purposes. Point-to-point T-1 circuits[7] and Asynchronous Digital Subscriber Line (ADSL) circuits[8] provide network connectivity to leased buildings in the Ann Arbor area that lie outside the "footprint" of the campus. Faculty and staff members residing in appropriate service areas can install ISDN, ADSL, or cable modem services in their homes.

The University of Michigan owns and operates a Nortel SL-100 telephone switch and twenty remote switches, providing over 45,000 voice circuits to the Ann Arbor, Dearborn, and Flint campuses. A

SONET[9] fiber optic ring carries voice traffic on the Ann Arbor campus, and microwave and ATM links provide voice services to the Dearborn and Flint campuses. Point-to-point T-1 circuits connect remote medical clinics to the Ann Arbor campus for telephone services. Numerous network connections to Ameritech and long-distance providers are also maintained.

Several administrative and academic units provide IT services to the Ann Arbor campus. The Information Technology Central Services unit (ITCS) is the largest of these service providers, and reports to the University Chief Information Officer. ITCS is responsible for providing technology infrastructure, telephony, data backbone, Internet access, video streaming, and cable television services to all administrative and academic units of the University. The Medical Center Information Technology unit (MCIT) provides administrative and professional networking and computing services to the University of Michigan Health System. The Computer Aided Engineering Network (CAEN) provides network support and services to the College of Engineering and the Media Union and operates the backbone network for the College of Engineering. CAEN also provides host connectivity and local network support for facilities it directly operates, and it runs a backbone network that connects North Campus to the rest of campus and the Internet. Other schools, colleges, and units maintain significant information technology service organizations that offer unique networking and computing services to their constituencies in addition to the campus-wide services provided by ITCS. A newly formed organization, Michigan Administrative Information Services (MAIS), provides enterprise administrative computing applications and operations to the University. Effective coordination of various IT organizations on campus is critical to ensure appropriate input on strategic and tactical issues concerning information infrastructure to University Executive Officers.

Backbone Network Infrastructure

The term "backbone network" refers to the high-speed data network infrastructure that connects various building networks or local area networks (LANs) and facilities on campus. For the purposes of this document, the external fiber cable plant itself and the rest of the backbone are treated separately.

There are three interconnected backbone networks on the University of Michigan Ann Arbor campus. They are provided by CAEN (supporting the College of Engineering), MCIT (supporting the U-M Health Systems), and ITCS (supporting the rest of campus). This split reflects local requirements in terms of capacity and financing as much or more than local technical issues. The three backbones interoperate as peer networks. The groups that support these networks work closely with each other in both planning and operating activities. Each network serves a large segment of the campus community as shown below:

	CAEN	**ITCS**	**MCIT**
Attached Networks	65	240	118
Major Buildings	TBD	TBD	25
Remote Sites	TBD	TBD	68
Workstations	13,000	42,000	14,000

When addressing the functionality provided by the backbone network, there are five fundamental issues:

- **Performance and Capacity**—choosing the necessary capacity and then providing the effective application of the available capacity to meet the backbone's production requirements.
- **Availability**—maintaining the accessibility and operational integrity of the backbone for 99.999% of the time. This means there should be less than five minutes of unplanned downtime for the backbone over the course of a year.
- **Service Capabilities**—deciding which network-level protocols should be supported and routed across the backbone.
- **Security**—maintaining the integrity of the backbone and the data that it transports in the face of external and internal attacks and mishaps.
- **Geographical Coverage—**determining the degree to which University locations are attached to the network. Today, all major U-M buildings have direct access to a backbone network.

When addressing any one of these issues, the University's IT community should work together and strive for the most effective and efficient implementations. The functionality of our backbone networks is not consistently kept in lock step with the computing needs of the rest of campus. The capacity and quality of the campus backbone should not be a barrier to instructional, research, and administrative uses of information technologies. We note that the recent upgrade of the campus backbone was the result of the collaborative work of the IT Federation Network Working Group, representing many of the major campus IT network service providers.

In-Building Network Infrastructure

The network infrastructure within buildings is responsible for providing connectivity from offices, classrooms, laboratories, and residence halls to the backbone network.[10] The quality of network connectivity within a building directly impacts the quality-of-service (delays in transmitting data and reliability of the packets transmitted) observed by an end-user sitting at a workstation in a teaching laboratory, classroom, or office. There are significant variations in the quality of building network connectivity across campus. A large percentage of the buildings on campus continue to have outmoded twisted pair or coaxial cable types, commonly installed more than 10 years ago. "Category 3" unshielded twisted pair copper cable installations are capable of only 10 Mbit/s. Coaxial cable installations are typically associated with "shared" Ethernet networks where many workstations share a single 10 Mbit/s data circuit. Re-cabling will be required to install the up-to-date Category 5e or Category 6 cable that has been recommended by the IT Federation Network Working Group.

Furthermore, the problem of in-building infrastructure is exacerbated by the need to frequently upgrade electronic devices such as switches and routers, which tend to have a 3–4 year life cycle. For example, it is estimated that 45% of LS&A buildings will require new horizontal wiring and 75% of the buildings will require new switching electronics to meet current needs. It is not uncommon to have a building with a shared 10Mbits per second Ethernet bus-based technology forcing hundreds of users to

contend for limited bandwidth. The G. G. Brown building in the College of Engineering is a good example of a shared Ethernet environment. In G. G. Brown, there are 400 workstations in a single-collision domain on a shared Ethernet network. Because of the contention for the network and data collisions, the total available bandwidth for the shared network is approximately 1.4 Mbit/s. The end result is that average bandwidth to each workstation is less than what is available from a dial-in modems. The IT Federation Network Working Group has prepared an initial building-by-building analysis and initial prioritization of upgrades based on existing in-building infrastructure and use of the building.

Because of these problems, data exchange and sharing is cumbersome for researchers. Poor local wiring prevents users from obtaining acceptable access to the campus backbone network, limiting access to information resources available locally within the University and globally across the Internet. A wide range of services, including day-to-day access to documents, e-mail, library resources and web services are impacted. It is difficult to provision separate high-capacity connections to research labs in most campus buildings.

Internet Connectivity

The University of Michigan receives its external Internet connectivity, both commodity and Internet2, from Merit Network Inc., a non-profit membership organization governed by all thirteen of Michigan's four-year public universities. Merit operates MichNet, which provides Internet access to the member universities as well as to a large number of educational, governmental, and community service organizations. U-M has network attachments to MichNet from Ann Arbor, Flint, and Dearborn, as well as a number of lower speed attachments serving the Biological Station in Pellston and Medical Center sites in Coldwater, Jackson, Stockbridge, and Lansing. A high-speed (OC12) full duplex ATM attachment carries Internet traffic between U-M's Ann Arbor campus and Merit.

In addition to its commodity Internet access, the U-M has had access to high performance networks for a number of years. The U-M first obtained high performance network access in August 1997 when a 155Mbits/s attachment to the NSF's very high speed Backbone Network Service (vBNS) was installed from Chicago to East Lansing; vBNS traffic was carried over a lower speed circuit between East Lansing and Ann Arbor, diminishing the capability of U-M's vBNS service. The U-M's high performance network attachment was upgraded in August 1999 to a 622Mbits/s attachment from Ann Arbor to the Internet2 "Abilene" network node in Cleveland. This higher speed link bypassed the network bottleneck and was initially shared by Michigan State University and Wayne State University. Michigan Technological University, Western Michigan University, and other institutions have now been attached to this circuit. Gateways link Internet2/Abilene, a number of international high performance research and education networks, and several high performance networks operated by federal agencies such as the Department of Energy, the Department of Defense, and the National Aeronautics and Space Administration. The Internet2 access is a critical resource that provides high speed access between the U-M campus and other academic institutions and research labs.

The University of Michigan has seen a doubling of Internet network traffic each year for the last several years. The annual cost of providing commodity Internet and Internet2 services has increased from approximately $200,000 in FY98 to over $1,000,000 in FY2001. The increased demand is consistent with similar patterns at other academic institutions. For the current academic year (2000-01) it was estimated that U-M would use a peak of approximately 215Mbits/s of commodity Internet bandwidth. In the previous academic year (1999-2000) this figure was 115Mbits/s. Final projections for the next academic year are not complete, but initial estimates are that U-M's peak commodity bandwidth use will again double to approximately 400-430Mbits/s. It is likely that U-M's network traffic growth during the last two years has been limited by bottlenecks at various levels within the campus network. The University must be prepared to deal with significant increase in demand for Internet access as these bottlenecks are removed, and as we witness the emergence of applications such distance learning, digital libraries, virtual collaboratories, and digital arts, entertainment and media. Recreational uses of IT, such as media serving systems like Napster, Gnutella, and CuteMX, can have a rapid and deleterious effect on network performance and Internet connectivity. The emergence of commercial and peer-to-peer streaming audio and video files presages dramatic and sometimes discontinuous growth in U-M's bandwidth needs.

APPENDIX C. Major Recommendations

Upgrading the Campus Physical Infrastructure

The University's dependence on its information technology infrastructure is increasing, and the demand has grown beyond the capabilities of the current infrastructure. We now face enormous challenges to our ability to provide an acceptable quality of service to the University community. Faculty, students, and staff using network services are dependent on the capability of the entire "end-to-end" network path in order to perform their tasks: The connection from their office to the building closet, from the closet to the building uplink to the network backbone, from the backbone to the server or servers they are using—on campus or off campus—must all be able to support the demands of the applications they use. If any of those components is not performing at a sufficient level, the demands the users have of the network will not be met. The building wiring may not be adequate and may only support a shared 10 Mbits/s network for all network users in the building. The building uplink may only provide 100 Mbits/s capacity for the entire building, and so on. To achieve adequate end-to-end performance for our faculty and students, each building should have a base level of network connectivity, and this recommended base level should be as consistent and as homogeneously provided as possible. The base level of network connectivity should satisfy all foreseen mainstream network uses.

There is great variance in the quality of the various portions of the network infrastructure on campus. In addition, various parts of the network, as we noted earlier, fall under different administrative domains—some are within the purview of the schools and colleges, some the central administration. For these reasons, it is difficult to define specific upgrades that will simultaneously provide the same level of improvement for all areas of campus or for all user communities. Each unit needs to under-

stand its own requirements as they relate to the areas of in-building and campus backbone cabling, and each unit must be prepared to work with the central administration in terms of funding and improving their network environments.

In addition, the types of work required to implement the various upgrades (such as installing electrical conduit and cable trays in buildings, installing underground ductwork and conduit, constructing building wiring closets, or pulling various types of cable and fiber within buildings) vary widely in cost and effort and will vary from location to location on campus. Because of these variations, the following upgrades are not presented in a strict priority order.

In terms of delivery of network service and operations, the campus network infrastructure will be required to:

- Provide the capacity to support one (1) Gbit/s connectivity to desktops and other specific locations in buildings, with a minimum desktop performance of 100 Mbit/s.
- Support a range of traffic types, such as voice, video, multimedia, and storage area networks and accommodate their various requirements, such as quality of service and capacity, while maintaining high-quality traditional data services.
- Ensure security and privacy of valuable digital records and assets through rigorous and continuous assessment of policies and practices.
- Include an integrated and secure wireless LAN component.
- Be manageable in terms of day-to-day operations, measurable in terms of our ability to measure utilization and quality of service, and maintainable in terms of the integrity of the services it supports.
- Allow for the broad allocation of bandwidth and other resources to various areas and groups on campus.
- Allow installation of extra network capacity where needed.

Task 1: In-Building Infrastructure Upgrade

We recommend that the upgrades of network "edges" (in-building horizontal and riser cable and electronics) be developed and planned in concert with the upgrades of the backbone networks (outdoor fiber plant and core network electronics). A great deal of this work could be done in parallel.

The active components of a building network such as switches are also a critical part of the overall network plant. A review process or consultative process should be followed to ensure that specific building upgrade plans are consonant with the mission and goals of academic and administrative units, as well as with the overall campus network architecture. This review process will allow the reasonable variances that reflect the use and purpose of each facility while guaranteeing that fundamental and up-to-date network services (such as multicast or Voice over IP) will work in each building.

In-building wiring recommendations have already been made by the IT Federation Network Working Group, and the Subcommission endorses those recommendations.

Task 2: Campus Backbone Upgrades

Outside Wiring Plant: The outside wiring plant refers to all telecommunication facilities external to campus buildings including underground manholes, underground ducts (conduits or raceways), conduit facilities in the U-M steam tunnel system, and cabling (twisted copper pair cables, fiber optic cables, and coaxial broadband cables). The Ann Arbor outside fiber plant, which extends to approximately 200 buildings, was primarily installed in the 1980s and early 1990s and should now be significantly updated.

Campus buildings are currently served by six (6) single mode fibers and either twelve (12) or twenty-four (24) multi-mode fibers. The Subcommission recommends that those buildings that are deemed "core" because of their location with respect to the duct system be served by 288 fibers. In some cases this will require installing new ductwork since some ducts are at capacity. The committee also recommends that on-campus ductwork to these core buildings be encased in concrete or some similar material to better protect it against accidental cuts and disruptions in the future.

The Subcommission recommends that those buildings that are deemed "edge" because of their distance from the duct system be upgraded on a case by case basis to "core" status or have their fiber reinforced to twenty-four (24) single mode fibers. The increase in the amount of fiber installed will enable a decrease and cost saving in the number of active components. The extra fiber will provide capacity for other non-backbone uses, such as high-bandwidth specialized applications and the construction of test networks.

The Subcommission recommends that fiber be provided to as many buildings as possible in such a way as to provide two independent fiber paths to the building. In the case of buildings such as Wolverine Tower where the expense of a second fiber path would be prohibitive, either a radio or laser link is recommended to provide redundancy.

The Subcommission recommends that any new construction, remodeling or building acquisitions be used as opportunities to update facilities to the current recommended level of fiber optic connectivity.

This recommended fiber plant upgrade will take us well into the future. Concrete duct is expected to last fifty (50) years. Fiber optic cable is expected to last ten (10) to twenty (20) years. Although the fiber itself will last longer than ten to twenty years, new fiber optic specifications may be issued in that timeframe. It is important to move ahead quickly with this fiber plan since it will take some time to manufacture and install the fiber. When the upgraded fiber facilities are in place, it will then be possible to make relatively quicker changes to the active backbone components to increase network performance or to add new capabilities. Activities and support issues related to the fiber plant, such as documentation, maintenance, and "lighting" the fiber as it comes on-line will require ongoing staff support and other costs.

Backbone Electronics: A very stable period for the network backbone from 1989-1996 meant that the campus backbone networks required relatively little management. The resources that were made available were concentrated on upgrades at the edges of the campus backbones—within departments and between the departments and the campus backbones. In the late 1980s and early 1990s the campus backbones were some 30 to 50 times faster than the national network (the T1 NSFNET) and 10 to 100 times faster than the typical end user network connection on campus. The campus FDDI networks operating at 100 Mbits/s were reasonably matched to the external networks.

Now, however, the on-campus backbone speeds are the same as the fastest links to external networks and only six (6) to ten (10) times faster than most departmental attachments. As a result we no longer have the huge amount of available "headroom" on our campus backbone networks that we had ten years ago. This in turn means that the campus backbone networks must be much more actively managed. Furthermore, the campus backbones must be upgraded every year or two unless or until we can move to a new backbone technology that supports speeds of 50 to 100 times the departmental connection and external connection speeds. At the same time, there is a constant need to continue upgrades at the edge of the campus backbones—within departments and between departments and the campus backbones.

The Subcommission recommends the following:

- Establish as a mid-range goal campus backbones that operate at 10 Gbits/s. Either 10 Gbits/s Ethernet or OC-192 ATM operates at that speed. A migration plan from the current ATM OC-12 backbone has already been prepared.
- Develop plans to support a digital video infrastructure on campus.
- Provide departments on campus with the ability to request and obtain access to external differentiated quality of service environments.
- Announce a transition plan and time line for an IP-only backbone.
- Allow the appropriate flexibility in equipping buildings with the electronics needed to access the backbone.
- Support fail-over routing on the core network backbone so that fiber cuts will not prevent the network from operating.
- Make decisions related to differentiated levels of network services and costs for significant campus communities (researchers, residences, student computing sites, and so on) or specific academic units or administrative areas.

Task 3: Addressing Potential Impact on External Connectivity

It is likely that U-M's Internet network traffic growth during the last two years has been limited by bottlenecks at various levels within the campus network. With the upgrades of all three campus network backbones to either Gigabit Ethernet or 622Mbit/s (OC12c) ATM cores, current bottlenecks are now mostly located in departmental networks, at the links between departmental networks and the campus backbone routers, and at the links between the campus backbone routers and the upgraded

campus backbone core networks. As these constraints are removed one by one, the University must be prepared to deal with a significant increase in demand for network connectivity including Internet traffic. Because it can take at least four to six months for MichNet to obtain additional commodity bandwidth at the relatively high levels (T3, OC3, OC12) needed to meet the requirements of its members, it is usually not possible to quickly remedy poor network performance even if a decision is made to spend additional funds. Under these circumstances, the University may be faced with the decision to limit the amount of bandwidth that it consumes until additional bandwidth can be obtained. This also points out how important it is to make realistic estimates of future bandwidth usage. It must also be acknowledged how difficult it is to make good estimates 15 months in advance in the face of overnight success of emerging applications such as Napster. These developments can radically change network usage patterns in only a few months, making projections based on historical data almost useless.

An important decision for the University is whether it will provide the resources necessary to meet all or almost all campus networking needs at a very high level, or if the campus will instead implement infrastructure with the necessary controls and administrative procedures to ration network access in some fashion when there are not enough resources to meet all demands. If resources are not sufficient to meet all or almost all needs, we may still need to implement varying levels of service or certain forms of "bandwidth rationing." Such control mechanisms should be implemented at a very high level and kept very simple. Perhaps setting different levels of network access for each of the main campus backbones (CAEN, MCIT and ITCOM) and possibly for some large well-defined constituencies connected to those backbones (such as Housing) would be a reasonable approach. This is an important concept for all IT services but is especially significant in the area of external Internet connectivity. Sharing expectations between campus IT leadership and U-M budget decision-makers about what the University should expect to spend each year to support networking activities would also improve the network provisioning effort.

One of the historic issues that the University must address is the ongoing difficulty of getting very high-speed connectivity into Michigan. At the present time, the University tries to fill its needs for bandwidth from sources in Cleveland and Chicago. The University should work actively with the State of Michigan, in-state telecommunications providers, peer universities in Michigan, and the regional business community to locate a Network Access Point (NAP) in Southeast Michigan, preferably in the Ann Arbor area.

Experimental Deployment and Evaluation of Emerging Technologies

The University of Michigan network infrastructure will need to evolve and adapt at an increasing pace to anticipate changing user requirements, emergence of new applications, and breathtaking advances in networking technology. The following recommendations identify three specific areas where investment in experimental deployment and evaluation of emerging technologies will ensure the capabilities required by the University's research and instructional missions:

- Pilot Wireless Infrastructure Initiative
- Advanced Technologies and Services for Emerging Applications
- Voice over IP Initiative

Pilot Wireless Infrastructure Initiative

Several broad trends in information technology are transforming the era of workstations and personal computers into an era of ubiquitous access to information and computation: 1) the proliferation of portable inexpensive computers from lightweight laptops and multi-function palmtops to small sensor-based devices embedded into everyday objects; 2) the rapid convergence of voice and data networks into a single universal network based on the Internet Protocol (IP); and 3) the promise of a global mobile infrastructure enabled by advances in wireless technologies. These broad technology trends are paving the way for an era of ubiquitous access to information and knowledge. This new era will be defined by:

Seamless, ubiquitous access to computation, information and services
-from any location or while on the move: office, classroom, home, travel,
-interacting with many kinds of devices: laptop, handheld, kiosk,
-supported by infrastructure: sensors, actuators, smart devices and spaces,
-enabling collaboration: learning, design, manufacturing, medicine, and research

The Subcommission believes that wireless networking is a key enabling technology that represents the future of connectivity for users both on and off campus. There is an opportunity for the University of Michigan to be one the leading institutions in the world with a very large-scale campus-wide wireless infrastructure if this effort is undertaken in the near future.

As the migration from desktop computers to laptop computers and to PDAs is accelerating, the current generation of laptops can be equipped with wireless LAN capability at a relatively low per-unit cost. We also expect that the rapidly improving capabilities of palmtop computing will result in increasing reliance on mobile handheld devices across campus, and that the change will likely occur in a "discontinuous" fashion. Furthermore, a wireless LAN infrastructure may be a solution to providing acceptable network connectivity in buildings where installing traditional network cabling may not be an option in the near term. We note that today's wireless technologies require that a campus wireless infrastructure be "overbuilt" on top of the existing wired network, and it should not be viewed as either a wholesale replacement or a lower-cost alternative for a wired infrastructure.

A number of individual units across campus have begun to install and operate a variety of wireless local networks in response to demand for wireless access. However, there is a significant need to develop an integrated campus-wide wireless LAN environment and to aggregate the existing independent "wireless islands." The amount of coordination needed for a campus-wide infrastructure is beyond what individual departments can offer each other informally. The increase in bandwidth, greater standards compliance by vendors, and significantly lower prices have all contributed to the

rapid adoption of wireless technologies. A campus-wide initiative is necessary for addressing technological, implementation and policy barriers associated with a strategic service that can benefit the entire University.

SPECIFIC RECOMMENDATIONS

- Create a common campus-wide infrastructure that allows units to fund and provide their own wireless LAN environment or to contract for wireless service from another unit on campus.
- Make infrastructure components such as DHCP, security, and authentication identical across the campus regardless of who is providing the service. Identify a strategic and operational point of integration for the data required to support these activities.
- Develop a campus-wide wireless agreement where all units agree to provide network access to roaming users from other units on campus.
- Initiate a pilot deployment. A focused pilot deployment will be more effective than attempting a campus-wide deployment at this time. Infrastructure and experience developed during the pilot will be shared with the rest of campus. A pilot deployment will provide an opportunity for partnering with vendors.
- Establish governance and planning activities. This needs to happen to make sure the desired interoperability and local control can coexist.

PROPOSED PILOT PROJECT

The Subcommission recommends that a wireless pilot program be undertaken before mass deployment of wireless technology across the entire campus. The pilot needs to be large enough to provide tangible benefits to the campus community, yet not so large that the execution or management of the pilot overwhelms the learning opportunities. The pilot needs to capture a representative portion of the very diverse campus environment and provide an attractive opportunity for partnering with equipment and software vendors. We propose that the pilot deployment of a comprehensive wireless environment occur on the North Campus.

The North Campus includes a range of buildings, open spaces, and academic and service units that closely mirror the overall campus environment. It also hosts a wide and fluid range of the campus community.

There are several challenges that must be overcome in order for a campus-wide wireless LAN deployment to succeed. There are currently no shared common basic infrastructure elements on campus such as DHCP or authentication and access controls for wireless users. A range of operational procedures and end-user support and consulting issues must be addressed. Staff training and development opportunities for support staff need to be provided. A successful pilot project will encourage other campus units to implement wireless environments at their sites.

This pilot will also provide insights into technical, policy, and social aspects of this deployment. We hope to gain the following from a pilot wireless network on North Campus:

Assessment of vendor interoperability in different areas.

- Experience integrating vendor software into the existing campus infrastructure such as Kerberos and UMCE.
- Experience operating a wireless network across different physical networks.
- Development of centralized services for authenticated wireless users, such as access to software or printers, and experience with use of standards-based tools to authenticate access to the wireless network for users coming from different programs and schools.
- Evaluation of the impacts on the University's Campus Computing Sites by allowing students to have wireless access for simple tasks such as e-mail, web browsing, and other general purpose computing.
- Evaluation of the use of wireless networking for teaching and social computing around campus.

Advanced Technologies and Services for Emerging Applications

The existence of a capable network infrastructure is a critical prerequisite for a greatly improved environment to support domain-specific research and applications. A wide range of advanced technologies and services must be available so that individual researchers and instructors can fully utilize the network's capacity without the need to generate or negotiate their own support. A growing number of emerging research and instructional applications will directly benefit from campus-wide availability of such services. These services include:

- Distance Learning.
- Digital arts and multimedia asset management.
- Functional MRI (fMRI) and other 3-dimensional medical and bio-science applications.
- International high energy physics research.
- Bioinformatics and computational biology.
- Distributed modeling and simulation.
- Collaborative design and manufacturing.
- Large-scale data mining and trends analysis.

This Subcommission recommends that pilot projects and prototype demonstrations of the following services and technologies be supported as applied to these emerging applications:

- High performance end-to-end computing.
- Multicast networking protocols.
- Virtual Private Data Networks.
- Large scale storage, retrieval, and transmission of multimedia files, massive amounts of research data in real time, and very large data sets.

- Visualization and Virtual Reality technologies.
- Collaborative technologies.

An example of a system that would take advantage of a number of these facilities on campus is the "Access Grid."[11] This is a multi-group video-conferencing room built on a design developed at Argonne National Laboratory. The intent is to support group-to-group meetings for two to twenty-plus groups with the best possible audio, video, and tele-immersive support in a multi-cast environment. This desire to support high-quality, low-latency audio, video, and immersive graphics between numerous sites simultaneously is also reflected in other projects, such as the Connection Project at the School of Information. The Access Grid is also meant to integrate with the Globus Grid initiative.[12]

Voice over IP Initiative

The rapid convergence of voice and data networks into a single "universal network" based on the Internet Protocol (IP) is an important technology trend. The future of what we now call "telephone service" lies with "Voice over IP" (VoIP) technology. This technology converts analog voice signals into IP data packets and carries those packets across data networks to IP-capable telephone sets. The availability of VoIP technology provides the opportunity to build one network infrastructure rather than two, but there will be a significant one-time investment required to enter the VoIP arena.

The University has already begun the migration to VoIP services. There are currently over 300 IP phones in production at U-M, and by the end of calendar year 2001 there will be approximately 1,000 IP phones. This pilot deployment is critically important for gaining experience as the VoIP technology further matures.

RECOMMENDATIONS:

- Design a common campus-wide architecture that enables IP telephony functionality yet distributes control of the service to units as much as feasible.
- Develop a plan to phase in IP telephony across campus through partnership with a vendor. This is expected be a five- to ten-year plan to ensure that the existing telephony infrastructure is appropriately amortized, and to ensure that the University can continue to receive needed telephony services from external service providers. A pilot program is highly recommended to reduce the risks associated with early deployment of an emerging technology.
- In the move toward IP telephony, units who are not able to move ahead quickly should not bear an additional financial burden caused by those who do. This means that central funding will be needed to insure the migration to ubiquitous IP telephony services.
- Make infrastructure components such as DHCP, security, cable tracking databases, and authentication uniform across campus regardless of who is providing the service. Identify a strategic and operational point of integration for the data required to support these activities.

Unbundling Services and Pricing Guidelines

A key principle held by this Subcommission is that IT services should be unbundled and that basic and specialized IT services should be clearly separated. The Subcommission supports the efforts made to date in clearly separating telephony and networking rates, and for removing the historic subsidy of the network by telephone customers. In terms of service availability and cost allocations, various components of the network infrastructure should be offered and priced as unbundled services and not tied to or related to each other. This will allow units to better plan and allocate their own resources in terms of their own missions and priorities. We believe that most units probably will opt for a set of services from a provider, and that option should be available to them. This should not prevent service providers from developing scales of economy. This approach should accomplish the following:

- Allow units to take advantage of and exploit local economies and opportunities that do not detract from opportunities or add to costs for other units on campus.
- Ensure that there are no hidden subsidies or pass-through arrangements present in prices.
- Treat backbone providers consistently in terms of resource and cost allocations.
- Ensure that pricing and cost models do not detract from the rational operation of the network, with the goal of providing the greatest overall advantage to the University.
- Support the unbundling of services and the flexible organization of cost centers.

Campus Backbone: The backbone network should be provided as a commodity service with minimal bundling or tying with other services. The backbone network should be provided to the campus with the lowest overhead possible. Costs located here will ripple through the entire network cost structure because of the entire campus uses the backbone. There should be very little "value added" services provided in this arena by service providers. To the degree the installed campus backbone produces capacity with low marginal costs, the advantages of those low marginal costs should be passed along to the campus community. Because of the enormous capacity of fiber, the incremental or marginal cost for more bandwidth over existing or the same fiber can be relatively low. The cost of the fiber component of the network should not be based on per strand usage. The campus backbone should be considered a strategic resource in which all campus units have a stake.

The components of the campus backbone are:

- External fiber plant
- Electronics within the core backbone
- Technical and operational support staff

Fiber strands should be made available at the true cost to those who have appropriate uses for it and who are able to provision specialized services that use it independent of other services. Examples of fiber use outside of the campus backbone include augmenting backbone connectivity where needed and to provision new services. For example, two data centers where traffic would have an adverse

impact on the rest of the backbone could be directly connected by a private fiber circuit. An example of new service would be a campus-wide Storage Area Network (SAN). Having adequate fiber will help minimize overall network costs by allowing for flexibility in network topology and configuration decisions.

The amount of skill, experience, and expertise required to operate the backbone network is significant. The staff in this area represent a very rare and valuable resource to the campus and adequately staffing this area will present a very significant challenge. Hence, staff support of the backbone will need to be better coordinated between central and college-based IT professionals. The priorities of these staff members will be to maintain the operational integrity of the backbone, and to plan and perform campus-wide backbone monitoring and measurement.

Network-related Service: There are many other network-related services that can be centrally provided, distributed, or provided by more than one shared provider on campus. There are several reasons that these services should be unbundled from the network backbone. They can in many cases be provided in a much more decentralized or shared way than can the network backbone. They represent very different added values, cost structures, and levels of effort to provide. Because of the wide range of added value, costs, and levels of effort required to provide these services, these services should be unbundled from the backbone network. They lend themselves to a different sort of planning process and requirements analysis. Different parts of the campus community have very different levels of involvement and requirements for these services.

Example of these sorts of services include:

- Domain Name Service (DNS)
- Dynamic Host Configuration Protocol (DHCP)
- Advanced Directory services
- Network authentication and authorization
- Variable quality of service and bandwidth reservation
- Host security audits and security-related incident response
- Virtual Private Data Networks
- Monitoring departmental networks and other network-based services and hosts

Impact on Units: Not automatically offering a single, large integrated network services package requires that units will have to be more involved in and aware of their network requirements and costs. This should bring about an overall increase in efficiency and better service offerings as customer requirements and constraints are more explicitly included in the planning process. The unbundling of services should make it easier to develop an informed point of view about choices and make it easier to produce and describe cost-related information.

Pricing Guidelines

Cost and pricing models for such a large and complex enterprise will require significant thought and consideration. The Subcommission offers these general guidelines that may provide a context for those discussions.

The principle of unbundled services helps provide a framework for pricing and cost allocation decisions. This approach should be balanced with identifying those services that will be provided in a "common good" manner through central funding and those specialized and/or advanced services that will be cost-recovered via chargeback. Another key fundamental concept is that the true costs of these infrastructure services should be determined by the implementation of rigorous cost-accounting practices, with an avoidance of complex or vague subsidies and pass-through arrangements. Pricing is a powerful tool for encouraging or discouraging some behavior. A pricing system should not encourage people to "game" the system or to obscure the true costs of the underlying services.

We expect that the proposed IT infrastructure upgrade plan will be quite costly to implement and funding it will be a challenge. Priorities will have to be established and cost controls will be important. The informed involvement of Executive Officers and academic and administrative units will be critical. The campus infrastructure will be used more effectively if stakeholders have a more informed and in-depth involvement with defining their use of the infrastructure.

In the current system, where costs are fully recovered and recharged to end users (either schools and colleges, departments, or individual users) both strategic and operational aspects of networking on campus are difficult and goals are harder to accomplish. This in turn also makes it difficult for units to have an awareness of their costs as they relate to the services they use, and it allows them no means of controlling those costs. Yet on the other hand, central funding for the entire network may not encourage appropriate use of the resource.

Campus budget decision-makers need to have some realistic idea of what the University should spend each year to support an expected level of network service. Today we have much tension between our desire to provide high-quality networking on campus and our desire not to spend too much money to do so. In terms of external connectivity, this tension is one factor that causes us to underestimate the amount of external bandwidth we are likely to need. A vicious cycle begins, where underestimates of usage lead to a failure to provide sufficient capacity, which in turn results in poor performance and network congestion, yielding artificially low network traffic statistics, on which are based future estimates of network usage! Network providers who do not control demand are only indirectly in control of the costs they must pay, especially for external connectivity.

It is important to note that capital investments in IT infrastructure must be managed over the long term and must be divorced from the 12-month general fund budgeting model. We need to establish funding streams that cut across multiple fiscal years. At the same time, we will likely encounter some instances of "discontinuous change" which will result in significant funding needs within a fiscal year.

Another impact on price would be to provide "wholesale" and "retail" network services to units. The unit then could analyze what could be provided internally and what should be contracted from another source. This analysis would need to be examined to ensure that everyone was using similar metrics and calculations to support this decision-making.

Subsidies could be applied to ease transition costs to future technologies, for example from traditional telephony to VoIP or to smooth out prices to make billing easier. Trust, good faith, openness, and executive direction-setting will be important prerequisites for cost analysis, price setting, and subsidies.

Assuming there is a standard level of service, additional unit requirements may be met by adding more capacity. The price for this extra capacity should closely reflect the direct cost of providing that capacity and reflect whatever margins are available for that capacity. If the basic level of service were funded centrally, additional requirements could be funded directly by the unit. This could provide an opportunity to capture costs from researchers. Within the context of common approaches to service provision and costs, units should be allowed to have the flexibility they need to exploit local opportunities for saving.

In terms of cost and related pricing decisions, the campus information infrastructure will be required to:

- Consider the provision of desktop connectivity as utilities for the general good, like electricity and water, and fund them similarly.
- Not allow pricing and cost considerations to detract from the rational operation of the network, with the goal of providing the greatest overall advantage to the University.
- Allow for the unbundling of services and the flexible organization of cost centers.
- Allow units to take advantage of and exploit local economies and opportunities that do not detract from opportunities or add to costs for other units on campus.
- Not have any hidden subsidies present in the costing and pricing of services.
- Treat backbone providers fairly in terms of resource and cost allocations.
- Not subsidize IT infrastructure upgrades through operating margins from telephone tolls unless where explicitly approved by executives.

Formation of Campus IT Pricing and Services Commission

It is important that campus IT service providers receive input from the relevant parts of the campus community. This could be provided at different levels. A "public service commission" called the "Campus IT Pricing and Services Commission" could be formed at a senior strategic level to discuss overall service and pricing issues. Advisory committees for campus networking should be formed. One committee could provide technology input and another could provide financial and business operations input. Strategic plans should be meshed and coordinated with financial and operational plans.

Formation of a Campus-wide Monitoring and Measurement Infrastructure

The subcommission recommends deployment of a monitoring and measurement infrastructure to aid in the collection and analysis of both short-term and historical data. The IT staff in various administrative units need access to information and supporting tools for day-to-day network engineering and long-term capacity planning. A campus-wide traffic monitoring and measurement infrastructure will provide the IT operation staff the necessary tools for managing on-campus and Internet traffic. This infrastructure will also provide critical input to the Campus IT Pricing and Services Commission and the University executives in establishing pricing guidelines and allocating resources.

Organizational Structure and Governance

For reasons implicit and explicit in this report, it is plain that the quality of the University's data networks has profound implications for the ability of the University to achieve its research and educational missions. Many of our schools, colleges, and research centers and institutes require very high bandwidth in order to function effectively, and absolutely everyone requires a level of connectivity far in excess of what was thought adequate only recently.

The tradition of decentralized decision-making at Michigan is helpful in that it prevents us from having a "one size fits all" set of standards that would deliver more than is needed in some places and less in others. But it causes difficulty in other ways, for at least two reasons. First, decentralized mechanisms can fail to provide the right level of shared central services (e.g., the fiber in the ground between buildings that is an essential part of the backbone, as well as the centrally owned and operated hardware and software that everyone will use). Second, and related, decentralized structures often produce a somewhat "garbled" view of shared problems from the perspective of the University's Executive Officers and other senior leadership. In order for the Executive Officers to make good decisions for the campus as a whole—including decisions about which services should be provided centrally and which should be of local responsibility—there needs to be a mechanism that assures that campus-wide issues are brought to their attention in a timely and persuasive way.

There are many administrative structures that could lead to the right result. All would involve a clear path from the IT professionals who really do the work (potentially well-represented and coordinated through the IT Federation) to the administrators (Executive Officers and Deans) who must commit the time and resources and conduct campus-wide planning. We are agnostic on what the right administrative structure might be. We are sure that it involves a high level of coordination at levels (Executive Officers and Deans) where decision can be made. The Subcommission proposes a simple test of whether the governance structure is minimally adequate:

Addressing the network infrastructure requires informed Executive-level attention of a kind that has been missing for many years. If the Executive Officers have not approved an overall campus networking plan that addresses the recommendations of this committee within six months of the release of this report, including the identification of resources to support the needed upgrades, it is plain that our governance structure is inadequate to the task at hand.

For the future, the campus needs to develop a set of mechanisms such that the President, Provost, Chief Financial Officer, and Executive Vice President for Medical Affairs, at a minimum, have periodic briefings on the state of the IT infrastructure, from both central and unit perspectives. Without this type of activity, we will not have the certainty that vital strategic and tactical decisions will be made effectively and in a timely fashion. IT generally, and networking in particular, are every bit as much a part of the essential infrastructure of the campus as are academic buildings, business rules and procedures, and academic operations. Decisions about buildings and campus-wide procedures are vetted carefully at many levels; and decisions regarding the IT infrastructure require a similar level of attention.

Campus-wide Security and Information Assurance Function

The increasing reliance on information technology for teaching, research, and administrative function has resulted in an explosive growth in size and complexity of the underlying IT infrastructure. This dependency on timely and reliable access to information and services is not without risk. Reports of technology-based security attacks on university campuses, government sites, and commercial enterprises appear regularly in the news media. Experts believe that the frequency and severity of such security compromises will continue to increase. Universities especially face the dual challenge of protecting systems and services from outside attacks while protecting the Internet from attacks originating on campus. The security and privacy of valuable digital records and assets across campus, especially those in the Hospital and student records, demand rigorous and continuous review and assessment. The University's high-bandwidth connections to the Internet make University systems an ideal "launch pad" for distributed Denial of Service (DoS) attacks.

The University has historically given priority to security issues. "The recent advent of the M-Pathways Project, the resulting distribution of business operations and security authority from a centrally controlled environment to a more decentralized departmental environment, and the reliance on the data network to provide access to University technology services have elevated the importance of this issue." Responding to this need, the University Chief Information Officer charged a University Security Architecture Task Force (USATF) to provide an initial analysis of information security at the University. By endorsing the USATF's framework for information technology security at the University, the Subcommission emphasizes the need for continued attention to the security policies and practices by the administrators who have responsibility for institutional data and those who provide IT services to the campus.

Assuring the confidentiality, integrity, and availability of our academic and administrative computing environments directly supports the mission of the University. It is important to note that the security requirements for the academic and administrative computing environment differ greatly. Academic computing requires open access to the Internet for experimentation, education, and research by students and faculty. Administrative computing requires a more rigid set of security measures to guard legally protected and sensitive information such as medical records, student records, human resource information, and other vital business and finance records from unauthorized access or modification.

The dichotomy between academic and administrative technologies serves to undermine a "one size fits all" approach to securing systems and resources. The Subcommission is emphasizing the need for continued attention to the security policies and practices that take into account the different requirements of the two environments.

The subcommission believes that the University of Michigan should establish itself as one of the leaders in IT security among colleges and universities. The Subcommission strongly recommends the establishment of a campus-wide security and information assurance function with appropriate representation from various IT administrative units to:

- Assess and review campus-wide security policies and practices on an ongoing basis.
- Ensure implementation of baseline security in the University-wide shared infrastructure and services shared by the academic and administrative environments.
- Establish mechanisms to ensure that "preventative IT security measures are available" to the entire campus.
- Provide consulting services to individual units in their implementation of security policies.
- Establish a "Crisis Response Team" representing service providers on campus to coordinate a University-wide response to potential technology-based attacks and security intrusions originating from outside as well as within the University, in real-time.

Recruiting, Training and Retaining IT Professional Staff

The University is facing unprecedented challenges in providing effective IT support to its growing diverse community of users. The recruitment and retention of IT professionals is a campus-wide problem. From 1996 to 1999, the use of information technology (IT) by faculty, students and staff has increased substantially. Today, about 95% of the University community uses IT on a daily basis. This expanded IT user community is also using a growing set of applications ranging from e-mail and data analysis, to collaboration, complex modeling and visualization, administrative transaction processing, and service delivery. Accompanying this expansion of usage is an increasing reliance on IT based resources and services, such that 24 x 7 availability is now expected.

Critical to the University's ability to deliver 24 x 7 access to IT is an adequate level of technical support. Today, the University employs over 1,700 IT professionals, up from 1,400 in 1998. Faculty satisfaction with campus IT services improved significantly between 1996 and 1999. Only 16% of faculty participating in the 1996 CIO Faculty Survey expressed satisfaction with campus IT services; in the 1999 Faculty Survey, 23% of faculty were "very satisfied" with campus IT services and 51% were "somewhat satisfied."13 While overall faculty satisfaction has increased, there remain several key areas of concern for U-M's faculty members. Support in some research areas, particularly for advanced IT functions, and support for some in-classroom activities, is still problematic. In the 1999 Faculty Survey, the priority concerns of faculty were identified as technical support and reliability of IT systems and

services. Faculty further cited the importance of local availability of technical support over remote help desks or automated knowledge bases. Faculty want to focus their efforts on using IT to accomplish their objectives, not on troubleshooting or fixing problems. The vast majority of faculty consider IT as just one more available utility.

In the past few years, IT units at the University have experienced greater difficulty in retaining professional staff and attracting them at market-competitive salaries. Positions that are especially difficult to fill and retain are for System Administrators, Network Engineers, Application Programmer/Analysts, and Web Designer Developers with five (5) to six (6) years of experience. The need for high-end technology and discipline specific skills is also expanding. These include, for example, programming for parallel architectures, complex simulation, advanced visualization, and virtual reality. These specialized skills have in the past been addressed mostly through individual research projects, as the University has not in recent years supported research computing needs in a systematic or comprehensive way. Furthermore, the uses of technology for research, instruction, and service are no longer distinct from each other.

As the demand for IT professionals continues to exceed the supply, the University must develop a multi-faceted approach to handle the IT support needs for instruction, research, and administration. The Subcommission recognizes the need for an institutional response to the challenges of recruiting, developing, and retaining qualified IT staff. The Subcommission strongly recommends that the University make a long-term commitment, starting immediately, to recruit and hire needed IT professional staff and to further develop and maintain critically needed skills through ongoing training and retraining of IT personnel. The University must also consider salary increases and innovative compensation packages to be more competitive with industry in recruiting professional IT staff. Even in critical areas such as network and system administration, "across the board" increases that do not take into account performance or importance to the organization may not have the intended consequences. Having said this, we recognize that the University needs a reasonably uniform compensation program that will reward excellence and ensure retention of experienced IT staff. Requests for salary market adjustments for IT professionals should be afforded serious consideration by decision-makers.

Implementation of the proposed IT infrastructure upgrades must begin with a re-organization and re-purposing of the existing IT professional staff. A newly integrated University team, capitalizing and expanding on the existing base of IT professionals, should be focused around a future vision and the milestones and deliverables to achieve it. The key will be to re-balance the mix between the many highly decentralized IT service units by empowered and well-financed central leadership.

The Subcommission also endorses creation of internship and training programs, partnership programs, and transition programs to move new graduates and incumbent support staff into IT support and technical roles. Confronting these challenges must be done through an alliance between centralized IT departments (CAEN, ITCS, MAIS, and MCIT) and school and college IT units.

APPENDIX D. Information Infrastructure and Services Taxonomy[14]

The IT Infrastructure Subcommission views information infrastructure as more than wires, switches, and hubs. Five classes of information infrastructure are discussed in this report: 1) Physical infrastructure—including buildings, network backbone, and internet connectivity; 2) Facilities and operations; 3) Middleware and enabling technologies; 4) Core applications and services; and 5) Specialized applications. Of course, our most valuable and vulnerable infrastructure resource is the professional IT staff who support the infrastructure.

Physical Infrastructure: The lowest layer of the IT architectural model includes the components that are traditionally thought of as IT infrastructure—the physical telecommunications channels which link campus computing resources and users. This layer includes the voice, video, and data communications systems—the wiring, fiber, routers, hubs, controllers, and switches that are hidden underground or behind building walls. In today's environment, we also include the IT infrastructure to support wireless communications in this layer. In this report, we are primarily concerned with data networks, and divide these into 1) Building infrastructure; 2) Backbone infrastructure; and 3) Internet connectivity.

Facilities and Operations: Facilities represent additional "hard" structural components that are essential for campus IT service delivery. Facilities include data centers, public access computer laboratories, classrooms, training rooms, and performance spaces. With IT applicable to virtually every aspect of the campus learning and research missions, the relationship between the physical environment and the technology environment becomes more complex and critical. Campuses are faced with the need to balance ubiquity, reliability, flexibility, diversity, and costs.

Middleware and Enabling Technologies: Middleware and enabling services are the least understood of all the layers in the architectural model. They are essential for any of the core or specialized IT applications to work. This layer is significantly impacted by increased user demands and by the advent of closely integrated and dependent applications. Included in this layer are directory services, identification, authentication and authorization services, and security services. While the University has provided such services for many years, they have not always been implemented to ensure robustness and scalability on a campus-wide, around-the-clock basis. The University embodies a culture of openness and knowledge-sharing which must be balanced with the need to provide secure access to individual and institutional data, transactions, and applications. Securing data and applications are relatively recent requirements. In today's environment, security and privacy needs are priorities that require serious campus-wide attention.

Core Applications and Services: Core applications are defined as those IT applications provided universally to the campus community. These applications include such services as e-mail, Internet access, word processing and office productivity tools, statistical applications, mathematical subroutine libraries, access to library resources, and access to administrative information systems supporting such functions as student records, financial transactions, and personnel records. These services are those

that all individuals in the campus community should be able to assume are available to them by virtue of their employment or enrollment. As new learning technologies evolve into ubiquitous, they also fall into this layer. Clearly, the actual components comprising this layer vary from campus to campus and school to school, and the components change significantly over time.

Specialized Applications and Services: These applications are defined as those provided based on needs to selected members of the campus community, demonstration projects or pilot projects. For example, High Performance Computing and Networking (e.g. Internet2) is a core service for research projects in several domains such as high-energy physics, geographic information systems (GIS), life sciences and bioinformatics, and music composition. It should be considered infrastructure as a specialized level of service and be available to the University community at large. Another example of specialized applications and services is on-line learning systems. Before moving a mature specialized application to a lower core application level, the impact on the application on all lower levels must be fully understood so that infrastructure performance can be maintained. This layer is somewhat experimental in its nature, and is the place to "try out" applications before they become pervasively deployed. The Subcommission notes that the University community will see a growing number of specialized applications and services as we witness a further proliferation of information technology in support of the educational and research missions.

Notes

1. Asynchronous Transfer Mode operating at 622 Megabits per second. By comparison, a standard Ethernet connection operates at 10 Megabits per second.
2. Internet Protocol.
3. Fiber Distributed Data Interface operating at 100 Megabits per second.
4. For more information on Merit Network Inc., please see http://www.merit.net
5. Commodity Internet traffic supports most typical uses of the Internet: browsing at other collegiate and business sites, file transfers from other institutions, and most commercially available services.
6. For more information on the Abilene high speed Internet project (see http://www.ucaid.edu/abilene/)
7. Digital circuit operating at 1.5 Megabits per second.
8. ADSL circuits provide a digital data connection over a conditioned telephone line. Connection speeds range from 128 Kilobits per second to 1.5 Megabits per second.
9. Synchronous Optical Network.
10. Building network infrastructure includes riser cabling, horizontal cabling and switching, and routing electronics.
11. Please refer to http://www-fp.mcs.anl.gov/fl/accessgrid/ for more details on that project.
12. Please refer to http://www.globus.org/ for details.

13. "University of Michigan Faculty Information Technology Uses and Needs," Office of the University Chief Information Officer, February 2000.
14. "The Art and Science of IT Infrastructure," Jose-Marie Griffiths and Alan McCord, in *Technology Enhanced Learning Opportunities for Change,* edited by Paul Goodman, Laurence Erlbaum Publishing, August 2001.

