# DATA COMMUNICATION NETWORKS:
# A COMPARATIVE EVALUATION OF THE MIT AND HARVARD ENVIRONMENTS

by

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**ABSTRACT**

A comparative evaluation of data communications networks at two universities was conducted in order to illuminate some of the critical connectivity issues and problems facing planners of Information Systems. The author first notes that the user community consists of different segments with differing goals and preparation. The author then develops a framework for evaluating data networks, identifying the functions and performance criteria relevant to the users.

Research was conducted through personal interviews and the collection of survey questionnaire data. Findings suggest the impact of organizational as well as protocol incompatibility issues on information systems planning. These result from the decentralized nature of systems acquisition within as diverse an organization as a university. The issue of data network security is also raised as a critical requirement for an integrated data network in a university environment.

The author examines internetworking in an International Standards Organization Open System Interconnection reference model as it applies to both environments. The appropriateness of the current and planned network architectures is considered and appraised.

The study concludes by highlighting future development plans using insights gained through this evaluation.

Thesis Supervisor: Stuart E. Madnick

Title: Associate Professor, Management Science

## BIOGRAPHICAL NOTE

Phillip S. Yoo attended Harvard University from 1979 to 1983, receiving his A.B. *cum laude* in Engineering and Applied Science in June 1983. His specialization was Computer Science and Electrical Engineering. He distinguished himself as a Harvard College scholar and was the recipient of a National Merit Scholarship.

Mr. Yoo was employed by Bolt Beranek and Newman (BBN) as an Associate Scientist and later as Staff Scientist from 1983 through 1986 in BBN's Information Sciences Division. Bolt Beranek and Newman specializes in computer and communications technology, offering research, consulting, and products to meet Fortune 1000 customers' needs. BBN's corporate network is both sophisticated and prolific, incorporating coaxial cable, fiber-optic, microwave, and satellite media.

At BBN, Mr. Yoo was involved in the Interactive Simulation Networking Project (SIMNET) for the Defense Advanced Research Projects Agency. The project is the state-of-the-art in large scale distributed real-time simulation, extending graphics and communications technology. Mr. Yoo designed and implemented simulation and networking protocols and system software.

Mr. Yoo has extensive experience in the university computing environment both as a teaching assistant and as a systems consultant and operator for Harvard.

## ACKNOWLEDGEMENTS

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## 1 Research Objective and Methodology

The objective of this research is to explore the issues and problems faced by Information Systems executives in managing the data communications needs of the organization. Particular attention is paid to problems associated with data network connectivity.

For these purposes, the organization is assumed to consist of a number of departments or functional groups with differing needs and agendas that must be serviced by a central Information Systems organization. Close examination of two sophisticated existing environments may illuminate policy alternatives for IS planners.

A data communications network must support the services required by the various users of the system. The design and implementation of a system to satisfy these requirements must take into account certain historical restrictions and constraints inherited from existing systems. The issues that the author has identified are:

- **Heterogeneous hardware** — different departments and subgroups will have made independent decisions regarding their own computing needs that may not conform to the organization's formal or informal standards. A network design must accommodate and integrate these existing systems.

- **Architectural constraints** — characteristics of the organization's buildings may preclude or alter certain network design decisions. Network solutions may be sub-optimal but necessary in view of these constraints.

- **Wide range of user sophistication** — the data network must be accessible and adequate for both the novice and expert user. Education and support become key issues that must be addressed.

- **Wide range of user needs** — various different users will have different needs and requirements. Some will require different services, while others may require strict data security. For yet a different group, cost containment will be their primary concern. All these issues must be satisfied by a successful complete data network solution.

- **Existing networks** — departments and groups within the organization may have found it necessary to implement data networks to satisfy their own needs. These solutions must be integrated into any overall design in order to be successful.

- **Data networks are evolutionary** — the topology of a network is constantly changing as incremental users request and are granted service. It may be exceedingly difficult to adhere strictly to a planned design.

- **Network management is often fragmented** — since the data network must satisfy both department-specific needs as well as central planning issues, management is often shared between the central agent and the departmental groups.

This list is not intended to be exhaustive, however, it represents the core of critical issues that must be addressed by IS planners.

The author has selected the MIT and Harvard University environments for study because they demonstrate all of the above historical issues.

- **They are technologically sophisticated** — both universities have complex and diverse communications needs.

- **They are populated with heterogeneous hardware** — products are acquired both through decentralized purchasing decisions and outright grants. Universities are unable to enforce any hardware standards and must therefore address integration issues.

- **University buildings often predate data network needs** — a number of the buildings both at MIT and Harvard are poorly adapted to accommodate data network wiring .

- **They have both very sophisticated and novice users**

- **There are three distinct classes of users** — students, faculty, and administrative users all have different needs and requirements that complicate the data network planning process.

- **Many departments have implemented their own network solutions** — networks are often provided by together with equipment grants or are implemented to meet departmental needs. Often these solutions are closed solutions, proprietary to the donor vendor and present significant integration problems. Both MIT and Harvard possess numerous links to external networks giving rise to security problems not faced by closed systems.

- **Both their networks have evolved over time**
- **Their networks are managed jointly by central and departmental agents** — both universities have a central IS planning office as well as departmental network managers that serve their own groups.

## 1.1 The Use of Comparative Evaluation

Comprehensive evaluation requires an ideal standard for objective comparison. Since data networks evolve through incremental additions, the current topology and technology rarely adheres to a notion of an optimal solution. If an organization possessed infinite financial resources and could afford the time to completely replace the system and retrain all the users, then it could alter its network in response to every technological advance. This is hardly a reasonable assumption.

The use of a comparative evaluation eliminates this difficulty. The definition of an objective standard is a task beyond the scope of this work. The comparative evaluation will examine both the current network implementations of both universities as well as their plans for future expansion. Both networks will be judged on their ability to meet the needs of each university. This examination will be made with respect to a number of evaluation criteria.

## 1.2 Scope of the Evaluation

This evaluation examines data networks as they are used at both institutions. Both universities contain "islands of networks" as well as a more prolific "main" system[1]. The author examines both these components since it is likely that the existence of isolated data networks suggest inadequacies and incapabilities of the main network to service critical needs.

[1] Modem connections for ad hoc communications are not treated as network links.

The author nonetheless takes the perspective of the central IS planner in his task of successfully integrating and supporting the variegated needs, resources, and sophistication of numerous clients.

## 2 Evaluation Methodology

The data central to the evaluation is obtained through interviews with Information Systems network managers as well as survey questionnaire data. The survey data shed light on the network's effectiveness in servicing the various types of users in the target community. The survey asks respondents to evaluate the network on several different criteria.

### 2.1 User Community

The target user community consists of faculty, administration, and students. Each group has a slightly different set of needs and preferences. The appraisals of these groups needs not be identical since they may be receiving different levels of service.

Faculty users use the network to support their research and to help coordinate collaborative efforts with colleagues. Students use the network to gain access to the host computers they need for coursework, papers, games, and mail. Administrative users make heavy use of internal databases, presenting unique security issues.

### 2.2 Evaluation Criteria

A number of factors must be examined in order to adequately evaluate a data network. Some of the factors address the coverage of service delivered to the users. Other issues relate to the manageability and operability of the network design. The following evaluation criteria will be applied:

- Functionality
- Network Reach — Connectivity
- Network Performance and Reliability
- Network Control

- Network Support — Maintainability
- Security
- Planning

### 2.2.1 Functionality

A data network can provide many functions above and beyond connecting terminals to computers. It maintains information on all the computers and resources it connects so that it can route, store, and translate messages from one computer to another with a minimum of user training.

In a university environment, Harvard University has found the following functions to be critical to the user community, listed in descending priority.

- **Database Access** makes information stored in computers available to users. This includes gateways to outside databases and the network computer resource directory.

- **Resource Sharing** allows for sharing expensive disk drives, printers, plotters, file servers, *etc.*, among a number of personal or small departmental computers with a minimum of special commands or software modifications.

- **Document Interchange** converts revisable word processing documents into a standard form so that they may be communicated on the network and reconverted for use on a different word processor.

- **File Transfer** enables users to move data and/or text documents across the network.

- **Image Communications** provides high-speed communications to meet the special requirements of electronic publishing and graphics/image transmission.

- **Electronic Mail** maintains a university-wide user directory and stores and forwards messages to multiple locations. Electronic mail acts as the envelope and the post office for the delivery of all kinds of electronic communication including revisable WP documents and images. A university electronic mail system should provide connectivity between other electronic mail systems on and off campus.

- **Terminal-Host Communications** enable users to access host computers using simple interactive terminals over the network.

It should be noted that the various segments of the user community may assign differing levels of importance to these varying services, based on their own needs and requirements.

### 2.2.2 Network Reach — Connectivity

In addition to providing the functional services required by the users, a data network must reach all clients and resources to which users desire access. Furthermore, users that desire service should be able to gain access. It is not sufficient for a network to simply support file transfer to a select set of users. When protocol incompatibility or the lack of a physical connection prevent this transaction with the desired host computer or file server, the network is not providing adequate connectivity.

Assessing connectivity involves both physical links as well as protocol compatibility. The establishment of a physical connection depends critically on the current wiring to date. If network drops have already been established nearby, then the task is simple and inexpensive. If the building has not yet been wired, then the incremental costs may be considerable (over $20,000).

The incompatibility of protocols can interfere with connectivity as well. A user may desire communication with another client physically connected to the network, but be unable because his machine doesn't understand the other's protocol.

### 2.2.3 Network Performance and Reliability

The next important criteria is the raw performance of the network in moving data. Once the user has seen to it that the services he desires have been supported, and that the network has sufficient reach to provide him access to whomever and whatever he wishes; his concern turns to the network's speed and reliability in providing the service.

Performance is normally measured in terms of the data rate (or *bandwidth)* supported by the network, data link, and physical layers. The principal Ethernet standard has a bandwidth of 10 million bits per second (Mbps). However, the actual data throughput performance may be a mere fraction of this. Higher level protocols consume a significant chunk of the available bandwidth in order to effect error detection and correction. One widespread protocol, TCP/IP delivers an effective bandwidth of approximately 1.5 Mbps over a typical Ethernet.

The above measures are still performance measures for ideal conditions. The observed performance is very much a function of the load factor on the network. If several machines are contending for the same network at the exact same time, a great deal of bandwidth will be consumed in resolving the contention.

### 2.2.4 Network Control

In addition to providing requisite functional services, the data network must have control elements to help it to respond to users' needs. Research at Harvard University has uncovered two principal issues:

- Cost control — the ability to monitor and limit usage of the network, shared resources, and databases accessed by the network.

- Network management — the ability to monitor network performance, to administer network identification and password information, and to perform diagnosis on network components[2].

Faculty groups would like to be able to control the usage costs of outside research databases. Additionally, administrative users would like to be able to control network usage costs for external networks.

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[2] "Harvard University Long-Range Telecommunications Plan: Needs Assessment Summary," Harvard University Office for Information Technology, Telecommunications Services Division, August 13, 1986, p. III-20.

### 2.2.5 Network Support — Maintainability

A data network is much more than simply providing a technology. It also includes support functions to ensure that the network is installed properly and that users are trained in its operation. Support issues fall into three primary areas:

- Technical — assistance to users on how to install data center network software, resolve technical problems, and provide data center users with an understanding of how the network functions;

- End-user training — on how to access the network, the steps required to connect to different computers, and how to identify and report problems with the network;

- Maintenance — such as installing new software updates, diagnosing network errors, and installing new facilities[3]

### 2.2.6 Security

The data security issue is critically important in a university environment. Students must be denied access to the class work of their classmates. Sensitive administrative information like grades, financial situation, and payroll must be kept secure.

It is interesting that the critical issue is not a general measure of data security, but the perception of security by users requiring it. Users in the Medical area or the Office of the Registrar have more stringent security requirements than do faculty members concerned with student plagiarism.

The security issue is complex, because in order to ensure security for administrative data, the network must be designed to limit student access to machines that contain sensitive information.

### 2.2.7 Planning

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[3] *Ibid*, pp. III-22 and III-23.

This criterion attempts to address the efficacy of central planning in anticipating and addressing users' needs in defining future expansion and redesigning the network. It also attempts to assess the success of the IS planner in effectively coordinating the implementation by gaining the cooperation of the key stakeholders like departmental Information Systems managers.

## 3 Principal Protocols

In order to fully appreciate some of the connectivity and functionality issues encountered in data networks it is necessary to understand the capabilities and limitations of the menu of principal protocols in use in the networking environment. All the protocols described below are incompatible with one another. Often network managers do not have a choice in adopting network protocols, since they may be dictated by the hardware vendor.

The network protocols refer to the middle three layers of the Reference Model of Open System Interconnection (OSI) developed by the International Standards Organization (ISO)[4]. The OSI defines distinct layers according to defined principles:

- A layer should be created where a different level of abstraction is needed;
- Each layer should perform a well defined function;
- The function of each layer should be chosen with an eye toward defining internationally standardized protocols;
- The layer boundaries should be chosen to minimize the information flow across the interfaces;
- The number of layers should be large enough that distinct functions need not be thrown together in the same layer out of necessity and small enough that the architecture does not become unwieldy[5].

Protocols that adhere strictly to the OSI layer boundaries will map very closely to one another, facilitating protocol conversion. Furthermore, the simplification of the interface indicates that upper layer protocols may be laid over any of several different lower layer protocols without difficulty.

The ISO OSI reference model defines seven layers:

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[4] Andrew S. Tanenbaum, *Computer Networks* (Englewood Cliffs, NJ: Prentice Hall, 1981), pp. 15-21.

[5] H. Zimmerman, "OSI Reference Model — The ISO Model of Architecture for Open Systems Interconnection," *IEEE Transactions on Communications*, Vol. COM-28, April 1980, pp. 425-432.

7. Application layer — The content of this layer is up to the individual user. When two user programs on different machines communicate, they alone determine the set of allowed messages and the action taken upon receipt of each.

6. Presentation layer — performs functions that are requested sufficiently often to warrant finding a general solution for them, rather than letting each user solve the problems. These functions can often be performed by library routines called by the user.

5. Session layer — is the user's interface into the network. The user must negotiate with this layer to establish a connection with a process on another machine.

4. Transport layer — also known as the host-to-host layer, accepts data from the session layer, splits them up into smaller units (if need be), pass these to the network layer, and ensure that the pieces all arrive correctly at the other end.

3. Network layer — sometimes called the communication subnet layer, controls the operation of the subnet. This layer basically accepts messages from the source host, converts them to packets, and sees to it that the packets get directed toward the destination.

2. Data link layer — takes a raw transmission facility and transforms it into a line that appears free of transmission errors to the network layer.

1. Physical layer — concerned with transmitting raw bits over a communications channel. The design issues here largely deal with mechanical, electrical, and procedural interfacing to the subnet.

The lower three layers are primarily dictated by the transport medium (*e.g.*, Ethernet and X.25 public packet-switch networks). The application layer is of primary interest to sophisticated users beyond the scope of this study. The presentation layer contains general purpose services like remote login, file transfer, and data encryption which are of interest. However, compatibility within the middle three layers will determine the ability of networks to offer uniform presentation layers.

Differing network protocols for the middle layers may be laid on top of the same network layer. DECNET, SNA, XNS, and TCP/IP may all be implemented on an Ethernet (often simultaneously). This study examines protocol decisions at the middle layers of the ISO reference model.

## 3.1 TCP/IP

The Department of Defense developed the Transmission Control Protocol/ Internet Protocol (TCP/IP) for its ARPANET. Because ARPANET is a nationwide network of protocols, TCP/IP was designed to be extremely flexible. It can connect with many different kinds of computers and its addressing system can accommodate hosts on many different networks. TCP/IP supports three standard functions: network mail, file transfer, and remote login[6].

Almost all TCP/IP hosts implement two standard user applications (protocols): FTP, or File Transfer Protocol, and TELNET, a basic remote login protocol. The Simple Mail Transfer Protocol (SMTP) is widely used to distribute electronic mail messages throughout the Internet domain. TCP/IP has become the closest thing to a protocol standard at the transport and presentation layers of the ISO networking standard. The TCP/IP protocols have been implemented on a number of hardware platforms and operating systems. Notably, nearly all UNIX systems use TCP/IP networking protocols.

## 3.2 DECNET

DECNET protocols are a central component of Digital Equipment Corporation's Digital Network Architecture (DNA). DECNETs are closed systems in that the protocols are proprietary to DEC. DECNET will run over both generations of Ethernet (thin and fat cable) as well as over fiber-optic cable and twisted-pair cables. DEC also supports wide area network (WAN) capabilities to help users link local area networks spanning several

[6] "Networks at MIT," Information Systems Series Memo IS-10-1, MIT, November 13, 1986, p. 5.

cities or countries throughout the world.

DECNET supports several application functions, including: file transfer between any two devices in the network, electronic mail, and remote login (subject to privilege security restrictions). A facility called finger allows a user to determine who is logged onto the DECNET environment and where.

DEC also provides some related services that are part of the Digital Network Architecture. The Maintenance Operations Protocol (MOP) enables the system manager to download software over the network as well as run diagnostics on remote machines. The Local Area Transfer protocol (LAT) is used to link DEC's terminal servers to DECNET hosts.

An important recent extension is DEC's Local Area VAX Clustering (LAVC) supported over the Ethernet. This service provides for remote booting and remote file serving among DEC VAX machines. The LAVC protocol as well as all the above are registered with ISO though they are proprietary to the Digital Equipment Corporation[7].

## 3.3 SNA

Systems Network Architecture (SNA), announced by IBM in 1974, is IBM's strategic communications blueprint from which to define, design, and implement interconnection and resource sharing among communications network products. These specifications provide the set of rules, logical structures, procedures, formats, and protocols that are implemented in various hardware and software products[8].

SNA is implemented in a variety of IBM hardware and software products, but IBM seems to be favoring the adoption of SNA as an open standard. The company has

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[7] *Networks and Communications Buyer's Guide*, Digital Equipment Corporation, Maynard MA, 1986 October — December, pp. 1.1-1.9.

[8] Thomas J. Routt, "Distributed SNA: A network architecture gets on track," *Data Communications*, February 1987, p. 116.

significantly extended its architecture to provide the broad range of services required of a fully functional network architecture. IBM supports the interconnection of distinct and separate SNA networks through its SNA Network Interconnection (SNI). It has further recently introduced distributed services to address trends toward general decentralization and the migration of data processing and communications capabilities to desktop workstations.

SNA currently provides support for remote login, mail, and file transfer. Future products will soon support document interchange and distribution services as well.

### 3.4 PRONET

PRONET was developed by PROTEON to support its networking products. It is the basis for PROTEON's NOVELL operating system that provides users a broad range of services in addition to the basic file transfer, remote login, and electronic mail. NOVELL is a network operating system designed especially for microcomputers that has rapidly become an industry standard for package software developers. PROTEON has widely distributed the specifications for interfacing to NOVELL and most major software developers now offer a NOVELL network version (*e.g.*, DBase, Microsoft Word).

NOVELL offers the ability to share files as well as printers. For file access, NOVELL provides superb security. Multiple users can access the same file and even modify different records within the same file simultaneously. Most workstations in a NOVELL environment have only a floppy disk drive — a single copy of all applications software is maintained on a shared file server.

In addition to its distributed functionality, NOVELL offers fast access and fault tolerance. The user interface is menu-driven for ease of use. NOVELL users are reluctant to relinquish the greater flexibility and functionality merely to gain TCP/IP compatibility.

## 3.5 NFS

Sun Microsystems developed the Network File System (NFS) to support its broad range of "disked" and diskless workstation products. It provides users with highly transparent file access. A user may be oblivious to the fact that his files do not actually reside on his host or workstation, but may be maintained on a remote file server. NFS functions between different types of operating systems, giving users on NFS hosts access to files on "alien" machines.

Like PROTEON's NOVELL, NFS offers a number of benefits. Being able to move heavily accessed files to central servers can greatly reduce workstation costs by shrinking the remote station's disk capacity. Having a central file server lowers maintenance costs and simplifies the process of making tape backups. SUN has provided additional resources to facilitate shared development among programming teams as well.

## 3.6 XNS

Xerox Networking Service (XNS) is a set of protocols developed by Xerox for local area networking. The XNS protocols parallel TCP/IP in their functionality. It offers file sharing services lying somewhere between TCP/IP FTP and SUN's NFS. Unlike NFS, XNS users edit a copy of their document, but the link is much tighter than with FTP. With XNS services, users download their files from a central server to their local workstation for editing and development. When finished, the user uploads the modified documents to the central server.

XNS also provides centralized servers for electronic mail, authentication, and printer spooling. Xerox has not been very successful in establishing XNS as a *de facto* standard.

# 4 Characterization of the MIT Environment

MIT has one of the most highly networked computing environments in the country.

## 4.1 Network Topology

The MIT data network consists of a campus-wide backbone network linking client sub-networks as well as a number of isolated "islands of networks." Backbone and attached client subnets are referred to as the MIT Campus Network. The Campus Network maintains links to a number of external networks as well. A number of departments like the Medical department, Administrative Systems, and Registrar's office maintain their own local area networks that are not a part of the Campus Network.

### 4.1.1 Internal Networks

#### 4.1.1.1 Backbone

The backbone is a 10-megabit fiber optic token ring consisting of gateways to each of the sub-net clients. The backbone runs both TCP/IP and CHAOSNET, TCP/IP being the standard for all campus-wide communication. The central IS manager, Telecommunications Systems, supports and maintains the fiber optic transmission medium as well as the gateways. Campus Network service is supplied by installing a gateway (MicroVAX II) in the building being served as well as running cable to the host.

#### 4.1.1.2 Subnets

The sub-networks are almost all Ethernet (10-megabit coaxial) with half-repeater/fiber optic connections to other buildings. Several different protocols are utilized by the various sub-nets (DECNET, TCP/IP, XNS, CHAOSNET). These sub-networks are managed by departmental managers who often hire their own technical staff to support and maintain their LANs.

Since the backbone protocol standard is TCP/IP, any communications between sub-networks must use TCP/IP. This is not a difficulty for subnets using that protocol, but DECNET and XNS LANs have difficulties gaining inter-subnetwork service. These difficulties will be discussed at length in Chapter 7. The onus falls on the departmental manager to purchase the protocol conversion hardware and software in order to enable inter-subnetwork communication.

At MIT, the TCP/IP set of protocols runs on several kinds of hardware and with a variety of operating systems. All Project Athena machines run TCP/IP. Even before the initiation of the campus-wide network, all computers with direct connections to the ARPANET ran TCP/IP as did some computers that accessed ARPANET via these directly connected machines.

#### 4.1.1.3 Isolated Networks

Some sub-nets are isolated from the backbone, both by choice and through connectivity problems. LANs for the Medical Department, the Office of the Registrar, and Administrative Systems are isolated from the Campus Network for security reasons. All three organizations are concerned a compromise of network data security could result in the release of sensitive information. As a result, they maintain their own closed network, resorting to dedicated terminal lines or modems to gain access to administrative timeshare host computers on an as necessary basis.

Administrative Systems and the Medical Department are using Proteon PRONET protocols together with NOVELL operating system. They are both reluctant to go to TCP/IP because it does not support the full functionality they require within their local network environment. NOVELL capabilities in sharing files and printers are very valuable to these users.

The Medical Department has used a central file server to eliminate the cost of a hard disk for each its IBM PC workstations. Workers keep personal files on floppies or on the central server. A single network version of DBase or Microsoft Word is more cost effective than supplying each user with his own copy. Maintenance and tape backup are streamlined since one copy is less time consuming than 40. Printer spoolers improve the accessibility and affordability of laser printing.

Both would quickly adopt a solution enabling them to use both NOVELL and TCP/IP for inter-network communications tasks (file transfer, electronic mail, and remote login) but do not have the resources or technical expertise to create a solution. The problem could be solved through software, but neither group has the technical staff to complete the development. A hardware solution could be purchased but would run $20,000-25,000.

Other networks are isolated because of difficulties in wiring that particular building. Still others present severe protocol incompatibility problems that preclude joining the Campus Network without undertaking a significant development project.

#### 4.1.1.4 CHAOSNET

The CHAOSNET is a home-grown MIT product, developed at the Artificial Intelligence Laboratory as a local network for its LISP machines. It outgrew this original form and spread to other research groups around campus. Before the advent of the Campus Network, the CHAOSNET was the largest-scale attempt at a coherent medium for communication between MIT computer facilities.

Though the CHAOSNET protocol is incompatible with TCP/IP, it features a very similar user interface, including both the FTP and TELNET protocols. In spite of this superficial resemblance, you cannot usually transfer files between IP and CHAOS hosts or log in to a host on the other networks via TELNET[9]. Special multi-protocol gateways must be installed to support transfer between specific sub-networks.

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[9] "Networks at MIT," Information Systems Series Memo IS-10-1, MIT, November 13, 1986, p. 5.

### 4.1.2 External Networks

#### 4.1.2.1 ARPANET

The ARPANET is one of the oldest, largest, and most fully-implemented of the long-distance networks. Established by the Department of Defense, access is limited to organizations and people engaged in federally funded research. This network was recently split in half. The military and defense contractors were separated onto their own secure and reliable network called MILNET. The ARPANET remains more experimental, serving the more general research institutions. A gateway between the two networks lets outsiders send mail to MILNET members. The TCP/IP protocols implemented at MIT were originally developed for the ARPANET[10].

#### 4.1.2.2 CSNET

CSNET is a research network linking computer scientists and engineers at sites throughout the United States, Canada, and Europe. It was developed to provide TCP/IP-type services to computer science institutions that weren't part of the ARPANET, and to make electronic mail exchange possible with ARPANET hosts. Initial funding was furnished by the National Science Foundation with the understanding that eventually the network would become self-sufficient.

Membership in CSNET is open to any organization engaged in research or advanced development in computer science or computer engineering, Members include universities, corporations, government agencies, and non-profit organizations. CSNET users are professors, graduate students, undergraduates, corporate research staff, visiting scientists, government researchers, and other professionals in the field of computer science and electrical engineering[11].

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[10] *Ibid*, p. 8.
[11] *Ibid*, p. 9.

#### 4.1.2.3 BITNET

BITNET connects mainframes at universities and other research institutions worldwide. It is expanding rapidly and now includes about 1500 sites (network nodes). All users at member institutions can access the facilities that BITNET offers. At present these include electronic messages and mail, and the transfer of programs and documents, but not remote login.

BITNET is inexpensive to use and maintain. Rather than designing its own network software, or using the TCP/IP protocols, BITNET takes advantage of a standard IBM facility called RSCS (Remote Spooling Communications Subsystem) for VM, and JES2 or JES3 for MVS, which are already in place on the network hosts. Because of the network's rampant growth, "JNET" software has also been developed to connect to BITNET from DEC computers running VMS, and "UREP" software to connect UNIX systems. Each member institution contributes its share of the network by leasing a line from a telephone company to link with a nearby network node, and accessing this line through a 9600 bps modem[12].

#### 4.1.2.4 USENET

Just as BITNET uses RSCS, the USENET network uses software that comes as part of UNIX. The name UUCP (UNIX-to-UNIX Copy) can be applied to two different network services.

The original UUCP is a file transfer program. It permits the transfer of files between two UNIX systems, either over hardwired lines or by dialing up. A mail service was subsequently grafted on top of the original UUCP, forming a mail network. UUCP

[12] *Ibid*, p. 7.

mail permits forwarding of mail over several systems, but does not handle the routing or acknowledge errors.

#### 4.1.2.5 Supercomputer networks (JVNC Net)

MIT maintains T1 network links both to the John von Neumann Computing facility in Princeton, NJ as well as Harvard University. This network supports National Science Foundation work in supercomputing.

#### 4.1.2.6 Centrex

MIT's voice network needs are currently served by an IA ESS Centrex system located in New England Telephone's Central Office on Ware Street in Cambridge. In addition to basic telephone service, Centrex supports low speed dial-up communications up to 4800 bits per second (bps) using modems. This capability is currently being used for time-sharing computer access, asynchronous file transfers and access to external networks and remote database. MIT is in the process of acquiring a 5 ESS voice/data PBX to replace its Centrex system. The ramifications will be examined in Chapter 7.

## 4.2 Telecommunications Systems

Telecommunication Systems is the central administrator of both the MIT Campus Network backbone and telecommunications services. It operates and services the campus-wide phone services. It also operates and maintains the Proteon token ring backbone. Any client wishing to join the Campus Network must negotiate with Telecommunications Systems to acquire service.

Telecommunications Systems handles all installation and maintenance of gateways to the Campus Network backbone. Consulting services are available on a fee basis.

## 4.3 Project Athena

Project Athena is a five-year program to explore new, innovative uses of computing in the MIT curriculum. Major computer manufacturers have developed high-performance graphics affordable workstations that may significantly impact undergraduate education. The MIT faculty was concerned that too little was being done to integrate the new computational technology into the undergraduate educational experience. Project Athena arose from this concern.

Project Athena's workstation clusters are scattered throughout the Campus Network. Project Athena staff play a major role in defining and influencing planning for the entire network[13]. Athena is significantly advancing the state of the art in distributed computing.

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[13] Steven R. Lerman, "Questions and Answers About Project Athena," MIT Project Athena, Revision C, November 1986, p. 2.

# 5 Characterization of the Harvard Environment

Harvard University trails MIT in terms of communications sophistication. There is no real central backbone interconnecting the various sub-networks that populate the campus.

## 5.1 Network Topology

At present, Harvard University does not have in place a campus-wide network. There are a variety of data network resources put into place to meet the needs of the faculties and departments at Harvard.

### 5.1.1 Internal Networks

#### 5.1.1.1 Centrex

Like MIT, Harvard University's voice network needs are currently served by an IA ESS Centrex system. Harvard also uses Centrex to support 4800 baud dial-up communications through modems. This capability is currently being used for time-sharing computer access, asynchronous file transfers and access to external networks and remote databases[14].

#### 5.1.1.2 OIT Network

The Computing and Information Utilities Division (CIU) of the Office of Information Technology (OIT) operates a network to provide users throughout the university access to its centralized computing facilities at 1730 Cambridge Street.

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[14] "Harvard University Long Range Telecommunications Plan: Resource Summary," Harvard University Office for Information Technology, Telecommunications Services Division, August 13, 1986, p. III-1.

Network services include low speed dial-up services via Centrex facilities, dedicated links for support of IBM 3270 Bisync devices at 9600 bps, and specialized networks such as the Harvard On-Line Library Information System (HOLLIS). CIU also provides protocol conversion service to allow asynchronous terminals and other devices to access applications designed for the IBM 3270 environment[15].

#### 5.1.1.3 Harvard Business School Network

The Harvard Business School operates a network linking approximately 1800 users to its mainframe systems located in Baker Library. Terminals and PCs running terminal emulation programs access either of the Business School's two mainframes — a DEC 1091 and an IBM 4381 — via an IDX 3000 Data Switch. All devices are directly connected to the data switch using multiplexers distributed throughout the campus and operate asynchronously at 9600 bps[16].

#### 5.1.1.4 FASNET

The Faculty of Arts and Sciences Network (FASNET) is a broadband, coaxial cable network serving a number of faculty and administration buildings as well as the computing resources at 1730 Cambridge Street (OIT), the Science Center, and the Aiken Computational Laboratory.

The primary network service provided on FASNET is Sytek's LocalNet 20, an asynchronous terminal-to-host application operating at 9600 bps. Several hundred ports provide connections among terminals, PCs, and 30 host computers throughout the served area.

Another network service implemented on FASNET is the IBM PCNet. PCNet is a 2 Mbps local area network (LAN) designed to connect IBM PCs for communications and

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[15] *Ibid.*
[16] *Ibid,* p. III-2.

resource sharing (printers, disks, file, *etc.*). Several IBM PCs in administration buildings are currently connected via such a LAN[17].

#### 5.1.1.5 Ethernets

Ethernet is a high speed LAN designed to support the exchange of data among devices within a limited geographical area. It is based on coaxial cable technology and is primarily configured to operate at a rate of 10 Mbps. At Harvard, Ethernets are primarily employed in computer-intensive environments such as computer rooms and research laboratory areas.

In early 1986, the FAS implemented an Ethernet using fiber optic cable. This 10 Mbps network interconnects computer networks (including other Ethernets) in over a dozen buildings providing high speed file sharing and image transfer capabilities. It is also the primary network providing access to the external supercomputer network via a DEC VAX 11/750 located in the Aiken Computational Laboratory. Since it was designed as a transparent transport facility, the FAS Fiber Optic Ethernet supports a variety of network protocols such as DECNET, TCP/IP, and XNS[18].

### 5.1.2 External Networks

- ARPANET
- CSNET
- BITNET
- USENET
- Supercomputer Networks

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17 *Ibid.*
18 *Ibid.*

## 5.2 The Office of Information Technology

The Office of Information Technology (OIT) is in the process of implementing a plan to create a university-wide communications network incorporating voice, data, and imaging. OIT is charged with the operation of telecommunication services for the university. OIT has historically operated and maintained only large mainframe computing facilities and provided phone line access to their machines.

# 6 Comparative Evaluation on Criteria

In evaluating the networks it is necessary to examine the impact on all three segments of the user community — the faculty, the administration, and the students. The evaluation will be based on personal interviews with key network planning personnel supplemented by questionnaire data.

The perspective throughout this analysis will be the examination of how protocol standardization (or non-standardization) contributes to the service delivery failure. The critical issue is that of network connectivity.

Data for the evaluation was obtained through personal interviews and survey questionnaires. The author also draws conclusions from data obtained by Harvard University pursuant to designing their University Network. Twenty-five questionnaire responses from MIT users form the complement to the Harvard data. The principal network managers for both universities were interviewed, in addition to lead users in all three segments of both environments.

## 6.1 General User Characteristics

Before considering the several evaluation criteria with regard to the three segments of the user community, it is worthwhile to make some general remarks about the use characteristics of these segments.

### 6.1.1 Administration

Administrative users utilize data processing to manage resources and facilitate processing of paperwork. They are typically heavy computer users, averaging 5 to 6 hours a day on a computer or terminal. Their first priority is database access. The questionnaire data gathered did not qualify administrative users' database needs as either on-line or batch. Some administrators may be satisfied with infrequent batch report generation. Most administrators agreed, however, that access to central administration databases was needed to provide more timely information, eliminate duplication of data entry, and reduce the amount of paper that flows between offices. Three classes of databases were identified:

- Financial: budgets, Accounts Payable/Accounts Receivable, purchasing
- Human resources: payroll, personnel, appointments
- Physical: facilities management

In addition to database access, electronic mail, file transfer, and resource sharing are also high priorities. As a result of their heavy use, administrative staff are experienced and, once trained, they are quite capable in their work. They tend, however, to be relatively unsophisticated from a technical standpoint. Administrative users use data communications primarily within their physical local office and often have technical or consulting support within their office.

### 6.1.2 Faculty

Faculty members make use of computer resources in order to advance their research using library database access for on-line cataloguing and on-line circulation (OCLC). Databases accessed may reside both within the university and outside it as well. Electronic mail can keep a faculty member in touch with colleagues at other universities or research institutions. The ability to transfer and to exchange editable word processing documents between collaborators and publishers also becomes a priority. For electronic publishing, it is important to be able to circulate image as well as text.

Faculty members are infrequent computer users. A simple, easy to use (and remember) interface is very attractive to them. They generally require more consulting and troubleshooting assistance than administrative users. Their communications are largely geographically centered around their department or school. Local area networks are often able to meet all the needs of faculty users. Often the department or school maintains some consulting resources of their own to meet their members needs.

### 6.1.3 Students

Students use computing facilities primarily in support of their coursework as well as for word processing for papers and thesis. Since students are expected to complete their own work, document interchange is not an important service. Resource sharing (printers, file servers, *etc.*) and file transfer are more important. Students need to be able to gain access to timesharing hosts from remote workstations or terminals as well as use electronic mail to exchange information with classmates and course administration.

Student users are scattered throughout the campus. Some are very sophisticated users that demand advanced functionality and are able to educate themselves quickly regarding difficult and complicated interfaces. Others are computer novices that have questions about nearly everything. The diversity of the population results in varying usage from light (less than 1 hour/day) to heavy (5 to 6 hours/day).

## 6.2 Functionality

The several user service requirements will here be considered one at a time. When segments of the user community provide differing evaluations, the distinction is noted.

### 6.2.1 Database Access

Database access is most important to administrative users. Offices like the Registrar, Budget, and University Administration depend on timely access to internal databases to perform their jobs. Security issues, however, prevent most of these offices from joining the mainstream network.

At MIT, databases are maintained on dedicated administration machines on closed local area networks. They cannot be accessed from the Campus Network. As a result, databases are maintained independently. Users requiring information from another system must gain access through IBM 3270 terminal access on an as needed basis.

MIT's administrative users gave the data network slightly favorable marks on its support of access to central databases. The principal complaints pertain to the awkwardness of transfer methods forced by security difficulties. The Medical Department has adopted the method of having 2400 foot magnetic tapes created and physically transferred to gain access to the data it needs.

Student and personnel information is updated on a daily basis by the registrar and personnel offices. Without on-line access, the process of creating the tape, transporting it, and extracting the information can take two to three days. The process is time consuming and Knott updates her data only as often as she has to (approximately twice a month). Since this is neither timely nor cost efficient, Alison Knott, Manager for Information Systems for the Medical Department is desperately seeking an alternative[19].

Harvard has approached the problem similarly, dedicating IBM hosts to maintaining the administrative databases. Access from remote hosts is on an ad hoc basis. On the FAS Ethernet, database access is well-supported by NFS. However, the FAS Ethernet is populated with non-NFS hosts that cannot take advantage of the Network File System.

Some faculty users rely on internal and external databases for research information. In both institutions, this service receives slightly favorable ratings. Local area networks facilitate access to data internal to the department or research area, like MIT's Plasma Fusion Laboratory and Harvard's Aiken Computational Laboratory.

### 6.2.2 Resource Sharing

[19] Personal interview with Alison Knott, Manager of Information Systems, Medical Department on April 29, 1987.

This service is generally served quite adequately by both the Harvard and MIT data networks. For all classes of users, resource sharing is primarily at the local area network level. Since each LAN is configured to serve the local users, it is pretty effective in delivering the necessary service.

MIT's administrative users gave the highest marks; it was evident that the most attention was paid to resource sharing at the departmental level. The Medical Department and Administrative Systems have invested heavily in their local environments (NOVELL, print servers, file servers) and have achieved effective support of their local groups.

The Medical Department elected to install its own computing and network facilities in support of its users, The use of the NOVELL network operating system created the opportunity to provide for each user a low cost workstation with free access to word processing (Microsoft Word), database management (DBase), central file and data, and printers. A user is not constrained by the failure of his single workstation; he can simply continue work on another and access the same resources.

Faculty members were quite variable, depending on the resources and sophistication of the department. A professor at the Sloan School finds himself isolated without any shared resources whereas a physicist in the Center for Space Research gives highest marks to his ability to share resources like printers and database servers. Students gave lower but satisfied marks, but may have been unaware of the underlying resource sharing of Project Athena.

### 6.2.3 Document Interchange

This service is required by administration and faculty users. The ability to exchange modifiable word processing documents greatly facilitates research and work for both sets of users. This service is possible to a great extent due to a standardization in word processing packages. In environments where a single package dominates, document interchange is easy. Other environments are populated by a wide variety of word processing packages which exacerbate the problem.

Within MIT's Administrative Systems, incompatibility between DECMate WIPS format and the various IBM PC word processing package formats (Word Perfect, Multimate, *etc.*) create difficulty in exchanging documents. Users have to resort to exchanging plain text documents to circumvent the difficulty. While this does result in the elimination of repetitive re-typing, a true standard for document interchange would be a decided win.

Attempts have been made to establish a standard. The Microcomputer Center's consultants encourage users to acquire Microsoft Word, since it provides excellent functionality and supports document exchange between the IBM PC and Apple Macintosh versions. Nonetheless users are reluctant to learn a new editor and word processing package once they have invested considerable time and money in another package. Moreover, users that do not avail themselves of the advice of consultants will not receive guidance and will make their own decisions. No formal standard is in place.

The appropriate agency to effect a document interchange standard is Telecommunications Systems. This office should officially endorse a standard document format (like Microsoft Word or Document Interchange Format) and offer an internetwork document transfer utility to user of the Campus Network. This would create an incentive for users to adhere to the standard and would greatly improve network service to users.

### 6.2.4 File Transfer

File transfer within a LAN is well-supported. Transfer across the network depends critically on protocol compatibility.

In the MIT environment, any file transfer across the Campus Network must use TCP/IP. Networks running TCP/IP have no difficulty with this. LANs that have selected other network protocols however are left stranded without backbone support. These isolated networks have installed dedicated lines or modem connections for ad hoc file transfer capability. The Medical Department has resorted to transferring data by physically transporting magnetic tapes, because the bandwidth of terminal-to-host transfer is insufficient for their needs.

The Harvard environment consists of a number of disjoint islands of networking. Transfers between networks are often impossible. Even within the FAS Ethernet, TCP/IP and DECNET hosts are unable to transfer files even though they are physically connected.

All classes of users view file transfer as a priority. Since most transfers are transacted within a local network, the service level seen by users is mostly adequate to their needs. Only users desiring transfers from protocol-incompatible external networks observe difficulties.

### 6.2.5 Image Communications

The absence of image document standards is a great obstacle to effective image communications. The ability to exchange image documents was universally rated quite poor. No general format has reached anywhere near the stature of an effective standard even within local environments. Macintosh PICT resources are commonly exchanged but only among Macintosh users. With more faculty and student users demanding the capabilities of electronic publishing, the need for image communications is viewed to be a significant growth area in the next five years.

### 6.2.6 Electronic Mail

Unlike some of the above services which are adequate when supported only at the local level, electronic mail is greatly desired across the entire university network. This poses a great challenge in protocol compatibility and conversion. All classes of users use electronic mail to broadcast organizational and coordinating information.

At MIT, Telecommunication Systems attempts to arrive at solutions that will solve the compatibility problems for each non-TCP/IP subnetwork. In a number of cases, a host is identified that can act as a mail gateway for its sub-network. This host will convert mail messages received via TCP/IP and will distribute messages to users/hosts on its own sub-network.

Given the responses, users that are a part of the Campus Network are very pleased with their ability to receive and transmit electronic mail. Isolated networks are also satisfied with electronic mail support.

The system manager at Harvard's Aiken Computational Laboratory has attempted to resolve electronic mail problems by distributing a standard set of mail protocols for all Harvard hosts. This standardization effort has met with some success and has greatly facilitated the reception and transmission of electronic mail.

### 6.2.7 Terminal-Host Communications

Terminal-to-Host communications is still a critical service required by all classes of users. Part of this importance stems from connectivity problems described above. Administrative users both at MIT and Harvard rely on remote login access to timeshare hosts for database access as well as processing needs.

Again protocol compatibility determines the domain of hosts to which a user can gain access. At MIT, Project Athena uses TCP/IP, giving student users access to nearly any coursework-related host on the Campus Network. Dedicated lines and local area networks serve faculty and administrative users. The dial-in services provided by Centrex are also used to support low speed interactive login sessions. Service is generally adequate since any acute need has been met by the implementation of an *ad hoc* solution.

Harvard also relies quite heavily on Centrex to support administrative users. The FASNET supports remote login service for faculty and college administration. Harvard is still very much constrained by the absence of a university-wide network facility that would connect the various "islands" of networking.

## 6.3 Network Reach — Connectivity

Two factors interfere with the network's ability to reach all users desiring data communications service: difficulties in establishing a physical connection and protocol compatibility problems.

### 6.3.1 Physical Connection

In both the Harvard and MIT environments, users that desire access are denied it for physical connection issues. Harvard's lack of a university-wide spine makes it impossible for users across the river at Harvard Business School to gain high speed access to the rest of the data networks. The only links now supported are through dedicated phone lines connected to the OIT administrative hosts.

At MIT, the physical connection issue is slightly different. There exist users in buildings that make it nearly impossible to wire for Campus Network access. In addition, the incremental wiring costs for the first user in a building preclude some users from gaining access. The costs for adding a building to the Campus Network run on the order of $50,000. These must be assumed by the first user desiring service. The second subscriber may be assessed charges as low as $5,000 once the building is already on the Campus Network.

In buildings not yet wired for the Campus Network, departments not willing to spend $50K play a waiting game for someone else to "take the plunge." If no group has the willingness and the resources to do so, then all groups will be permanently isolated from the Campus Network.

Jeff Schiller, Networking Director for Telecommunications Systems, describes two examples where coalitions of departments have banded together to share the initial costs of wiring the building. This helps spread the initial wiring burden among a number of departments and helps alleviate the problem. It is necessary to have several groups all simultaneously desiring and prepared to "be networked."

It should be noted that in the two example Schiller cited, three departments were involved and worked together on an ongoing basis. The decision to share networking costs was a natural extension of an existing spirit of cooperation.

In buildings occupied by many more small and unrelated departments, cooperation may be more difficult to achieve. If the preparation and network requirements of the groups varies greatly, then the "novice" users have an incentive to withhold their support and save money, in the hopes that the remaining groups will install it anyway (due to their greater motivation).

Still, there may be a role for Telecommunications Systems to play in arranging and facilitating these coalitions. It would improve the physical connectivity and improve the reach of the Campus Network.

### 6.3.2 Protocol Incompatibility

Harvard has not yet faced some of the more difficult issues in protocol incompatibility. The fiber optic FAS Ethernet avoids protocol difficulties by using fiber star bridges that transparently join Ethernets, creating one logical network. TCP/IP, NFS, DECNET, and XNS hosts all communicate over the same Ethernet without interfering with one another (except in degrading performance, see below). Hosts running incompatible protocols still have difficulty talking to one another. Nonetheless, users desiring access can be easily connected to the network to communicate with other hosts running the same protocols.

Because MIT has adopted a protocol standard for Campus Network backbone communications, compatibility does become an issue. Alison Knott, manager of Information Systems for the Medical Department, would like to join the Campus Network but does not want to sacrifice the functionality of NOVELL just to obtain TCP/IP compatibility. It would be possible to invest in a PRONET to TCP/IP gateway to rectify the problem, but the investment (about $25,000) is beyond the department's resources.

The problems MIT is facing and that Harvard will soon face point up the acute need for inter-networking protocol standards to alleviate the obstacles to an integrated university-wide network.

## 6.4 Network Performance and Reliability

Network performance is generally very good in both environments. At MIT, only 10% of the available bandwidth of the campus backbone is used even at instantaneous peak load. Bandwidth is not a problem. Faculty and administrative users report satisfaction with network performance. Some students perceive poor response for remote login, but interviews reveal that the true source is a bottleneck at the timeshare host. Reliability is generally good, though somewhat sensitive to power surges and drops. Telecommunications Systems has taken steps to correct this problem by placing both the network bootstrap host and the Kerberos authentication server on uninterruptable power supplies.

At Harvard, the HBS network is adequate to its own needs. The FAS Ethernet presents a different problem. FAS Ethernet is now quite large with a number of diskless SUN workstations accessing filesystems through NFS, Xerox workstations, and DEC VAXs. This creates a problem since Ethernet is a broadcast medium. Performance falls off rapidly as the Ethernet approaches saturation. Hosts are being inundated with broadcast traffic. Network performance suffers as a result.

A Ethernet LAN bridge helps partition a single logical Ethernet by only allowing packets addressed to the far side of the bridge. Broadcast traffic of course must go through. The FAS Ethernet may have to be split into distinct networks to alleviate the problem.

### 6.5 Network Control

Cost is a major source of concern. Users regard the installation and operating costs as prohibitively high. Three years ago, MIT Medical Department spent over $300,000 for timeshare support through dedicated lines and for operations. The manager had no choice but to opt for their own dedicated local area network. The department's operating costs are now $178,000, less than half what her costs would be today. She has in place now computing resources that deliver an order of magnitude better performance and functionality at a fraction the cost. Now, initial wiring ($20,000), gateway ($25,000) and monthly operating costs total over a quarter of her operating budget. The price of connectivity is currently beyond her means, especially in light of her discomfort with the security of the Campus Network (see below).

At Harvard, the opposite situation prevails. OIT charges departments for their usage of systems they manage. The principal data network segment, however, is managed by the Faculty of Arts and Sciences and the managers have not established a charge back system. Users are not assuming their share of the costs.

Network management is difficult in both environments, due to the proliferation of Ethernet. Ethernet is a passive medium and is difficult to partition. With some Ethernet transceivers (like 3Com), it is necessary to interrupt service in order to change the topology. Adding a 3Com transceiver requires breaking the cable and plugging each of two ends on either side of the transceiver. Invasive or "vampire" transceivers connect by penetrating the insulation of the coaxial cable to make contact.

Invasive taps promote flexibility, since the cable need not be cut into many different lengths in anticipation of expansion. They can also damage the cable. In-line transceivers (3Com) make more solid connections but interrupt the cable for installation. The best solution is the use of a multi-port Ethernet transceiver (like DEC's DELNI). This is a product that can connect up to eight hosts from a single interruption in the cable. Traffic monitoring is very simple on Ethernet and can be conducted from any node of the network. Diagnosis of coaxial Ethernets is a fairly simple task.

Fiber-optic cable is very difficult to work with, due to its fragility. Diagnosis of fiber problems require special equipment that Harvard and MIT have only recently acquired. Prior to their acquisition, both FAS and Telecommunications Systems managers were plagued by debugging headaches.

### 6.6 Network Support — Maintainability

Without exception, this is the area where all users in both environments desired the most improvement. MIT has more resources in place to support the user community. Telecommunications Systems maintains consulting support for administrative and faculty users on a fee basis. All users (including students) can receive systems advice from the Microcomputer Store on the selection and installation of microcomputer systems. Project Athena maintains a staff of over 40 consultants to answer student questions free of charge. Consultants staff high activity workstation clusters during peak periods as well as maintaining a user "hot line" for on-line inquiries.

Harvard's OIT attempts to meet the needs of faculty and administration users, but comes short of user expectations. The Faculty of Arts and Sciences maintains user support consultants (terminal watchers) at the Science Center to answer student questions. The Technology Products Center serves the same role as MIT's Microcomputer Store for Harvard University.

Users all would like better information dissemination regarding network news as well as future plans. Sub-network managers are left to their own devices to plan and troubleshoot their LANs. They desire greater technical support and end-user training.

## 6.7 Security

Network data security is a critical issue for administrative users. Sensitive information must be protected from even the most determined efforts of mischievous students. Security directly impacts on the network reach issue in that even though a physical connection can be established and even if a protocol standard (or protocol conversion) is created, administrative users will not open their networks unless their security requirements are satisfied.

This issue is particularly difficult on broadcast medium like the Ethernet. Every host on the Ethernet "sees" each packet, that is each bundle of information transmitted on the Ethernet cable can be disassembled and read by every host. This problem can be solved in part by not sending sensitive information as plain text, employing a data encryption scheme. But this solution requires a sophisticated system of "key" distribution for encoding and decoding encrypted packets.

MIT's Project Athena has made significant progress in this area through the development of the Kerberos authentication server. Kerberos distributes "tickets" to authenticate communications connections for authorized users. Kerberos verification is necessary to establish user-to-host interaction as well as host-to-host and host-to-server sessions.

Kerberos authentication operates for all Internet (TCP/IP) communications. Any client (user or host) requesting a connection triggers a request of the Kerberos authentication server to obtain tickets to verify access to the desired service. Without appropriate Kerberos tickets the target host will deny access. Project Athena hopes to distribute freely the Kerberos authentication scheme to all MIT network managers as soon it is satisfied with the system.

Harvard trails MIT in the security issue. Password protection is in effect on all timeshare systems, of course, but OIT has yet to attempt to address the problem of data network security.

## 6.8 Planning

Network planning is more an organizational problem than a technical one. The decentralized nature of the acquisition and installation of systems exacerbates the situation. Sub-network managers would like assistance and information regarding future expansion and technology but are unable to obtain it from central planning. In order for network planning to be effective, it is critically important that the IS planner involve the sub-network managers and users in the process. As the results have shown, the effectiveness of the data network depends not only on decisions made by the central office but also on decisions made by other stakeholders as well.

MIT's Telecommunication Systems is largely reacting to requests. The network topology evolves as requests incrementally add nodes to the network. Telecommunications Systems is woefully understaffed to meet any planning needs. The director of networking for Telecommunications Systems splits his time between Project Athena and the Campus Network, which fully occupies his time. Staff members at the Laboratory for Computer Science have undertaken independent surveys of users' needs in order to develop a strategic plan for voice, data, and video networks. Telecommunications Systems has not formally endorsed the project and results are still pending.

Harvard's OIT is currently undertaking a major effort to install a university-wide network. They have faced the reality of organizational difficulties and have created a steering committee of the major stakeholders in order to improve the quality of the network design as well as to facilitate its implementation. OIT has hired an outside consultant to assist in the design process of an integrated voice, data, and video network. The design process consists of six phases:

1. Research Plan — defines the data requirements, data collection methodology, and data analysis methodology for the network design

2. Needs Assessment — user needs are identified using information gathered from 120 interviews and 300 questionnaires

3. Resource Summary — describes the existing network facilities for voice, data, and video

4. Network Architecture Recommendation — identifies the optimal network design, considering traffic analysis, functional requirements, and existing resources

5. Request for Proposal — describes the specific implementation in sufficient detail for vendors to bid on the project

6. Implementation

OIT has circulated their Request for Proposal and is reviewing vendor proposals. The research findings and network architecture recommendation have been incorporated into the analysis in the next chapter.

Harvard's methodology for defining the design as well as managing the organizational issues is quite commendable and may serve as an example for future IS planners.

## 6.9 Evaluation Summary

The following table summarizes the results of the author's research.

| | MIT | | | Harvard | | |
|---|---|---|---|---|---|---|
| | Students | Faculty | Admin | Students | Faculty | Admin |
| Functionality | + | o | + | o | o | - |
| Network reach | + | o | o | + | o | - |
| Network reliability & performance | - | o | + | o | o | o |
| Network control | o | o | - | o | o | o |
| Network support | + | - | - | o | - | - |
| Security | o | o | - | o | o | - |
| Planning | + | - | - | o | + | + |

+ Superior
o Average
- Inferior

## 7 Network Backbone — The Choice of a Protocol Standard

Given the diversity of the individual networks and user requirements in the university environment, what is the optimal approach to linking them all together? Which protocol architecture will provide the most interoperable internetwork environment? Examining the answers planners have found for Harvard and MIT may help answer these questions.

MIT's Campus Network consists of a central backbone linking the client sub-networks around the Institute. Harvard's planned University-wide network has adopted an identical architecture. TCP/IP is the protocol standard for MIT's backbone communications. Harvard's Request for Proposal recommends that TCP/IP be the protocol implemented over their High Speed Data Network backbone. In view of the manifold problems with protocol incompatibility, the selection of a protocol standard is a critically important decision for network planning.

### 7.1 ISO Internetworking — Implications for the Backbone

Internetworking is communications among an interconnected set of networks. An interoperable internetwork is one that provides services to heterogeneous hosts on different subnetworks. The International Standards Organization's goal is to provide protocol standards that will support a homogeneous set of services across heterogeneous hosts and subnetworks.

Network designers have investigated and implemented a number of interconnection strategies that attempt to facilitate communications among computers and terminals connected to different networks. The selection of an optimal strategy depends on the characteristics of the networks to be connected. One critical characteristic regards the nature of the interactions between network clients — either connection-based or connectionless.

A network is connection-based if interactions are primarily point-to-point with some duration. A session is initiated by an application establishing a connection with a remote application. Once established, the applications can freely exchange data. When complete, the connection is released. This paradigm is also referred to as a virtual circuit.

The classic example is the voice telephone network, which is operated by human users who establish connections (call), transfer data (talk), and release connections (hang up). In a connection-based network, applications (like bulk file transfer or remote login) establish connections, transfer data and when completed, release the connection.

A connectionless network, on the other hand, does not establish or maintain any relationship between individual data transfers. All of the addressing and other information needed to convey data from source to destination is included explicitly in each data unit. Broadcast communications, periodic data sampling, and other request/response applications (such as directory and identification services) in which a single request is followed by a single response, benefit from connectionless interaction[20]. Network designers also refer to this as a datagram paradigm.

Piscitello finds two fundamental strategies to be most applicable to internetworking in an OSI network:

- Hop-by-hop enhancement
- Internetwork protocol (which Piscitello refers to as connection-less internetworking)

The determination of the preferred strategy depends on the characteristics of the subnetworks that are to be connected.

### 7.1.1 Hop-By-Hop Enhancement

This strategy is preferred if the networks to be connected:

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[20] David M. Piscitello *et al.*, "Internetworking in an OSI environment," *Data Communications*, May 1986, pp. 120-121.

- Offer predominantly connection-oriented services
- Exist where close cooperation among the network administrators can be achieved and enforced
- Exist where the extent to which the individual network services differ is limited

With this approach, connection-oriented internetworking may be achieved by relaying the services of one network directly onto corresponding services of other networks. An underlying assumption of this network interconnection is that it is easier to solve when the services that the subnetworks offer are the same than when they are different.

All subnetworks that are to be interconnected must provide exactly the OSI Network Layer service. Any subnetwork that does not provide this service must be enhanced or modified to do so. Relays are used to passively map the connection establishment, data transfer, and connection release utilities of one subnetwork onto another whenever network connection cross subnetwork boundaries.

Consider a host that desires a connection with a host residing on another subnetwork. If the "calling" host's subnetwork already supports the OSI Network Layer service, then his packets are relayed through a gateway mapping the requested service to the adjacent subnetwork's Network Layer service. If the "receiving" host resides on the adjacent subnetwork, then the trip takes only one hop. [See Figure 1]

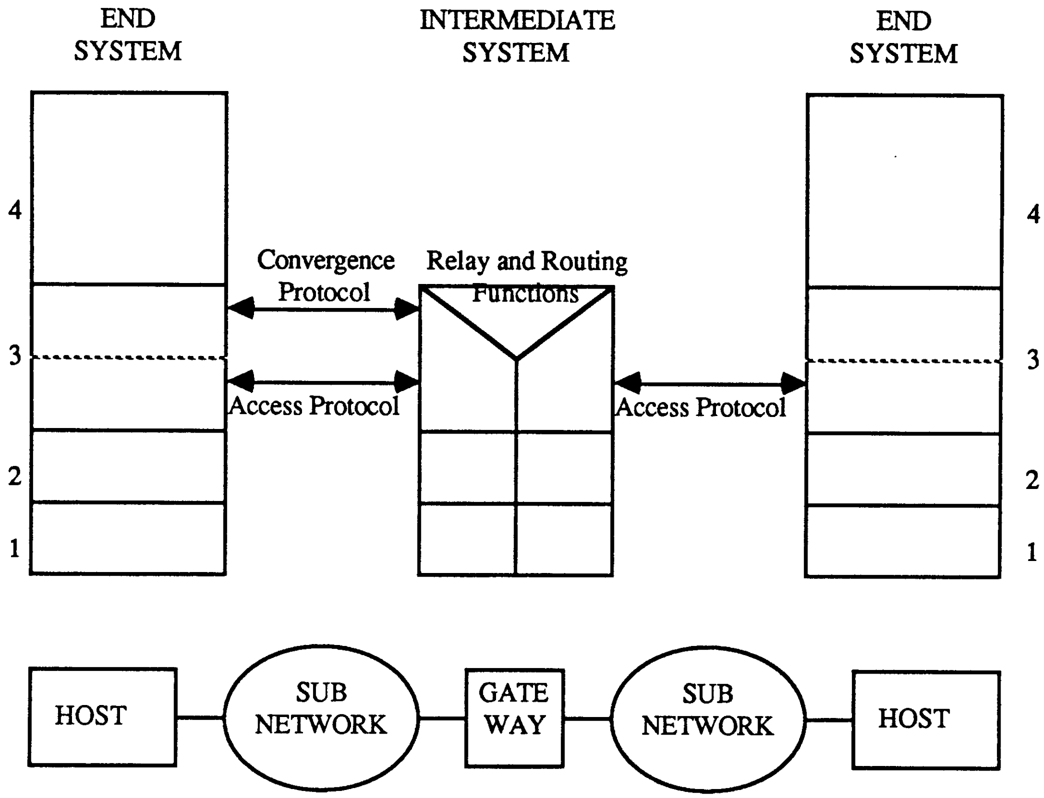


Figure 1: Hop-by-Hop Enhancement
Source: Piscitello *et al, Data Communications,* May 1986, p. 122.

Now if the "calling" host's subnetwork does not provide an OSI Network Layer (perhaps only a subset), then that subnetwork protocol must be enhanced to provide the interfaces and functionality required of a network service. That is the function of a convergence protocol, shown in Figure 1 above. This hop has to enhanced in order to support internetwork communications.

In this strategy, gateways perform a mapping of the service offered by one network onto another. In general, the gateways do not add services. Rather, they perform the relaying and switching functions necessary to bind the individual subnetworks into a unified or global network. A consequence of this approach is that either all of the subnetworks must inherently provide equivalent services or each must be enhanced to some common level of service.

The enhancement of subnetworks up to OSI network service may be accomplished either by direct modification of the subnetwork protocol or through the use of a subnetwork dependent convergence protocol (SNDCP). An SNDCP operates on top of a subnet access protocol to provide the elements of the OSI network service that are missing from the access protocol[21].

### 7.1.2 Internet Protocol

This strategy is preferred if the networks to be connected:

- Offer predominantly connectionless services or a mix of connectionless and connection-based service
- Exist where network administrators are largely autonomous
- Exist where the extent to which the individual network services differ cannot be predicted or controlled

It differs from the hop-by-hop approach in that instead of creating a pairwise protocol map for each gateway, a single explicit standard Internet Protocol (henceforth ISO IP) is used for all end-end communications.

Since the ISO IP is a Network Layer service, it performs the addressing and routing functions necessary for end-to-end communications. Because this protocol set adheres to the ISO OSI model, the protocol will function regardless of what the underlying data link layer is. The ISO IP could be layered over Ethernet, IEEE 802.5 Token Ring, X.25 Public Data Networks, or even twisted pair. ISO IP makes minimal assumptions about the services available — only those specified in the interface between the network and data link layers.

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21 *Ibid.*

Using this approach, a host wanting to broadcast a message over the internetwork simply uses the ISO IP to provide network service and takes care of routing its message over the internetwork.

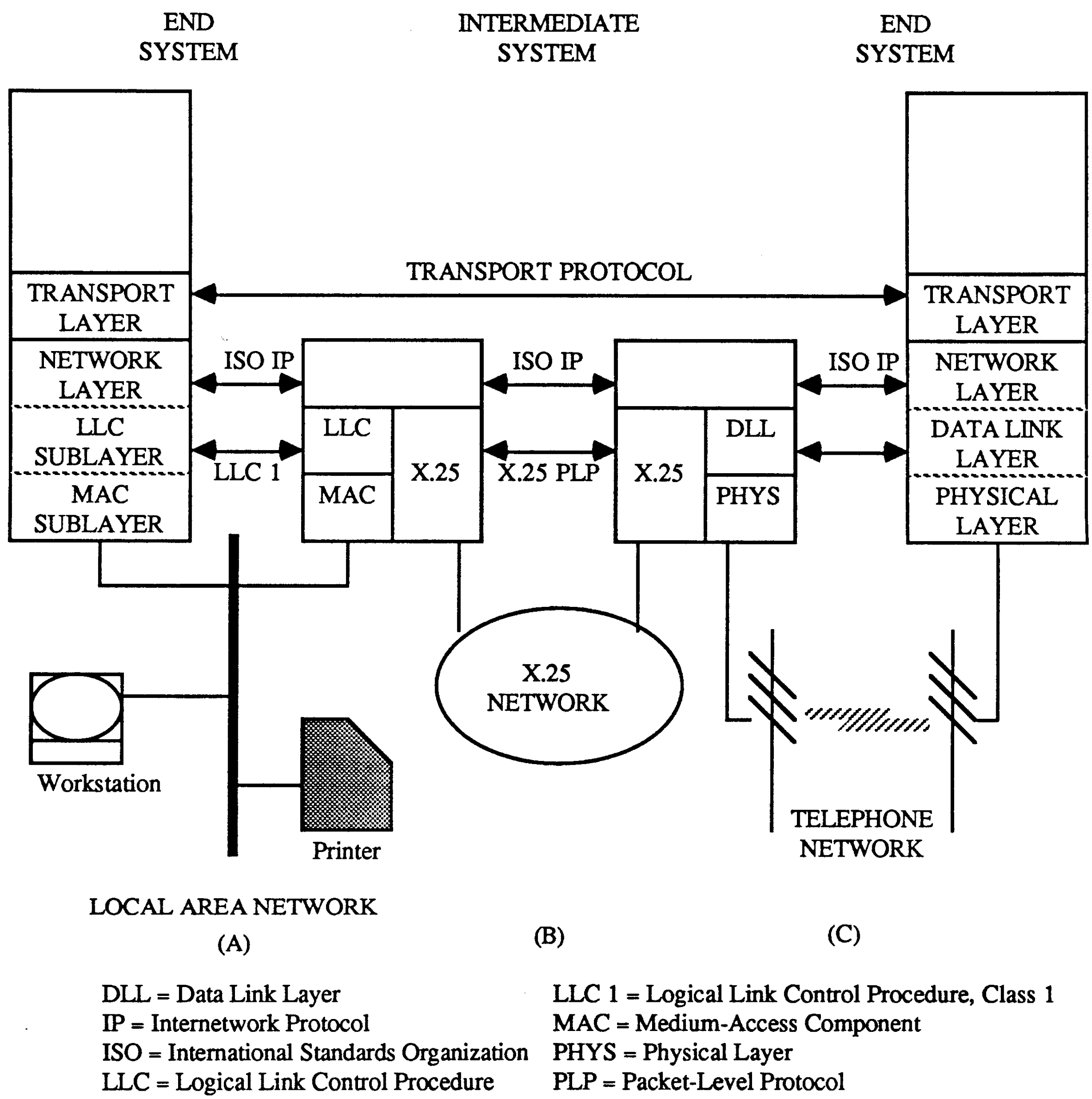


Figure 2: Internetworking Protocol
Source: Piscitello *et al, Data Communications,* May 1986, p. 125.

Since the ISO IP is connectionless, Internetworking Protocol Data Units (IPDU) form the basic packet of information. In order to create a virtual circuit, support from the Transport Layer is necessary. The Transport Layer protocol would take care of guaranteeing arrival, sequencing the IPDUs, so that they might be interpreted as a continuous flow of information.

The important point here is that even if a "connection" has been established at the Transport Layer, the IPDUs conveying information might be routed independently. The transport layer service assembles and sorts the IPDUs to present a continuous connection-based data stream to the end hosts.

The underlying subnetworks should provide only a data transmission service. No subnetwork enhancement is necessary; an ISO IP can be operated directly over the Data Link Layer.

It is important to note that neither of these approaches interferes with subnetwork-specific operations. In the hop-by-hop approach, network service local to the subnetwork is conducted business as usual. For a DECNET, Transport Protocol (TP) messages that leave the local net are mapped into an equivalent Network Layer protocol for the target network. TP messages that stay local are unchanged.

ISO IP is just a complement to the subnetwork-specific network service (if it exists). DECNET might continue to offer TP support in addition to adding an ISO IP service. That way internetwork applications would use ISO IP, local ones could continue to use TP.

## 7.2 Network Requirements

Before evaluating the strategies elected by the two universities, the author first verifies that the two shared the same goals and technical requirements.

### 7.2.1 Harvard University

Harvard University has circulated a Request for Proposal for their University Network. They have specified a network architecture that calls for a High Speed Data Network (HSDN) backbone connecting the several access subnetworks around the university.

Harvard's Request for Proposal details the requirements for the High Speed Data Network[22]. The HSDN will become the primary information transport for the University, linking major schools, departments, building clusters, and individual buildings.

Of primary importance to Harvard is the technical adherence of the network and gateways to the principles set forth in the ISO recommendation for Open System Interconnection (OSI) as well as those of the IEEE 802 committees and proceedings as adopted to date. Harvard must be well positioned to move forward with implementations of systems based on the ISO/OSI reference model when they become available[23].

Functional support. Primary applications to be served fall into the following broad categories: message transfer and/or electronic mail (X.400); bulk file transfer to and from shared file servers and host resources; remote host log-in ; distributed data base; and high volume image data transfer.

Technical Requirements. The target medium will be fiber optic cable at a minimum data rate of 10 Mbps. Gateways to the HSDN must include the hardware and software necessary to interface the HSDN with existing data networks. The gateway devices must be capable of isolating local traffic from the backbone network and providing routing information to local network users. The HSDN must connect the following internal Harvard campus networks:

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22 "Request for Proposal for an Integrated Telecommunications Network for Harvard University," Harvard University Office for Information Technology, Telelcommunications Services Division, January 1987, Version 2, pp. 46-48.

23 *Ibid*, pp. 46-47.

- Ethernet (TCP/IP, DECNET, XNS, LAT)
- Star LAN 802.3
- Token Ring IEEE 802.5
- PBX — ISDN
- Broadband (Sytek — LocalNet 20, IBM PC Net, Ethernet)
- IBM Bisync and SDLC SNA
- Appletalk
- IDX 3000 Data PBX (T1)

As well as the following external network gateways:

- ARPANET (TCP/IP)
- BITNET (BSC)
- UUCP
- Public Packet Networks (X.25)
- Supercomputer Net (T1)

The Harvard University environment is characterized by primarily connection-oriented transactions as evidenced by the list of functions above. Furthermore, subnetwork administration is very autonomous. Subnetworks are managed by different departments and offices as well as by different schools possessing near complete independence. Services vary significantly from subnetwork to subnetwork.

### 7.2.2 MIT

MIT's network requirements are nearly identical to Harvard's. MIT's Campus Network backbone is a 10 Mbps PROTEON token ring linking the building Ethernets scattered across the Institute. The functions to be supported are the same. Both are implemented over high speed fiber optic cable. MIT's internal access requirements are not as demanding:

- Ethernet (TCP/IP, DECNET, XNS, LAT)
- Star LAN 802.3
- Token Ring IEEE 802.5
- PBX — ISDN
- Broadband (Ethernet)
- IBM Bisync
- Appletalk

The external network gateway requirements are identical. MIT's communications are dominated by connection-oriented applications, though the services supported on the access subnetworks are more alike than at Harvard. Again, network administration is highly decentralized with subnetwork managers having total control over their own resources.

## 7.3 Selection of TCP/IP

A summary of the network requirements below in Figure 3 clearly indicates that the two universities had nearly identical goals and technical requirements. Both universities standardized the backbone protocol by selecting TCP/IP.

The reasons that TCP/IP was selected are the same for both universities. Since MIT Campus Network has evolved much more than Harvard's the fact that there existed a significant installed base of TCP/IP hosts weighed more heavily in MIT's decision. Furthermore, at the time there existed no practical alternative that offered the same interoperability and flexibility in hardware support. TCP/IP is available on the largest number of vendors' equipment. Finally, the importance of the Defense Data Network

(ARPANET and MILNET) to MIT's research work and communication allowed no other decision.

| | HARVARD | MIT |
|---|---|---|
| Type of Service | Connection-based | Connection-based |
| Functional Requirements | Database access<br>Resource sharing<br>Document/File transfer<br>Image communications<br>Electronic mail | Document/File Transfer<br>Electronic Mail<br>Database Access<br>Resource Sharing |
| Subnetworks | Ethernet, Token Ring<br>PBX, Broadband, IBM Bisync | Ethernet, Token Ring<br>PBX, Broadband, IBM |
| Bisync | Appletalk, SNA | Appletalk |
| Administration | Autonomous | Autonomous |
| Backbone Medium | Fiber optic cable | Fiber optic cable |
| **Protocol Selected** | **TCP/IP** | **TCP/IP** |
| Reasons | Availability<br>Interoperability<br>Pre-installed base<br>Importance of DDN | Pre-installed base<br>Importance of DDN<br>Interoperability<br>Availability |
| Implementation | Multiple network layer protocols | Single network layer protocol |
| Implication | Requires convergence at gateway | Requires conversion at host |
| **Effective Strategy** | **Hop-by-Hop Enhancement** | **Internetworking Protocol** |

Figure 3: Summary of Internetworking Strategy

TCP/IP is the protocol recommended in Harvard's RFP. "Because of its emergence as a *de facto* standard in educational and research networking, the TCP/IP suite of protocols is preferred for the HSDN.[24]" TCP/IP offers the greatest interoperability of

[24] *RFP for Harvard University*, p. 47.

any existing protocol suite on the market. For a university with a number of different vendors, this issue is of paramount importance.

The TCP/IP protocols are not without their drawbacks as well. They do not conform to the ISO OSI reference model. The Internet IMP-IMP (Interface Message Processor) occupies both the data link and the network layers and the Source to destination IMP protocol overlaps the network and transport layers[25].

Since there does not exist a distinct OSI network layer, the migration path from TCP/IP to ISO IP may require significant modification of user internetwork applications[26].

Furthermore, the basic utilities supported with the Internet Protocols provide a subset of the capabilities supported by access subnetwork-specific protocols. FTP, TELNET, and SMTP do supply most of the functionality required in both environments, but in convergence mapping they represent bottlenecks. An example of this is described in Section 7.4.1 below.

### 7.3.1 Protocol Implementation

The two universities diverge on their implementation of the protocol. Harvard has elected to minimize the impact on existing networks by permitting the access subnetworks to continue to use the same network layer protocols for internetwork communication. This places the burden of standardization on the gateway hosts. They are collectively responsible for converting the various subnetwork to the backbone standard, TCP/IP. Each gateway is in essence performing a protocol convergence function.

The MIT environment maintains a single internetwork network layer protocol. This is partially an artifact of the early entrenchment of TCP/IP in the computing environment. It is necessary for network hosts to convert to TCP/IP to become full partners to the

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[25] Tanenbaum, p. 22.
[26] *Ibid*, pp. 226-231.

internetwork domain.

Non-TCP/IP hosts that do not convert can gain access through the acquisition of gateways. The difference between the gateways proposed by Harvard and those employed at MIT is that the function of the Harvard gateways are largely transparent to the user. On a Harvard DECNET host, a user could still use the familiar DEC Disk Access Protocol to retrieve files from TCP/IP hosts (See the DECNET section below). The gateway handles the mapping between applications. A user on an MIT DECNET host would currently have to have an account on the gateway machine in order to gain access. Furthermore he would have to learn to use TCP/IP's File Transfer Protocol to accomplish his ends.

### 7.3.2 Resultant Internetworking Strategies

The divergent implementation of the protocol standard has effectively chosen differing internetworking strategies for each university. Harvard's gateway convergence implementation makes their approach an extension of the hop-by-hop enhancement. All internetwork communication consists of exactly two hops — once onto the backbone and once off it into the target access subnet. This architecture greatly reduces the number of SNDCPs that must be implemented. In the original, each distinct subnetwork-to-subnetwork link required a SNDCP.

With 15 different subnetwork access protocols, 105 SNDCPs would have been required (15 choose 2). With a backbone, each access protocol must be converged only to the protocol standard for the backbone, requiring only 15 SNDCPs.

MIT has arrived at the Internetworking Protocol through simple standardization on TCP/IP at the host level. As remarked before, this was not likely a deliberate decision that anticipated future ISO work in internetworking. The level of TCP/IP support is more of a historical and evolutionary effect. The author would like, for the moment, postpone consideration of non-TCP/IP hosts under this schema to the following section and turn to the trade-offs between the two effective strategies.

Piscitello compares the hop-by-hop and ISO IP approaches and discovers some important advantages to the ISO IP strategy. The ISO IP should be used where LANs are involved in internetworking. Benefits are derived from resource optimization, throughput enhancement (through the use of load-splitting techniques) and redundancy and resiliency (the ability to adapt to redundancy)[27].

*Resource optimization.* Using the hop-by-hop approach, resources (such as buffers, a connection-state-information base and CPU) must be reserved at both end systems as well as at the gateways for the duration of the connection. The gateways must have ample capacity to maintain a number of connections even if no traffic is passed. Clearly, if connections remain idle for long periods of time, valuable network resources are wasted.

In contrast, if the ISO IP is used, the sending end system may free resources as soon as the data unit's transmission is completed. Any communicating pair of Network service users that has long periods of inactivity imposes no overhead. Therefore, the ability of the gateway to process requests from any other communicating pair remains unaffected. This typically results in highly efficient use of resources[28].

*Throughput enhancement.* In many internetworking scenarios, the ability to route IP data units independently is particularly useful. Data exchanged between hosts attached to one subnetwork can be routed to hosts on a different (remote) subnetwork without the constraint that all data must be routed down the same path. Using multiple paths to transmit data to the same destination typically improves throughput and reduces response time[29]. Figure 4 illustrates load splitting.

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[27] Piscitello, p. 130.
[28] *Ibid*, pp. 130-133.
[29] *Ibid*, p. 133.

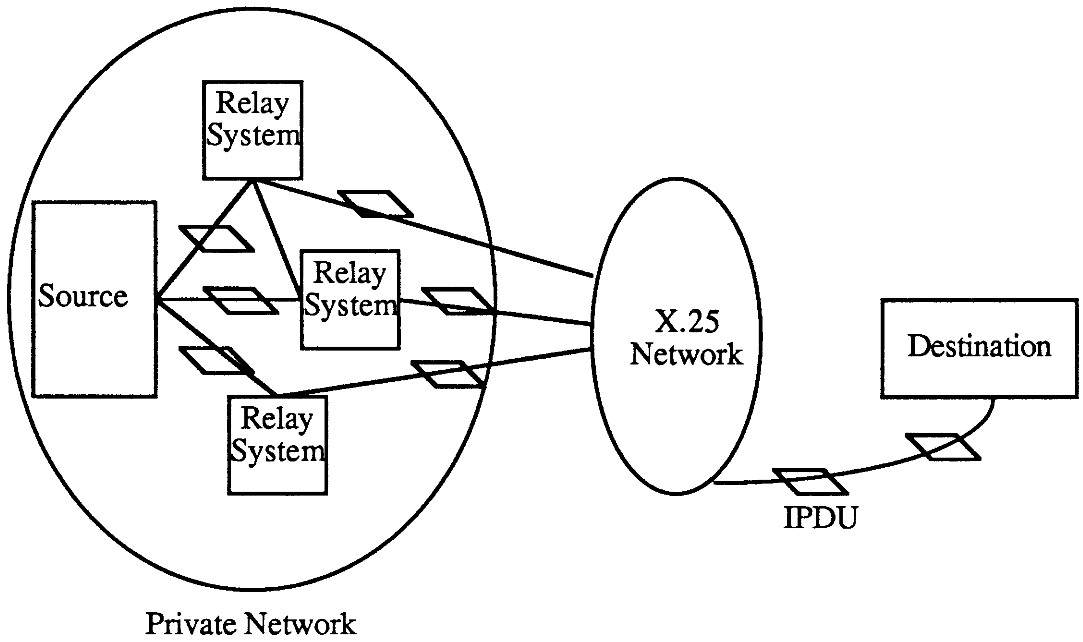


Figure 4: Load Splitting
Source: Piscitello, *Data Communications,* May 1986, p. 135.

On the surface, the Harvard and MIT data network implementations appear identical. Both use the same medium, subnetworks, protocols, and both use gateways. Nonetheless it has been shown that Harvard's resultant internetworking strategy is inferior to the MIT ISO IP approach.

## 7.4 TCP/IP — Implications for the Subnetworks

### 7.4.1 DECNET

Due to the availability of public domain TCP/IP support as well as recent product introductions, the DECNET manager has no concern over the selection of TCP/IP as the backbone standard.

Carnegie Mellon University has implemented TCP/IP for VAX/VMS systems, which it makes available at essentially no cost (only tape medium, documentation, and shipping costs). The protocol support is entirely software based and therefore requires no additional hardware. It provides TCP/IP capabilities and utilities to complement those already provided by DECNET. Users can use FTP to access files on Internet hosts and then switch to use Data Access Protocol (DAP) to access information on DECNET hosts.

There is a performance penalty, however. TCP/IP consumes an order of magnitude more resources (CPU and I/O bandwidth) than DECNET for analogous functions. Peter Roden, Manager of VMS Systems for Harvard's Science Center, believes that the poor performance stems from CMU's implementation rather than from anything inherent to the task. If this is true, than more efficient implementations may be obtained that do not impose this performance premium. The lack of a competitive offering suggests that system managers do not view the penalty enough to warrant laying out real money for a better product.

Digital Equipment Corporation has recently introduced a DECNET-Internet Gateway[30]. This product provides bidirectional access to system resources and utilities between DECNET and Internet resources based on a network applications mapping. It provides for file access and transfer, remote virtual terminal access, and mail exchange according to the following mapping:

| Application | DECNET Protocol | Internet Protocol |
|---|---|---|
| File Transfer | DAP (Data Access Protocol) | FTP (File Transfer Protocol) |
| Remote Terminal | CTERM (Command Terminal) | TELNET |
| Mail | MAIL-11 | SMTP (Simple Mail Transfer Protocol) |

The gateway gives DECNET users access to Internet nodes as well as giving Internet hosts access to DECNET services. Unlike previous products, this one does not require users accounts on the gateway node nor special software on systems that use its

30 Karen L. Gillin and Peter N. Harbo, "The DECnet-Internet Gateway," Networks and Communication Software Engineering Group, DEC, Littleton, MA, February 12, 1987, p. 1.

services. A user may access nodes on the alternate network using the network applications with which he is familiar as though the node were resident on the same network. Specific knowledge of the foreign network applications or syntax is not required. This is a decided improvement over the dual TCP/IP and DECNET implementation approach described above.

Since the DECNET and Internet services are not exactly symmetric, DECNET users may experience some slight variation. The DECNET utilities are supersets of the Internet utilities. FTP provides only a subset of the functionality the DAP provides. In many cases there is no corresponding FTP message for a DAP message[31].

FTP specifies 3-digit return codes to specify the success or failure of the requested action, with 100 different possible values. DAP has literally hundreds if error codes defined for basically any error that could be received on a DEC system. Although it is easy to map a DAP error code to an FTP return code, the converse is not true[32].

Due to the heterogeneous nature of the systems that may use the TELNET protocol, few assumptions are made about the remote systems and their capabilities. Therefore, TELNET keeps minimal information at the client end about the terminal at the server end. The CTERM protocol, on the other hand, keeps extensive information about the server process at the client end, enabling it to take better advantage of graphics workstation capabilities[33].

### 7.4.2 XNS

The implications for XNS subnetworks are much more severe. Harvard has two clusters of Xerox workstations, one in the Vanserg building for the Classics Department and the other in Aiken Computational Laboratory. The Vanserg cluster consists of Xerox

[31] *Ibid*, p. 5.
[32] *Ibid*, pp. 8-9.
[33] *Ibid*, p. 6.

Stars used to examine Greek texts in their original form, Xerox printer servers and a file server of 400 Megabytes of Greek literature. The Aiken cluster maintains some Stars as well as a central file server for the Xerox machines. The Classics Department also maintains accounts on a host at Harvard's Science Center Computing facility.

In the current implementation, all these buildings are a part of the FAS Ethernet. On this network, XNS, TCP/IP, DECNET, and LAT protocols all coexist without interfering with each other. All three buildings (Vanserg, Aiken, and the Science Center) are served by the Ethernet, so XNS operates transparently to the users.

In the proposed network architecture, the Ethernet would be split into discrete segments each serving individual buildings or clusters. Although there exists UNIX software that permit UNIX hosts to access XNS file servers, the unavailability of true XNS to TCP/IP gateways presents a difficult problem for the Classics Department.

One possibility might be to add TCP/IP support to all XNS hosts. The difficulty here is that Xerox's systems are proprietary and do not include source licenses. Any modifications would have to be implemented by Xerox, and may not be available on a timely basis, if at all.

The alternatives presently being considered are to install a separate XNS network link clustering the three buildings. The cost of this installation would have to be borne by the Classics Department and the Division of Applied Sciences and may be prohibitive. The other possibility under deliberation is for the Classics Department to acquire its own central file server to eliminate its dependence on Aiken's resources. The last alternative is to simply abandon the Xerox systems in favor of more compatible Sun or DEC products that would integrate more effectively in the University network plan.

The optimal solution depends greatly on the progress of ISO OSI in adoption by computer and communications vendors. If all vendors were to deliver ISO IP upgrades tomorrow, the Classics Department's problem would be solved. Segmentation of the Ethernet would pose no difficulty. If adoption of ISO IP is slowed, then the optimal solution would depend on the hardware prices the department would be able to obtain from the vendors for competing products.

MIT's Sloan School of Management possesses a number of Xerox workstations on its Ethernet. Since all the hosts reside on the same network, Sloan does not face Harvard's acute connectivity difficulties. Protocol incompatibility problems exist, but some have been worked around. Telecommunications Systems has installed XNS support on a UNIX host which serves as the electronic mail distribution point for the Sloan XNS clients.

### 7.4.3 PRONET

As described previously, PRONET users are reluctant to sacrifice the greater functionality of the NOVELL network operating system to gain TCP/IP compatibility. MIT's Medical Department has three principal concerns about joining the Campus Network. The biggest is the question of the security of the Campus Network. The others are the high cost of gaining connection ($50,000 for installation and gateway, plus operating charges) and the loss of functionality.

A gateway solution would allow the subnetwork to continue to use NOVELL without any interference from the Campus Network. The difficulties that NOVELL subnetwork managers identify are not difficulties arising from the selection of TCP/IP as a backbone standard protocol so much as they stem from broader security issues and cost constraints.

There are no NOVELL users at Harvard.

### 7.4.4 SNA

There are no SNA installations at MIT. Harvard, however, has SNA running on its IBM hosts at the OIT Computing Center. TCP/IP convergence is a difficult proposition but is being neatly avoided by an approach adopted by OIT. The SNA subnetwork will treat the backbone network simply as a data delivery system.

Bob Carroll, Director of the OIT Computing Center described the approach. The backbone gateways serving the SNA access networks will simply envelope the SNA packets inside the backbone protocol. At the receiving end, the TCP/IP envelopes will be removed, and the SNA packets will continue on the target SNA access net.

In this system, it does not matter what the backbone standard protocol is. Since no attempt is made to converge protocols, no incompatibility is encountered. This is, however, not a solution that offers any interoperability among SNA and non-SNA hosts. Unless IBM offers ISO IP support and Harvard migrates to an ISO IP approach, no real internetworking will be achieved.

A possible alternative solution would be the incorporation of SNA gateways to ISO IP products. For example, DECNET is moving quickly to an ISO OSI model to be reached the next implementation, Phase V. DEC offers a SNA/DECNET gateway product that could remedy the connectivity problem.

Harvard has committed in principle to moving toward ISO OSI (see Section 7.2.1). IBM supports the standardization of protocols, but is lobbying to have its SNA be that standard[34]. Nonetheless, ISO leaders are confident of the convergence toward protocol standardization on the OSI reference model among the major manufacturers[35].

### 7.4.5 NFS

The selection of TCP/IP is the best news that NFS managers could possibly receive. NFS operates over TCP/IP. The standardization of TCP/IP guarantees the maximum interoperability of NFS. NFS users will have no difficulty in mounting file systems across the backbone and even into external Internet domains.

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[34] Anura Guruge, *SNA: Theory and Practice — A comprehensive guide to IBM's Systems Network Architecture* (Exeter, Devonshire, England: A. Wheaton & Company Limited, 1984), pp. 383-386.

[35] Richard des Jardins, "Towards the Information Society: World Cooperation on Open Systems Standardization," *Computer Network Usage: Recent Experiences*, L. Csaba, K. Tarnay, and T.Szentivanyi eds., (New York: North-Holland, 1986), pp. 15-17.

## 8 Which Way to ISO Internetworking?

Consider the position today of an Information Systems planner deliberating the optimal strategy for internetworking. He has a network environment consisting of heterogeneous local area networks, some perhaps separated by significant distances. He is understands the significance and potential of ISO OSI protocol standardization, but has internetwork needs now. The following attempts to focus this decision.

### 8.1 Protocol Selection Criteria

There are a number of important issues influencing the selection of a protocol suite for internetwork communications. The author here examines the evaluation of Network Layer and Transport Layer protocols for internetworking. They fall into four major categories.

- Functionality
- Availability
- Interoperability
- Performance
- Cost

A protocol's functionality is an important issue in its evaluation. For research organizations with sophisticated users, a wide range of transport layer support is important. The sophisticated user will want access to both highly reliable virtual circuit and faster datagram support. Less sophisticated users value easy-to-use presentation and applications level utilities that support their basic networking needs (*e.g.*, file transfer, remote login, electronic mail).

There are multiple facets of availability. An important issue is time, particularly when the manager is considering ISO OSI protocols. The length of product introduction delays is uncertain and hard to predict. Another facet is the protocol's availability from various vendors. "Can I get protocol X support for my DEC VAX as well as my IBM 4341?" is the question being asked. This question is inextricably linked to the question of implementation examined above in contrasting Harvard and MIT's approaches.

Interoperability also consists of a number of sub-issues. The interface between this protocol suite and the protocols used on the subnetworks is one issue. Are gateways currently offered by computer and communications products manufacturers to facilitate the implementation of the planned internetwork architecture? How dependent is the network layer on the underlying data link support? Will the network layer provide support over Ethernet, token ring, as well as X.25 public data networks?

Performance measures have more to do with routing efficiency than with data lossage. A network and transport layer protocol suite if correctly implemented will provide users with the functionality required. The data link layer choices are the source of much of data lossage. If a network layer relies on static routing, then it lacks the flexibility to find alternate paths when a particular link is disrupted. Poor routing algorithms can result in excessive looping and therefore performance loss.

The cost issue includes the expense of acquiring protocol support as well as a measure of the hardware investment necessary to implement it.

## 8.2 Network Environment Characterization

As observed above the assessment of protocol selection depends greatly on the target environment. The network planner must answer a number of questions before he can begin to assess the relative merits of one internetwork approach over another.

- What kind of users do I have? Are their needs sophisticated or do they mainly need basic general utilities?

- What type of functionality must I support? What services must the internetwork provide?

- What are the various types of subnetworks that will need access to the internetwork? What are the data link layers involved? Which subnetwork-specific protocols are currently being used?

- What hardware is in use? How heterogeneous is the computing environment? Does one manufacturer's equipment dominate?

- How decentralized is network administration?

- What development and technical resources do I have available? Will I have to buy off-the-shelf products or can I develop some missing links myself? Do I have the technical support resources in-house or will I have to rely on a vendor?

These questions must be answered to generate a context for the evaluation.

### 8.3 Author's Evaluation

The author will exercise the evaluation approach by indulging in the evaluation of some alternative protocol suites from the above developed MIT/Harvard network context. The results are summarized below. Digital Equipment Corporation's DECNET has been included as an intermediate step between the static position of staying with TCP/IP and waiting for OSI. DEC is attempting to make its Digital Network Architecture (DNA) Phase V OSI compatible. Adoption of DECNET would provide some internetwork services immediately with a high likelihood of successful migration to OSI.

TCP/IP's biggest advantage is that it already has a tremendous installed base. The ARPANET and MIT's Project Athena are two important examples. Furthermore, TCP/IP's availability from the largest number of different vendors has made it a *de facto* standard. The biggest short coming is the uncertain path of migration to an OSI standard.

DECNET is available now and offers a better migration path to OSI. Its proprietary nature, however, makes it very limiting as an alternative for the heterogeneous MIT and Harvard environments.

| | TCP/IP | OSI | DECNET |
|---|---|---|---|
| Functionality | | | |
| Sophisticated user | o | + | + |
| Novice user | o | + | + |
| Availability | | | |
| Time | + | -- | + |
| Multiple vendor | + | ++ | -- |
| Uncertainty | + | -- | + |
| Interoperability | | | |
| Interface to subnetworks | + | ++ | o |
| Flexibility over data links | o | ++ | + |
| Performance | | | |
| Routing efficiency | + | + | o |
| Cost | | | |
| Installation | ++ | ? | - |
| Operating costs | o | ? | - |
| Migration to OSI | -- | ++ | + |

++ Excellent
+
o Satisfactory
-
-- Poor

Figure 5: Author's Evaluation for Harvard/MIT Environment

OSI IP will offer the greatest interoperability of any of the alternatives. This assumes that manufacturers will in fact eventually conform to the OSI standard. The author confesses a certain enthusiasm for OSI and a degree of optimism that this will indeed happen. The sole difficulty is that OSI IP is not available. Moreover, it is difficult to predict when the major manufacturers will all offer OSI products. Leadership by one vendor will provide some momentum, but unless all major vendors follow suit complete interoperability will never be achieved.

For the Harvard/MIT context, the author would select OSI IP. Both universities are able to take a long-term view for planning. The uncertainty regarding the timing of vendor product convergence on the OSI standard is important. MIT is in a better position to wait, but Harvard has much more to gain by waiting. It will certainly be possible for Harvard to migrate to OSI IP when it becomes available, but the cost may not be expensive.

# 9 Plans for the Future

Both universities are looking into their future communications needs and are attempting to acquire facilities that will meet or exceed these requirements well into the 1990s. The uncertainty regarding the timetable of the arrival of ISO OSI protocols makes current network design decisions difficult.

## 9.1 Harvard's University Network

Harvard's Request for Proposal details an integrated voice, data, and video network. The architecture calls for an integrated voice and data PBX as well as parallel backbones to support data and video communications. It is difficult to evaluate their future plans since proposals are still being formalized by the bidding vendors.

Harvard's OIT has done a remarkable job of gaining the cooperation and support of the various schools and departments around the campus. Harvard's schools are known to value their independence, and OIT's efforts are a real accomplishment.

Examination of the short-range implementation of the University Network indicates that it falls far short of an interoperable internetworking environment. The views voiced by the OIT Computing Center indicate that not all access subnetworks will be full partners in sharing services. Harvard must be prepared to move quickly to an ISO IP implementation to achieve a truly interoperable internetwork.

## 9.2 MIT Campus Network

Much more can be said about the state and course of the MIT Campus Network. The network is in a state of transition with the addition of a major new telecommunications system. Now is a time of opportunity.

### 9.2.1 5 ESS Voice/Data PBX

MIT's Telecommunications Systems is in the process of acquiring a 5 ESS integrated voice/data PBX to replace their current CENTREX system. Immediate plans call for installation of voice capability only, however, wiring will be completed for four wire pairs to support voice transmission as well as four additional pairs to support Local Area Network access when that service is added. Fiber optic links will join all the switches.

Dennis Baron, a manager for Telecommunications Systems, believes that the PBX will be used primarily to replace dedicated lines for administration users. He sees the 5 ESS installation as encouraging a reorganization or possible replacement of the backbone. Baron would like to relocate the Campus Network gateways to concentrate them in the switch node locations. Since the switch nodes are linked by fiber optic cable, these links could provide some valuable redundancy.

Thus, the 5 ESS creates the opportunity for a profound change in MIT's Campus Network. When ISO IP implementations become available, MIT should migrate to such a connectionless internetwork environment. The 5 ESS links will offer a tremendous amount of redundancy that an ISO IP scheme could utilize to greatly increase the throughput of the network. Individual packets of a single session could be routed independently to eliminate bottlenecks and improve performance.

The most significant aspect of the PBX system is its reach. Everyone has a telephone. The ISO IP approach of treating the subnetworks simply as data pipelines without regard for their speed, bandwidth, and reliability gives it the flexibility to incorporate the voice/data switch into the internetwork environment. The PBX trunks and lines will provide a tremendous amount of redundancy that would improve the overall robustness of the Campus Network.

### 9.2.2 Security

Data security is a high priority for administrative users in a university environment. It must be addressed if administrative networks are to become full-fledged clients to a university-wide system. It is interesting to note that the key issue here is "perceived" security rather than any objective measure.

MIT's Kerberos authentication scheme helps protect against unauthorized users from gaining access to privileged or sensitive information, but does not solve the problem of intruders intercepting the data at the network level. Some sort of Data Encryption Standard (DES) must be implemented to safeguard the content of the data. Maintaining network transmission at the lowest power levels can help discover attempts at tampering with the physical transmission medium.

### 9.2.3 Planning as a Problem in Organizational Behavior

Even if the the IS planner develops a network design that solves the protocol compatibility problem as well as addressing the security issue, he must attend to the organizational issue of co-opting possible opposition among the key stakeholders. Because the decision-making process about the acquisition of computing and communications hardware is decentralized, it is necessary for the IS planner to gain the cooperation of the departmental decision makers or at least to mollify them.

The method that Harvard has adopted in defining its university-wide network is worth careful consideration as a model. From the outset, users were informed what the goals were and how they would be achieved. Reports summarizing progress and findings were published as soon as possible so that stakeholders could observe and participate in the process. A steering committee was created with every school and administrative group represented, giving formal recognition of their opinions.

Since the process has not yet advanced into the implementation phase, it would be premature to pass judgement on Harvard's methodology. However, it is certainly the case that the major stakeholders are satisfied that their views have been heard. Furthermore, the steering committee representatives serve as champions of the network plan within their own organizations.

MIT is attempting a project that incorporates some of the same attention to stakeholder positions. Presently, administrative users that require access to central administration data maintained on another network were forced to negotiate access on an *ad hoc* basis with contacts in the organization responsible for the database. Administrative Systems is striving to develop a distributed database system that would greatly facilitate access as well as eliminate repetitive data entry.

In order to minimize the risk perceived by the client administrative groups, Administrative Systems is employing a phased implementation.

- Creation of read-only duplicate databases by the owning administrative group. Security issues are circumvented by permitting access only through dial-up. The owning group may isolate itself (and the integrity of its system) simply by disabling its modems. The control over the link satisfies the users' perception of security. Faculty and administrative groups can gain access to sections of the database pertaining to them (subject to authorization) on a read-only basis.

- User ability to modify low-level information like address and phone number. Owning organization allows write privileges for segments of their database. The duplicate database will be eliminated by each owning organization.

- Elimination of modem links in favor of Campus Network links. This will improve data rates for transfer and access by taking advantage of the superior bandwidth available over the Campus Network.

It is hoped that the system will eventually evolve into a true distributed system that would improve speed of access and eliminate all duplication and reduce paperwork. Tom Shea, of Administrative Systems, ultimately hopes that MIT can go to digital admissions applications, greatly reducing the paperwork burden for the Institute.

## 9.3 Summation

The author sets great store in the promise of the International Standards Organization's efforts to create internetworking standards within its Open Systems

Interconnection reference model. The cooperation and coordination of the major computer and communications vendors in adhering to these standards is the key to addressing the connectivity problems within any communications environment.

Specific to the university environment, the issues of data security and managing the planning process need direct attention. Without the support and cooperation of the autonomous subnetwork managers, the goal of a fully interoperable internetworking environment will be difficult to achieve.

## APPENDIX — SAMPLE MIT QUESTIONNAIRE

1. Name: ______________________________
   Title/Year: ___________________________

2. Please whether you are: (circle one)
   FACULTY
   ADMINISTRATION
   STUDENT

3. Department or School______________________

4. Location
   Office/Dorm ___________________________
   Extension ____________________________

5. What is your best estimate of the average total number of hours a day you use a computer or terminal? (Please circle one.)
   0-1 hour
   1-2 hours
   2-4 hours
   4-6 hours
   More than 6 hours

6. On the average, what percent of the time you currently spend communicating with other computers do you communicate with the following?

a. Local computer (located in your department) including shared disks and printers _______ %

b. Computer within your local subnetwork _______ %

c. One of the major computer centers outside your local subnet but within MIT _______ %

d. Networks outside MIT (e.g., ARPANET, BITNET, USENET, CSNET) _______ %

7. In general, which types of communications with MIT computers and outside networks do you utilize? Check each box that applies.

| Facility | Interactive Terminal | File Transfer |
|---|---|---|
| a. Local computer or file server (in your department) | | |
| b. Computer within your local subnet | | |
| c. Major computer center within MIT but outside your local subnet | | |
| d. Networks outside MIT | | |

8. Please read the following items and indicate whether the item is important to you. (Circle the letter corresponding to your response.)

| | | |
|---|---|---|
| A | means | NOT AT ALL IMPORTANT |
| B | means | SOMEWHAT IMPORTANT |
| C | means | IMPORTANT |
| D | means | VERY IMPORTANT |
| E | means | EXTREMELY IMPORTANT |

| | Circle your rating | | | | |
|---|---|---|---|---|---|
| Access to databases outside MIT for research | A | B | C | D | E |
| Access to databases inside MIT for departmental or administrative information | A | B | C | D | E |
| Ability to access different networks within MIT | A | B | C | D | E |
| Interchange revisable word processing documents | A | B | C | D | E |
| Electronic mail | A | B | C | D | E |
| File transfer | A | B | C | D | E |
| Share resources like printers, file servers, etc. | A | B | C | D | E |
| Remote login | A | B | C | D | E |
| Ability to communicate text and image documents | A | B | C | D | E |

What other services do you feel are important?

SERVICE #1 ____________________

SERVICE #2 ____________________

SERVICE #3 ____________________

9.Please rate MIT's current data network on its ability to fulfill your needs with regard to the following services:

| | Circle your rating | | | |
|---|---|---|---|---|
| | LOW | | | HIGH |
| Access to databases outside MIT for research | 1 | 2 | 3 | 4 | 5 |
| Access to databases inside MIT for departmental or administrative information | 1 | 2 | 3 | 4 | 5 |
| Ability to access different networks within MIT | 1 | 2 | 3 | 4 | 5 |
| Interchange revisable word processing documents | 1 | 2 | 3 | 4 | 5 |
| Electronic mail | 1 | 2 | 3 | 4 | 5 |
| File transfer | 1 | 2 | 3 | 4 | 5 |
| Share resources like printers, file servers, etc. | 1 | 2 | 3 | 4 | 5 |
| Remote login | 1 | 2 | 3 | 4 | 5 |
| Ability to communicate text and image documents | 1 | 2 | 3 | 4 | 5 |

10.Please read the following standards and rate the MIT data network by circling the appropriate number.

| | Circle your rating | | | | |
|---|---|---|---|---|---|
| | LOW | | | | HIGH |
| Ability to reach the entire user community | 1 | 2 | 3 | 4 | 5 |
| Performance (speed and response) | 1 | 2 | 3 | 4 | 5 |
| Reliability | 1 | 2 | 3 | 4 | 5 |
| Operating costs (your own) | 1 | 2 | 3 | 4 | 5 |
| Planning efficiency | 1 | 2 | 3 | 4 | 5 |
| Overall satisfaction with the MIT data network | 1 | 2 | 3 | 4 | 5 |

11. If there is a service that was not described and is very important to you, please describe that service below.

________________________________________

________________________________________

________________________________________

________________________________________

12. Which protocols are used on your subnetwork?

________________________________________

________________________________________

13. Please describe any specific problems that you have had with the MIT data network, specifically protocol incompatibilities.

________________________________________

________________________________________

________________________________________

________________________________________

14. Please describe any especially effective aspect(s) of the MIT data network.

________________________________________

________________________________________

________________________________________

________________________________________

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