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Project director(s):
DYER F.B OOD-GTRI (404)894-3539

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PROJECT ADMINISTRATION DATA

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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 06/07/90

Project No. G-36-621 Center No. R6700-0A0

Project Director ENSLOW P H JR School/Lab OIP

Sponsor BELLSOUTH ENTERPRISES/

Contract/Grant No. AGR DTD 3/15/89 Contract Entity GTRC

Prime Contract No.

Title COORDINATION OF TELECOMMUNICATIONS ACTIVITIES

Effective Completion Date 900131 (Performance) 900131 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

Future Campus Networks
A Vision of the Future

A Report Prepared For

BellSouth Enterprises
Atlanta, Georgia

by

Philip H. Enslow Jr.
Ronald R. Hutchins
Kimberly W. Kappel

School of Information and Computer Science
Georgia Institute of Technology
Atlanta, Georgia 30332-0280

Final Report
May, 1990

Work Supported by
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Abstract

It is well recognized, and oft-stated by many, that a major characteristic of future networks of all types — LANs, MANs, WANs, etc. — is that they will provide greater bandwidth to meet the insatiable demands of users. This paper acknowledges that the design and implementation of future campus networks will certainly be driven by the need and desire to fulfill those demands; however, this paper presents the argument that users will begin to realize that *they have other needs which are not being met* and that these needs will *have much greater impact*, than bandwidth, *on the usefulness of their networks* — these presently unmet needs are *"true" network integration-interoperability* and *effective network management.*

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Executive Summary

Primary Driving Forces

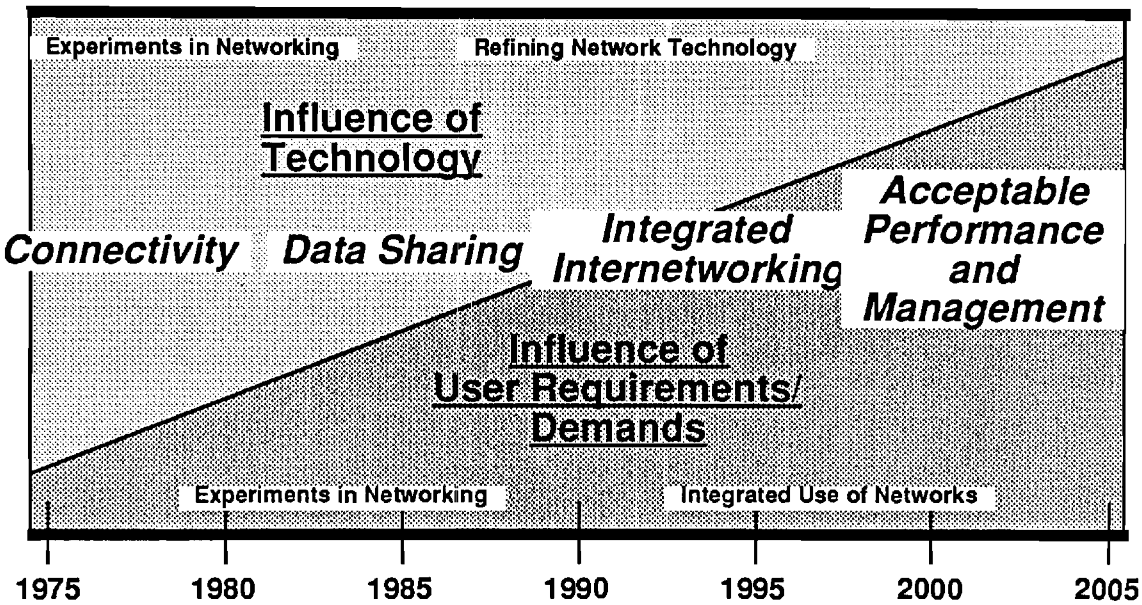
The growth and development of campus networks between the current time and the future, defined in this paper to be 1995-2005, will be influenced by many factors. Existing networks that are already installed will be modified and new networks will be planned and installed as part of this growth. The primary motivation directing the growth will be user demands for services performance that will require network designers and operators to *integrate all components seamlessly into a single network* and to *ensure the manageability of all components of that network.* The issues of integration or interoperability and network management are important issues in the communications industry today. In the past, technologies have usually been the driving forces; however, in network development, user requirements and demands are replacing the current influence of technology.

Role of Users

We are in the midst of some important changes in the attitudes and influence of network users. The influence of computer technologies, and the technologists responsible for them, were the main influences in the early days of campus networking. Over time we have seen slow but extremely important changes in the balance between these two major factors. (See Figure 1)

Figure 1

Influences on Campus Networking



We are now at a point on the chart (Figure 1) where an important aspect of how successful new networking technologies will be is how well they meet the requirements of the network users. Users are becoming a very vocal, demanding, and powerful influence on what products the commercial segment of the communications industry will make available. User "requirements" are *quite often* strongly influenced by the available and emerging technologies, but the reverse is also true. This effect of requirements driving technology will become increasingly important in the future. There are some emerging technologies such as ISDN and FDDI for which the user demand has not yet developed, and it is uncertain as to the success or impact that technologies which fall into this class will have on campus networks.

Role of Technologies

This is not to imply that emerging technologies for user interfaces, high speed networks, open network architectures, distributed systems, and the emerging standards for network transport, termination and interconnections (SONET, X.11 windows, FDDI, OSI, ODP, ISDN, SS7, etc.) will not play important roles. The success of any of these new technologies is, however, dependent on how well it is able to satisfy or contribute to achieving the two primary goals - *seamless integration* and *total manageability*. There are few network operators who will readily agree to discard or even phase out recently acquired network components. One point of view would hold the position that the acceptance of any of the newer technologies will be strongly governed by how well it works within the framework of existing networks in an evolutionary manner without causing massive disruption of user services. We hold the position that attempting to grow in a strictly evolutionary fashion may make it impossible to achieve the goals identified above. Therefore, compromises will need to take place based on the needs of the users and the management policy of the network owners.

Important Future Technologies

The advances of the last five years in the communications industry have been phenomenal. Projected progress in computing and communications technologies, including network management, and increased user expectations lead us to expect as much during the next five to ten years. The key technologies to watch will be:

- Interconnection and internetwork capabilities
    - The rapidly emerging international standards — Open Systems Interconnection (OSI), Open Distributed Processing (ODP), Electronic Document Interchange (EDI), and others.
    - New service termination standards — e.g. Integrated Services Digital Network (ISDN)

  - Extensive, integrated signaling — e.g. Signaling System 7 (SS7) and Integrated Services Digital Network (ISDN)
- Computer systems and networks organization
  - Advances in distributed computing — operating systems, file systems, client/server models, user interfaces, etc.
- High-speed transmission
  - Long-haul transmission — SONET (Synchronous Optical Network)
  - Local Area Network transmission — FDDI (Fiber Distributed Data Interface)
  - Special protocols for high speed — XTP (Express Transport Protocol) and its successors
  - Very high transmission speeds — gigabits per second

Purpose of This Report

This report presents a vision of an integrated and manageable network, describes where we are today in achieving that vision, identifies what the needs of future networks will, and describes some of the steps and advances required to achieve the vision.

Description of The "Future Networks" Project

This report and the study that produced it were funded by BellSouth Enterprises in order to create and document a vision of the future for campus networking. The mechanism for performing the research was to conduct a campus-wide survey at the Georgia Institute of Technology of all personnel involved with network planning, operation, or research. The purpose of that survey was to collect an initial set of networking concepts for the future defining the general characteristics and capabilities of campus networks in the five to ten year timeframe, with particular emphasis directed toward the Georgia Institute of Technology intra-campus network(s). (BellSouth Enterprises requested that this vision of the future specifically include the anticipated needs and requirements of the Georgia Institute of Technology.)

It is clear that visions of future wide area networks and campus networks will differ with individuals depending on many factors — their research interests, their industry alignment or their current needs. Opinions from the commercial sector span various points of view —

The Senior VP of Systems Software at Microsoft declared that

the four major trends for the 1990's will be graphical user interfaces, interoperability, information dispersion and the expansion of DOS.

The President of Symantec said that he believes

the industry will move from personal to workgroup computing, that computing revolutions will give way to customer-driven evolutions, and that products will have to operate across multiple platforms.

Ellen Hancock of IBM said that

the most significant changes today and tomorrow will come from LANS, and FDDI will play a role in that change.

The President of The Yankee Group believes that

the future introduction of new technologies will take seven to eight years as opposed to the commonly held conception [sic] of two to three.

These opinions are based primarily on commercial trends. This report attempts to move beyond the obvious commercial and industry trends and examines the user and technology issues to develop a vision of what is probable and possible. It also documents the limitations, both current and probable in the future, and areas that will require research efforts in order to fully develop and implement that vision.

Deliverables

This paper serves as the only report issued by the Georgia Institute of Technology on the "Future Campus Networks" project. The report has been developed jointly with the cooperation of all relevant groups on the Georgia Institute of Technology campus. It represents the differing viewpoints and interests from many groups on the campus including the faculties of the Schools of Electrical Engineering, Information and Computer Science (being reorganized as the "College of Computing"), and Industrial and Systems Engineering and the faculty of the College of Management as well as staff members of the Office of the Vice-President for Information Technology, the Georgia Tech Office of Computing Services, and the Georgia Tech Research Institute.

Other Uses of This Report

The material contained in this report may be used without restriction as long as proper reference to the source is given.

Definition of Terms Used In This Report

There is confusion over the meaning of many commonly used terms within the networking and telecommunications communities. This terminology problem creates difficulties in the human communication process. For this paper, the following definitions are used. (The definitions given below are not arranged alphabetically but, rather, in the order in which they are used to define one another.)

Future

Future is defined to be in the five to ten year timeframe (1995-2005).

Campus

A campus is defined by either of the following characteristics:

- Any geographically centralized group working together. This might be an office, an office complex, a factory, or a university.
- Any group, geographically centralized, that finds it useful, expedient, or cost-effective to operate a private interconnection service for either voice and/or data. (This would include shared tenant services or other third party services.)

Network

A network is a set of physical and logical components which cooperate to provide services for the transfer or exchange of information and the distributed computing facilities which are accessed via the network communications services. It includes both interconnection and processing components.

Subnetwork

That portion of the complete network that provides the interconnection services. The physical realization of the interconnection function including intermediate systems and interconnecting links.

LAN - Local Area Network

Local Area Networks refer to those interconnection subnetworks generally meeting the following characteristics.

- The geographical area served is small; typically 1-10 kms.
- The owner, operator, and user of the LAN is usually the same organization - LANS are not normally operated by the telephone company, any other public carrier, or any other party.
- The technical design of the LAN has typically ignored the most important characteristics of the public telephone system, the total focus of service provided being the 4KHz voice channel (or the 64 kbps digital equivalent).

LCN - Local Computer Network

Local Computer Networks refer to those complete computer networks generally meeting the following characteristics:

- The LCN makes use of a LAN as the interconnection subnetwork.
- There are a small number of host/server computers utilizing a specialized software suite to provide user services such as shared file access, shared peripherals, electronic mail, etc.
- The users of a LCN constitute a small homogeneous group.
- There are often no (or limited) interconnections to other networks.

MAN - Metropolitan Area Network

Metropolitan Area Networks refer to those interconnection subnetworks generally meeting the following characteristics:

- The geographical area served is moderate in size; typically 10-100 kms.
- The operator is normally a public carrier, although not necessarily the telephone company.
- The technical design, since it is done by a public carrier, often does take cognizance of the "4KHz voice channel" characteristic of public telephone networks.

WAN - Wide Area Network

Wide Area Networks are interconnection subnetworks generally meeting the following characteristics:

- The geographical area served is global.
- The operator is a public carrier.
- The technical design of the WAN is driven totally by the voice-channel orientation of existing and planned transmission systems.

Campus Network

Campus networks are complete computer networks, i.e. they include the hosts/servers and users as will as the interconnection subnetwork, that generally meet the following characteristics:

- The area served can vary from small (1km) to moderate (20km or more).
- Multiple interconnection subnetworks are usually component parts of the campus network.
  - The technologies of both LANs and MANs may be present.
  - These subnetworks must be interconnected to form the complete campus network.

- There are often multiple LCNs as components of the campus network and the LCNs usually utilize different LCN software.

Network Management

Network management is the utilization of the collection of facilities required to control, coordinate and monitor the resources which allow communication to take place and the distributed computing resources supporting the network applications.

Network Operator

Individual or organization responsible for the technical operations of a network, including network management.

Interoperable Network Management

The specification and application of the means by which network management products and services from different suppliers can work together to manage communications and computer networks.

Integrated Network Management

Integrated Network Management is network management characterized by the following:

- Ability to manage all resources contributing to network communications uniformly, in terms of the user interface and the network capabilities, regardless of architecture of the network management solution (hierarchical, peer-to-peer, centralized, distributed).
- Network Management capabilities should be designed and built into the resources being managed.

User

The consumer of network communications and network computing resources.

Network Manager

The user of the network management services.

An Internet

An internet is a set of interconnected networks which can be viewed as a single logical or single virtual network for accessing applications and/or using network services.

The (TCP/IP) Internet

The internet created by the interconnection of TCP/IP networks, i.e. networks utilizing TCP (Transmission Control Protocol) and IP (Internetworking Protocol) as the primary interconnection protocols. The administrative and technical control of the Internet is vested in the IAB, the Internet Advisory Board. The Internet is an outgrowth of the early DoD work on internetworking involving ARPANET and other subnetworks. The distinction of the TCP/IP Internet is often indicated only by the capitalization of the first letter, i.e. a (general) internet compared to the (TCP/IP) Internet.

Remote Procedure Call

A Remote Procedure Call (RPC) enables an application to be divided amongst intercommunicating, cooperating computers. A process running on one computer can call a process running on another, and all details of network addressing and routing are handled by the RPC mechanism.

Client-Server Computing

Client-Server Computing is an application program control architecture that implies the physical separation of an application process and the data and data handling process it utilizes into two separate entities that can be executed on one computer or distributed between or among multiple computers.

JTC1 — Joint Technical Committee 1

JTC1 is a joint committee formed by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) to consolidate all computer and data processing standards committees starting in 1989, all standards relating to OSI, including management, are jointly issued by JTC1.

Our Vision of the Future

Providing networking services, both interconnection and server services, has taken on many of the characteristics of a service-oriented industry. The network users are the consumers (or customers) and their levels of expectation, sophistication and requirements are continually being raised. The expectation of many current network users is summarized by this "User Bill of Rights" from The Gartner Group, which will certainly describe the expectations of most users in the not too distant future.

> *"To be able [any user] to [easily] access any data or computational resource regardless of location for which [the user is] authorized and suitably equipped."*

In order for this goal to be met, the user must be sophisticated and knowledgeable enough to know how to achieve the access to the resource *or* the network must be smart enough to do it for the user *or* some combination of the two must happen. The first situation, the "knowledgeable user," is what exists today; a key requirement for the future is that the network be smart enough to support the unsophisticated or "unknowledgeable" user.

General Goals and Objectives of Future Campus Networks

Our vision of the future centers around achieving two major goals (Figure 2).

- Access to all network resources should be easy and uniform — they must be accessible by even a novice network user; and
- Network resources must be manageable in an integrated and systematic way to enable network managers/operators to satisfy user requirements.

Figure 2

Future Campus Networks
Primary Goals and Objectives

An integrated network with access to all network resources
- **Easy, simple, and intuitive**
- **Uniform, straightforward**
- **Reliable, repeatable**

A Manageable network
- **Integrated**
- **Systematic**
- **Comprehensive**

In an integrated and manageable network, network users and network managers are able to interact with network applications and request network services in a consistent, easy to understand, transparent and reliable way. This capability is lacking in many current networks, and is required for the networks of the future in order for a network user to take advantage of advances in networking and computer technology. The network manager must be able to introduce, install, and maintain network services which fit into the management and user infrastructure.

The interactions described in the following scenarios are representative of the types of user and manager requirements which future networks must support.

- The user is able to request a connection to any network application or service with a simple, straightforward, and consistently organized action to make this choice via either menu, icon or command line.
- The user is able to interact with any network application using the same keystrokes for the same requested action: close a file, open a file, editing requests (cut, paste, delete), move a window. [Even with the very popular mouse, there are currently the one, two and three button versions, with each button being used differently by various systems.]
- The user is able to send electronic mail to anyone within his/her LCN or any connected network without knowing details about the destination machine. A given mail address should either always work or always be rejected regardless of the route a message might take through the network.
- The network manager is able to install new network applications and update network directories to allow users increasing levels of service without extensive training on how to achieve the access.

Integrated Networks

The user requirements for integration can be summarized with two phrases: *true interoperability* and *transparent internetworking* (Figure 3). The user must have easy, effective, usable and reliable access to all network services and interoperability with all connected networks. The more technical users are already taking advantage of interoperable networks, but there is no *true* integration or transparency at this time. In many cases, only the most technical of users can achieve access to an application in a network, and it often requires "magic" and in-depth knowledge of network configurations.

Internetworking includes all concerns related to general connectivity. This includes sharing of resources, distributed applications and functions, network layering required to interconnect and inter-process communication to accommodate communication among processes.

Interoperability deals with issues from a slightly different viewpoint. It accommodates the user need for easy and transparent access and the requirements for consistent levels of service being offered and delivered.

Figure 3

Future Campus Networks
Integrated Networks

The user view of network resources
- **True interoperability**
  - **Easy**
  - **Effective**
  - **Usable**
  - **Reliable**
- **For the unsophisticated user**

The user view of Internetworking
- **Transparent**
- **Users don't want to "see" the network**

Internetworking

From a users' viewpoint, the need for integrated and transparent internetworking is greater than the need for faster transmission speeds and advanced transport techniques. Users are beginning to demand networks that are "usable", not just faster.

At this time, the user requirements for internetworking are primarily based on the need to access remote files and/or databases, applications and other individuals' electronic mailboxes. The widespread commercial utilization of electronic mail applications has convinced users that they want to be able to communicate with all resources and humans reachable by the network to which they are physically connected. Many unsophisticated users are just being introduced to the advantages and increased level of service that a connection to an internet provides, capabilities that technical research, academic, and government oriented users have had available for years.

The slow introduction and spread of open network architectures and the problems of managing interconnected networks has limited the internetworking capabilities within many organizations. Most universities and many commercial organizations provide their network subscribers a connection to the world outside of their LCN, but the available services are usually limited. Electronic mail and file transfer are probably the most widely used services on these interconnected networks, and even those are often available only to the sophisticated user.

The transparency issue of the interconnection, from a user's perspective, is very important. This need applies to the interconnection, the data, and the applications. A network user must be able to request a connection to an application available within the network and succeed with the request without any knowledge of network configurations, routing tables, or network addresses. The user does not want to know that there is a network and a communications infrastructure associated with his applications.

Interoperability

Interoperability must be provided for the unsophisticated user, as well as the "knowledgeable" user. As previously mentioned, the interoperability of connected networks must be *easy to use in an effective and reliable way.*

In order for networks to interoperate effectively, steps must be taken to provide uniform levels and styles of service at the user interface for all network applications.

Figure 4

Future Campus Networks
Manageable Networks

Overall requirement for network manageability
- **Network technology must support management functions**
- **Management must be integrated**
- **There are multiple architectures which will work**

"User" network management
- **Users demanding access to management functions**
- **Exact requirements not defined yet**

"Network Operator" network management
- **Very sophisticated requirements emerging**
- **Impact of newest technologies (e.g. artificial intelligence)**

"Third party" network operations and management
- **Who will manage the network**
- **Protection of privacy**

Manageable Networks

Interconnected networks must be manageable in order to provide integrated and transparent services. Networks have grown and have become very complex in an effort to provide more networking services and utilize the latest in available technologies. This complexity may be characterized by the number of elements that must be managed, the number of technologies used within the network, the multitude of vendors providing the network components, and the number of interconnected networks.

The key to manageable networks is integrated management and control of all network elements, regardless of technology or vendor. This requirement does not necessarily imply centralized management. In fact, the architecture of the network management solution is not the issue. The issue is the ability to manage the physical resources and applications of the various networks and the internetworking with other corporate and public networks in an integrated manner. In order for this type of integration to be achievable, management capabilities must be built into all components of the network. By this we mean that network elements must be able to assume some of the burden of their own management. For instance, keeping count of errors for later reporting to a management system is a typical function that an element of the network must be able to perform. We would like to take this very simplistic example a bit further and require that all network elements collect and store the management information as specified in the emerging international standards in this area.

"User" Interaction with the Network Management System

Network users are not traditionally thought of as placing requirements on the network management applications. They have traditionally interacted with the individual serving as the network manager or system administrator. Network management data, if it was collected at all, was collected by a management system for the use of network operators and managers. Users then interacted with a help-desk, staffed by a human; or they utilized a problem management application to determine the status of their problems.

Some users now want to interact directly with the network management applications, although the exact requirements of those interactions are not fully defined. The following scenarios are now perceived as reasonable user interactions with network management systems:

- Accounting queries as to the status of a user account.
  - This may be calculated from measures of calls placed, call duration, packets/characters sent and/or disk space utilized.
- Configuration networking naming queries concerning
  - Name/address of a network service
  - Request changes in their own particular configuration
  - Request for access to additional services
- Problem reporting and status queries.

"Network Operator" Interaction with the Network Management System

The requirements of network operators are different from those of the network users because they must ensure the availability and performance levels of the network as well as act as users of the available network services. The complexity of the networks being managed has, as stated previously, greatly increased the complexity of managing a network. Network operator requirements are now becoming very sophisticated and advanced. Management oriented requirements that may develop, include the following:

- Creation and maintenance of configuration databases detailing all aspects of campus network configuration, including such data as the operating system and version running in each desktop computer, and applications installed.
- Automation of many procedures, including changing the configuration database when new software is installed, diagnosing problems with hardware and ordering replacement parts.
- The use of expert systems to assist in keeping the network operational at all times.
- Performance management applications which can detect performance degradations before a failure occurs;
- Network planning tools to enable network managers to predict network capacity requirements and determine optimal configurations;

Who Will Manage the Network?

Another aspect of network management which will most likely play a role in the future is the question of who will manage the network. Will it be the network providers (vendor of network equipment, long distance carriers) or the owner of the network?

Many vendors of network and computer components and long distance facilities are selling network management services as a product. There is a shortage of competent network operations personnel making it likely that many network owners will opt to allow one of their vendors to manage the network. This is particularly true of vendors like AT&T and MCI, who are now offering many network management services to augment their product lines. The carriers have more control over management of their partition of a customer's network because they have traditionally not allowed customer controlled access into their systems. The carriers are now, however, starting to open up their management services to customers. The main use of the customer interfaces into these management services is to add value with such applications as network optimization, disaster recovery, and alternate routing capabilities.

Vendors of networking and computing equipment are also entering the network management services market. Many of these vendors are offering integrating network management systems which allow other vendors' equipment to be managed from a single management system. They are also, in many cases, willing to manage the entire customer network, regardless of who provides the component pieces.

There is yet another aspect to the question of who will manage the network. There has been an emergence of "third party network management providers". These organizations do not provide any of the components within the network, but have developed a network management system which is able to act as the high-level point of integration for all network management data.

There are several scenarios which may become common answers for the question of who will manage the network.

- Owner/user is the operator and the manager
- Owner/user manages, but does not operate
- Owner/user operates, but does not manage
- Owner/user does not manage or operate

In each of the cases above, with the exception of the first, there is an issue of allowing outsiders access to potentially sensitive network data. Since this information and how it is protected are critical to the well being of the networks and, therefore, the well being of the campus, we believe that security must be addressed when third parties are involved.

Figure 5

Future Campus Networks
Services and Applications

Desktop computing
- **User Interfaces**
  - **•• Distributed access**
  - **•• Remote execution**
    - **••• Remote procedure calls (RPC)**
    - **••• Remote shared memory (RSM)**
  - **•• Workstation computing**
- **Desktop publishing**
- **Software distribution**

Document interchange
- **Electronic mail**
- **ODA — Office Document Architecture (ODA)**
- **EDI — Electronic Document Interchange**

File Access and Transfer
- **Mounting of remote files**
- **Access protection**
- **Data security**
- **Transferring files**

Future Services and Applications

The vision of the future is heavily influenced by the user expectations and demands. We find that user satisfaction is generally based on the ease with which they can utilize the network services and applications which enable them to perform their functions.

There are applications and technologies which will play an important role in the networks of the future primarily because of the services that they provide to the network users. These applications must become *integrated* and *manageable.* Integration will provide for commonality of user and network interfaces across all vendors' products and the ability to access an application easily from anywhere in the network. *The user doesn't want to see the infrastructure of the communications subnetwork.* Manageability will provide for seamless integration into the management solution for the network. (Figure 5)

Desktop Computing

The personal computer has drastically changed the office-place and improved the productivity of the technical, management and administrative staff through applications such as word processing, spreadsheets, and graphics software packages. The perceived power, productivity improvements, wealth of software and relatively low cost of personal computers have combined to create an environment where most managers, executives and administrators, as well as many of the clerical and support staff, in major companies have computers on their desks and have become totally dependent on the services they provide. Computers have been brought into the workplace of even those with no technical background. The failure of a computer and/or the interconnecting subnetwork can bring the activities of an office to an abrupt halt due to the non-technical background of many current users and the integral role of these services in corporate operations.

The desktop computer phenomenon brings computing into the individual office, but does not negate the need to access applications and data that may be on other systems. Utilizing LAN and LCN technologies developed in the last decade, desktop computers now act as remote access devices for services, applications, and resources which are directly connected to or running on other computers.

The future will bring additional changes to the campus environment as users of desktop computers become more adapted to and aware of the capabilities that the emerging technologies will bring. The developing interconnection standards promise greater interconnectivity and end-user transparency to allow users to focus on their particular task without dealing with the network directly. The new technologies for application architectures (e.g., client/server models), exchange of data (e.g., EDI, X.400, ODA), user interfaces (e.g., X.11, NeWS), will bring even more advanced services and applications to the desktop and distributed file systems (e.g., Andrew File System which allow singly rooted directory trees).

The remainder of this section highlights some of the aspects of desktop computing which will play a significant role in the future of campus networks.

User Interfaces

The advantages of highly interactive and sophisticated user interfaces, including windows and mice, have increased the user expectation of what constitutes an adequate or acceptable interface. The current challenges in user interfaces are primarily focused on the *ease of interaction* with the network from the desktop computer and the *standardization* of the interface.

Standardization may be partially addressed by the emergence of the windowing standard, X.11, and software developers' toolkits for building user interface software. Applications development products for building user interfaces will enable software developers to produce code supporting more standardized, user friendly interfaces, in a much shorter time period. This will allow the user interface of an application to be "mocked-up" for pretrials by users. Standardization will hopefully also address the consistency of an interface. Users are now faced with each vendors unique utilization of function keys, mouse buttons, color, error explanation mechanisms, etc. These interfaces are currently considered to be outside the scope of standards efforts, but we feel that user pressure may force vendors to work towards some commonalties in "look" and "feel".

There is much discussion in the industry today concerning "user friendly" interfaces. User friendly can be defined in many ways, and frequently ends up being defined by the developer of an application instead of a user. We believe that user friendly must translate to *ease of use* and be additionally defined by:

- Forgiving of user errors and lack of knowledge
- Adhere to any applicable standards
- Inform user of what is happening and reasons for delays in response
- Consistent use of keystroke sequences for commands

Distributed Access

Distributed access to computing resources has become very widely accepted over the last decade. Users are commonly using terminals or personal computers as access devices to applications residing on remote machines.

Users expect that they can access any application residing within their LCN or any connected LAN or WAN from their desktop device (remember the Gartner "Users' Bill of Rights"). Many applications, however, require a particular type of user access device and do not assume that a simple ASCII terminal will be used. This is particularly true with the advent of the sophisticated user interfaces.

The issue of distributed access involves several network management issues. Whose responsibility should it be to ensure that the access device and the application being accessed are compatible — the user, the application or the network administrator who sets up access privileges? How will network configurations be maintained to allow whomever is deemed responsible to troubleshoot these types of problems? It is clear that there are many problems inherent in moving towards distributed access and truly distributed computing environments.

Remote Execution

One of the major benefits of distributed computing is the ability to offload compute intensive jobs to other hosts and to utilize large storage resources of these hosts within a network. Prior to the development and widespread application of distributed computing technologies, many organizations (including campuses) used very large centralized computers with remote or directly connected access devices. In the past batch job submission was heavily used to run large jobs on very large centralized systems. Card decks, although bulky and cumbersome were fairly portable to larger machines. With the coming of the desktop workstation and large networked resources, remote execution and remote storage have become feasible and necessary. Remote execution implies that although the user of the program to be executed resides on the local machine, files are not copied to the local machine but the execution of that software happens on a remote location. Remote storage requires that the program be executed resides on disk storage across the network and pieces of the file are moved in small chunks as needed to the local machine's main memory for execution without using local disk for storage. These are descriptions of Remote Procedure Call (RPC) and Remote Shared Memory (RSM) respectively. RPC is a mechanism whereby a user can send parameters to a program on a remote system for execution and have the output from that program piped back to his local machine. RSM allows storage on another distributed system to be used as if it were locally connected.

Remote Procedure Call (RPC)

Distributed network applications will become very common in future networks. Software developers will require tools to build these distributed applications. Remote Procedure Call (RPC) applications development products will help to automate the process of tailoring applications to a networked environment as well as facilitating the development of new applications.

RPC products are essentially computer-aided software engineering tools geared to a network environment. The benefits of RPC to the technical development community are the ability to split application programs and easily redistribute the procedures to dispersed, intercommunicating computers. RPC tools relieve programmers from the necessity to know details of network operating systems and communications protocol on which their applications are to run.

Remote Shared Memory (RSM)

Much new research is being done in the area of RSM now. The CLOUDS distributed operation system, the V kernel and others are attempting to use RSM as a mechanism to provide access to distributed resources. This is not new, but with new algorithms it may be useful in providing a more uniform, orthogonal environment for users of distributed systems in the future.

Workstation Computing

The advances in the computer industry are providing for more powerful and less costly computers. What distinguishes a workstation from a computer? It is generally processing power, transmission capabilities, and the ability to act as a "stand-alone" workgroup resource. There are more and more workstations being installed throughout networks. Their increased demands for high-speed and high-bandwidth communication puts a greater burden on the network managers and the network communications services.

Desk Top Publishing

There are numerous commercial and public domain applications aimed at meeting the needs of the desk top publishing users ranging from the purely administrative secretary to the very technical programmer. Desk top publishing applications can also range in sophistication from using only a few function keys to full utilization of windows, icons, multiple colors, and mice. The high end applications take full advantage of all of the capabilities of the most powerful desktop computers.

In the future, we believe that the number of different applications must be reduced to a much smaller number or that the applications must become capable of direct interoperation. It is clear that applications which do not take advantage of the latest workstation technologies and which do not allow for interoperability with other applications will not survive except in small numbers for the isolated user.

Each desktop publishing application has its own internal format for the storage and representation of documents. These create environments in which co-workers must utilize the same package in order to collaborate on the development of a document or be forced to perform translations to move documents back and forth. This is unacceptable from a user's perspective. Standards are being developed for the exchange of documents which will influence the outcome in this area.

There are other aspects of desktop publishing which may impact the future of campus networks. Desktop publishing generally implies some number of shared physical resources within a workgroup. At the very least, there is a laser printer which is used by more than one person. The requirement to share network physical resources involves many of the previously discussed characteristics of future networks — interoperability, transparency, integration.

Software Distribution

Network users are openly sharing and exchanging software through many different mechanisms. There is an abundance of public domain, freeware, and shareware software for many different computer systems. Networks are a key factor in the popularity of this type of software since they allow for the distribution and broadcast of all types of information, including software. There are active news groups on the Internet which are there for the sole purpose of making software available either in source or binary format.

The installation onto a network of shared software presents many problems in managing the network configuration and needs to be controlled in some way. Many believe that this type of software can be responsible for introducing viruses and other destructive code into a computer system. It also makes the network managers job quite difficult in tracking software versions, etc. for configuration management and control.

Document Interchange

There are several standards which are either available or well on their way to availability which will influence the exchange of data between applications. The impact of the CCITT X.400 series of recommendations for message handling systems will be widespread.

The remainder of this section describes where the greatest impacts of the standards for data exchange will be seen.

Electronic Mail

Due in large part to the development of the Internet during the 1980's, electronic mail has become very important as a tool to facilitate communication and cooperative research among the users of interconnected networks. The number of commercial electronic mail users has increased from less than half a million in 1980 to nearly nine million today according to the "Electronic Mail & Micro Systems" newsletter. Additionally, the establishment of standards for the exchange of documents between message handling systems (X.400) has validated the crucial role that electronic message exchange will play in the future of networking.

There are many commercial electronic mail applications on the market today being utilized within and between organizations and networks. A problem that many users experience is how to get mail from one customer system and/or network to another. It can be a very difficult feat for even an experienced user of the Internet to figure out how to correctly address mail to get through the gateways, routers and corporate mail systems involved in reaching the appropriate mailbox of the intended recipient. Even if the mail is addressed properly, there is no way to verify, other than requesting a verification response, that the mail is actually received.

The primary user requirement in the area of electronic mail will be to transparently and reliably transfer and receive mail to and from users on other computers and networks regardless of the "mail" applications being utilized. This generates a need for standard interfaces to mail applications which create, send and receive mail. Interfaces between different mail systems and between mail systems and local applications must evolve to provide easy, standardized interfaces for using the capabilities of the mail system, for addressing mail properly, and for feeling secure about its receipt.

Office Document Architecture (ODA)

The ODA efforts underway within JTC1 will provide a standard document delivery format for exchanging final form as well as word processing documents. The realization of this capability will increase the user requirements on their desktop publishing applications, as discussed in the previous section.

Once ODA becomes widely implemented and installed, users will be able to transfer unformatted and formatted documents freely between applications and directly to another user's workstation without any reformatting and/or diskette transfer involved. This will be a major improvement for all cooperative work efforts, whether oriented towards research, product development, or secretarial support.

Electronic Data Interchange (EDI)

The EDI standard defines a common interchange format for the electronic transfer of common business forms. Currently, it is used primarily within the purchasing segment of businesses and is rapidly gaining popularity. Most large corporations are utilizing or testing EDI and finding that its use results in financial savings due to lower personnel costs and the speed with which transactions and transfers can be executed. It is important to remember that EDI is an application-to-application exchange of data, not computer-to-computer exchange although it relies on the underlying sublayers. Its full potential will not be realized until the appropriate applications are developed, but we believe that EDI (and other application interface standards) will contribute greatly to an environment of open, interoperating applications.

File Access

There are several products on the market today which allow sharing of files across networks. These products allow mounting of remote file systems on "file server" systems to allow access to files as if they were local. One major concern with using distributed file systems is the need to lock files when they are accessed. Since there may be many users wishing to use the same file transparently, there are potential for problems with consistency of the files. There is some level of locking built into the current systems; however, this is not sufficient for every case. Newer products as the Andrew File System (AFS) from Carnegie Mellon deliver much more powerful locking mechanisms as well as enhanced security functions.

Security in distributed file systems has usually been deferred since it is expected that small, consistent networks are populated with friendly, intelligent users who are not malicious. This is not really the case today since interconnectivity has become so widespread with increased usage of the Internet. This was shown by the power of the "Internet Worm of 1988." The trauma caused by this program has shown the need for much more rigorous security in internetworking, especially in distributed file systems. Kerberos has been included in AFS to provide public key encryption for the distributed file system. Also, access control lists are provided to allow or prevent use of files and machines by various individuals or groups. This versatility in security is much needed in local and extended networks.

Another issue associated with file access and the design and implementation of future networks is the placement of application programs and their associated data. It is likely that users would like their data files to migrate to wherever it is that they need them to be. This should be done intelligently and with no need for the user to perform any requests.

The physical access to a remote file is just one aspect of "file sharing." Equally important are the capabilities to identify the specific file desired and to specify where it is and how to reach it. Advertising a global name space and having a single root in a distributed file system are coming to be recognized as important facets of manageability in distributed file access. Global naming allows many systems with normally conflicting names to be advertised on the same network. Also, the complete path including the machine name is available to users as an access point. Having a single root allows for domain organization of files and machines and gives a consistent view of the shared space. From any machine on this file system, the singly rooted tree provides the ability to access a file from anywhere in a connected network with a standard name. This is a very powerful tool which allows users to have a consistent view of the file system from any machine attached to the network.

Where Are Campus Networks Today?

Current campus networks have just grown — primarily in response to the availability of networking technology with a small amount of influence from users. However, for the most part, the "users" have been "computer techies," highly knowledgeable and sophisticated users who see the network as much as a "plaything" as a valuable business resource or asset. The results have been a wide variety of network technologies and services. These provide useful ideas and concepts for the future; however, they often do not meet the real needs of the general user.

In a campus environment, there are always multiple constituencies which must be serviced. Each additional constituency which is added to the "picture" tends to make for more politics in setting and maintaining management policy. Also, there is frequently conflict between the management policy and what is technically feasible to do. New technology can only be added when it fits into an overall plan for growth and increasing service levels. This concept is often ignored.

The "Knowledgeable User" and Elitism

In current networks, knowledgeable users are able to achieve some degree of interoperability with the world outside their LCN and access a broad range of computing resources. The non-technical user may have a set of procedures written down which guides him/her through critical processes, but they can not take advantage of those resources for which it is difficult or not obvious how to gain access.

The research community of the present and immediate past have usually taken the attitude that users need to become more educated in computer-related subjects in order to take advantage of the advances in computer science. To some degree this is true, but there needs to be a change in the attitude of the knowledgeable research force which realizes the need to create systems which novice users can utilize to perform powerful tasks. This has already begun with the NextStep interface to UNIX provided by the NeXT machine. This interface allows users to use a mouse to access files and execute programs in an orthogonal manner. This effectively creates a new utility on top of the existing UNIX system without damaging the power of UNIX for the expert.

Decrease in Costs of Hardware and Its Effects

Another major factor contributing to the current environment is that the cost of network computing resources has been decreasing dramatically. This decrease has led to an environment where powerful desktop computers are common, time-sharing and remote access to centralized computing resources are characteristics of the past, and users are attempting more sophisticated interactions with networks. Also, the cost of communications has not decreased as fast as the cost of computing capacity. Even the dramatic improvements made possible by such techniques as specialized local area networks, fiber optics, and satellites have not matched the steady and spectacular progress made by computer hardware technology. This imbalanced growth has created environments where the power of the computer resources may exceed the capabilities of the communications resources and the ability to manage and utilize the computing elements within a network.

The Present Campus Network Environment — A General Description

Most typical, present-day campus networks exhibit many characteristics in common. There are usually multiple constituencies or user orientations. Typical examples are administrative, educational, research, executive and product development groups. Each constituency has differing, and often incompatible, requirements for computing and communications. Network services and applications may span computers belonging to multiple organizations.

Figure 6

Present Campus Networks

General Characteristics

- **Multiple constituencies**
  - **Various orientations**
  - **Often, incompatible requirements**
- **Multiple vendors for H/W and S/W**
- **Inadequately Integrated**
- **Inadequately managed**
- **No clear evolution — dead end**

Equipment (hardware and software) making up campus networks is supplied by multiple vendors and utilizes multiple network architectures with no integrated approach to management. Network components include the communications equipment, the end-user systems, combinations of mainframe and minicomputers, server systems, and the services offered to the user. The computer systems are typically very diverse, ranging from small microcomputers to large, multi-user mainframes and are physically distributed with no central authority over all of the component pieces.

At the present time, both users and operators of campus networks generally agree that the networks are not adequately integrated. Operation across the constituent LCNs is very cumbersome, difficult and not transparent. The networks are also not adequately managed. Problems within a user's LCN may take an extremely long period of time to solve and often involve several vendors, who may blame the problems on each other's products.

The lack of integration and management will be difficult, if not impossible, to correct in an evolutionary manner for many of the currently installed networks. In fact, although it is not an ideal solution, it may be necessary to replace network components that do not fit into the long term plans.

Major Weaknesses and Limitations of Present Campus Networks

The "uncontrolled" growth of current networks as described above caused the resulting networks to have a number of major weaknesses and/or limitations. (Figure 7)

Figure 7

Present Campus Networks

Major Weaknesses and Limitations

- **Lack of planning**
  - **Networks were driven by available technology**
- **Limited use of standards**
  - **Those available were often ignored**
  - **Not all necessary standards were available**
- **User needs were not adequately considered**
  - **User needs were not yet focused nor understood**
  - **No one effectively representing users to standards groups and vendors**
- **Technical limitations**
  - **Network interconnection**
    - **Non-uniform**
    - **Inefficient**
    - **Unreliable**
    - **Multitude of unique/proprietary solutions**
  - **Network interoperability often impossible**
  - **Poor user interfaces**
  - **Limited or no management capability**
  - **Lack of performance optimization tools**

Lack of Planning

The design and implementation of most current campus networks stemmed from the need to solve connectivity problems immediately. The problems were created by the need to support on-line communication from personal computers and terminals to mainframe hosts, direct communication between more personal computers serving as LCN servers and personal workstations and communication between connected LANs. Many current campus networks are just barely "workable" because of the unplanned nature of their growth. As new technologies became available, products were "added" to the networks without considering the impact on future configuration changes. This is particularly true in an academic campus where equipment supporting new technologies is frequently donated to a campus. Rather than let it go unused, the network operators just install it.

The network on the Georgia Institute of Technology campus is an excellent example of this evolution without a plan. There are multiple networking domains, each representing a different constituency, with different goals and needs. It has become difficult to even send electronic mail between faculty members due to the vagaries of the network configuration and the differences between the IBM PROFS system and the diverse set of computers which comprise the campus network.

Absence of User Input

User needs have not been adequately considered during the evolution of present campus networks or in the development of products which became components of these networks. Contributing to this dilemma is the fact that the needs of the users were not understood very well, even by the users themselves. Additionally, there are not effective mechanisms for representing such viewpoints to standards groups or vendors. Users are becoming more vocal, but their input must become more focused, directed to the right bodies, and demanding of solutions from vendors.

One key aspect of this problem is that product designers and implementors are quite often not in contact with actual users. They "think" they know what the market requires and would find useful, but this is usually not true. This practice has led to a situation where the needs of the novice user are usually ignored. Now that industry is becoming market driven, these novice users are being heard more often in the computer industry (e.g. the Macintosh and the NeXT computers) but not so often in the communications and networking arena. For example, the RBOCs have for many years been in a position of power where they could dictate to the users what can and cannot be connected to their network, what the acceptable data rates will be, and the design of attached equipment. *(Note: This was not necessarily a major restriction in the past; however, it has been cited as a problem in the current era.)* That environment led to the creation of a vast, highly connected network which spans the world, but users are now demanding more control and flexibility of their communications in order to create a manageable system.

Problems with Standards

There have been many standards developed and supported on an international level which provide low-level connectivity within networks and between networks. However, the standards that are available are often not used. There have been few, if any, high-level standards produced which provide for the top-level systems models and abstractions for creating networks and internetworks. These will be very necessary in the future if we are to be able to interconnect multiple networks and have them be manageable. The work taking place within CCITT and JTC1 on models for management of communications networks are a good example of the missing piece.

The development of standards is not enough to ensure intercommunicating networks, however. Standards are not intended to be used as implementation guides because they contain options and choices which must be made to form a specific profile or functional standard. In the case of OSI Management, the profiles must also specify the definitions of the objects which will be managed through the use of the protocols and message sets. In order for a standard to be implementable by a group of vendors, implementation agreements must be reached. These implementation agreements specify the choices for each available option, thereby allowing for products produced by different vendors to interoperate properly.

Additionally, there must be conformance procedures to make certain that each implementation actually has been done according to the agreements. There are conformance organizations (e.g. Corporation for Open Systems - COS) which have formed solely for the purpose of certifying products to be interoperable.

Technical Problems

There are many technical problems with current campus networks that can be attributed to their unplanned and unstructured growth, lack of user input, and lack of available and useable standards at the right time. This has led to networks that can be best described as a "hodgepodge" of unmanageable components and sub-systems. The problems which have resulted fall into these major categories:

- Interconnection and internetwork
- Computer systems and network organization
- Transmission capabilities
- Network Management
- Network Performance

Interconnecting Networks

The task of connecting the many diverse subnetworks of a campus is very difficult in the current environments. There are too many products which do not interoperate and are even difficult to interconnect. The applications which are installed on many computer systems physically do not adhere to OSI or any other networking standard and do not allow remote users to access them.

Computer Systems and Network Organization

Each computer within a network invariably supports different operating systems, file systems, electronic mail applications, etc. There are not currently standard choices for these components in a distributed computing environment. The network organizations or architectures are also very different and vary from OSI to SNA and other proprietary architectures even within a single logical network. The combined problems of diverse distributed computing components and diverse network architectures make management and planned evolution very difficult.

Further complicating the situation is that many computer networks and the underlying communications networks are managed as separate entities, with totally separate operations staffs. Decisions made by one group may not enhance the overall design of a *system* comprised of the computer and the communications equipment. This mentality of separation must be stopped in order to ensure a total systems approach to these networks.

Transmission Speeds

Transmission speeds on LANs and backbone long lines facilities keep getting higher and higher, but no one really knows how to properly utilize these capabilities. For example, LAN technologies have greatly increased the potential performance of the interconnection subnetwork, but few users have been able to utilize even a small portion of the transfer bandwidth currently available. LAN transmission speeds of 100 Mbps, e.g. FDDI, are already far along in development, although we have some concern about that particular technology from a network management point of view. SONET, and the optical hierarchy that it is a member of, is another source of high-speed transmission that will not be limited to the local area.

There is some concern in the industry about the usefulness or applicability of present protocols, e.g., TCP/IP, OSI, and others, in very high-speed networks. We see proposals such as XTP (express transport protocol) being advanced, but it is not at all clear that these alternative protocols will meet our manageability goal.

Network Management

One of the most active areas of research and product development within the computer and communications industries is that of network management. The rapid rise of network management to critical status is based primarily on the need to manage all aspects of corporate information and communications networks as an integrated system which is a critical asset of the organization. This requirement has become known as "enterprise management". An enterprise is "an organization which operates one or more communications networks, and wants to apply consistent network management policies and procedures, using interoperable management solutions, to meet some common business objectives." [OSI/NMF Forum Glossary Issue 1, January 1990 pg. 5] Enterprise management has become synonymous with the ability to manage all elements within a network — computers and communications equipment — in an integrated, uniform, and consistent manner, including communications systems and distributed enterprise applications. Users and vendors have become much more sophisticated and demanding in their requirements for seamless and transparent integration of network management applications running on different computers and supplied by different vendors. These efforts have led to many standardization efforts for network management — OSI, CCITT, IEEE, OSI/NMF, etc.

There is still no accepted standard for the management of diverse network elements in regard to the user interface to the management system and the protocols and message sets to perform management communications. This is a necessary component of the solution to the management of complex campus networks.

Network Performance

The networks currently installed for campus environments are very complex systems. This is due to the large and varied volume of traffic, and to the inherent structure of the network, consisting of a number of interconnected subnets. Performance of such a network is sensitive to parameters of routing and control policies, like flow control and congestion control. The main mechanisms to control and regulate such a network are the internal subnetwork protocols utilized. The choice of a protocol for a campus network should be based on the emerging standards. At the present, standardization of metropolitan-area network protocols is at the forefront of activities in various standard organizations, and future protocols for campus environments will probably be based on them.

How Do We Get to The Future?

Factors Limiting Advances in Campus Networks

There are many factors that may slow the implementation of campus networks that meet the primary goals stated at the beginning of this report — *fully integrated* and *manageable*. The issues may be best presented as a series of questions about the future. All of these questions are potential research areas — some only call for continued advances in areas already being addressed, others represent areas that we feel have not received the attention that they require.

- Will distributed applications become a reality? This depends in large part on the tools and service to support development, implementation and use of distributed applications.
    - There are few *really distributed* applications available. Most are just simple file sharing.
    - Will user interfaces become "easy" for the novice and expert users? As pointed out in this report, this entails many different factors.
- Architectural issues
    - Will the protocols that are available currently or in the future operate effectively and efficiently at the high speeds that will become available and affordable? The demands for increased data movement are already being voiced.
        - Will open network architectures, primarily OSI, survive the requirements for utilizing increased bandwidth (i.e. extremely large transport pipes)?
    - Will the data interchange standards, from low-level (files) to high-levels such as EDI, enable easy exchange of data between corporations and within workgroups?
- Transmission
    - Will fiber actually be brought to the desktop and will FDDI actually become a standard? (It is being held up by some management issues.)
- Network design
    - Will the tools be available to design networks with higher robustness, efficiency, and resiliency?
    - Will the tools be available to design networks to deliver a specific performance level in a cost-effective manner?
- Network management
    - Will the OSI management Common Management Information Protocol (CMIP) prove to be the application protocol that enables interoperable network management or will Simple Network Management Protocol (SNMP from the TCP/IP community) win that battle?

- •• Interoperability of management systems is critical, especially with regard to public and private interconnected networks. Will the carriers be able to "open" up their management capabilities to integrate seamlessly into a private corporate network?
- •• Will the network owners attempt to manage their own networks or will a third party be given this job?

Figure 8

Future Campus Networks

Factors Limiting Advances

- **Distributed applications - few yet defined**
- **Architectural issues**
  - **Capability to utilize high-speed transmission**
  - **Data interchange standards just being adopted**
- **Transmission systems**
  - **Future status of FDDI**
  - **Competing MAN technologies**
- **Software developments**
  - **Few tools available to aid implementors**
  - **Network services limited**
  - **Complex user interfaces**
- **Network design**
  - **Tools not available to design for**
    - **Target robustness and resiliency**
    - **Target efficiency and performance**
- **Network management**
  - **Lack of standards**
  - **No real implementations yet**

Technologies of Future Campus Networks

Any discussion of the future must be tempered by a reminder that very few of us could have predicted where we would end up in 1990 considering the situation in 1985 (only 5 years ago!). AT&T was still struggling with the realities of divestiture and some of the key network technologies today had just begun to be developed. Intelligent T1 multiplexors did not exist, and interest in Ethernet was just emerging.

Many of the technologies of the future are in development and/or in the initial testing stages today. Some of the "new" technologies are actually available today; however, the cost is still prohibitive for widespread use. The development and adoption of standards is often associated with a new technology, and that is often a slow, laborious process, unless there is already a de-facto standard in place. However, standards to address the key requirement areas that we have identified above — *network integration* and *network management* — are being motivated by user demands; and they are driving the development of the technology, not the other way around. The only delays that we attribute to the lack of standards in these areas is the lack of technology to provide the services desired.

The technological trends today are to integrate existing networks in an effective and seamless manner, to move towards higher transmission speeds by creating larger transport pipes, and to adopt open network architectures. Each of these trends plays a major part in the discussion of future technologies and each will have a major impact on the future of campus networks. In addition, we must also consider the increased impact of user needs and requirements. Figure 9 highlights the areas that must be addressed to achieve the vision of future networks as described in this report.

Figure 9

Future Campus Networks

<u>How to Get to the Future</u>

- **Understand Users**
  - **Needs/desires/requirements**
  - **Interfaces**
  - **Hard to Understand**
- **Technical Developments Required**
  - **Network Interconnection**
    - **Adherence to standards**
  - **Network Interoperability**
    - **Adherence to standards**
  - **User Interfaces**
    - **Forgiving**
    - **Uniform**
    - **Informative**
    - **Intuitive**
  - **Distributed Usability**
    - **Resilient**
    - **Robust**
    - **Reliable**
  - **Network Management**
    - **Adherence to standards**
    - **Designed into network elements**

Understanding User Requirements

Networks must be planned, designed, and implemented in a way which allows for meeting the user requirements. Users are becoming more and more dependent upon computers for wordprocessing, spreadsheets, data base applications, electronic mail, and other network services. If this trend is to continue, there must be changes in the ways which vendors consider the requirements of the users. As was mentioned previously, the current trend is to introduce varied functionality geared to the highly trained and skilled user. The untrained and uninitiated user is often not considered. User interfaces must be geared towards meeting the needs of both sets of users. This is a difficult undertaking, and study is required on how to provide intuitive user interfaces which will shield them from the lower level network complexities. The types of network interfaces and services that must be provided for easy-to-use and intuitive user interfaces are:

- Find the address of a remote user for mail access
- Find the location of user or system files on a distributed system or make finding that location completely unnecessary so that file migration may take place transparently to the user.
- Execute programs residing on remote systems without knowing where they reside or where they execute.
- Locate disk storage space or request additional space without knowing which machine or network it resides on.
- Make data base requests to various large data bases without understanding all the complexities of addressing and without being required to couch the request in technical language.

Some of these capabilities are now available in experimental products as the Andrew File System (AFS) . For example, a user may run out of disk storage space and more space can be allocated without the user ever knowing that this has happened or where the new space is located. Programs can reside on remote locations and can be executed locally with AFS and some other products, such as SUN Microsystems Network File System (NFS). This, however, does not offer the option of remote execution. The UNIX command RSH (remote shell execution) helps in this area, but the user must be very familiar with what is to happen in order to get things to work correctly. (RSH is not for the novice user.)

Interfaces to highly desirable network applications are still very difficult for many users to understand and easily utilize. Electronic mail is an application which we have cited many times within this report. It is still a problem for many users today. You must not only know the user name of the person that you wish to send mail to, you must also know the machine at which he receives mail, and sometimes the intervening machines on the route that must be followed in order to get to that machine. There are even different addressing notations that are used in the different mailing systems. The "!" (bang) notation and the "." (dot) notation are examples of just two of these.

There have been standards developed for accessing data stored in database applications. Standard Query Language (SQL) is one of these, but SQL is not a particularly user-friendly access language. Some database systems have been progressing toward a language which will allow users to phrase requests in a pseudo *speaking* way, but there is no allowance for variation from the strict syntax that is required and subtle changes can lead to completely incorrect results.

A key mechanism required to gain user satisfaction with computers and networks is the standardization and integration of applications running on several different systems. This integration will allow users to migrate from one platform to another, in a fashion very similar to the way that users can utilize phones in different states and countries, made by different vendors, to place a telephone call. There are many packages for word processing that will run on only one or a small number of platforms. Those that run under DOS will usually not run under UNIX, VMS or MVS, etc. This has been one of the major problems in getting users to migrate to larger more powerful systems. They will not leave the shelter of the word processor that they know on DOS.

Interfaces must be developed which are informative and helpful to the user. The interface should be as interactive as possible and powerful in that it can guide the user toward the correct snytax, etc. This type of intuitive, transparent and powerful tool has not been developed and is probably a long way off.

Technology Developments Required

Network Interconnection Technologies

There are several standards for network transport, termination, and interconnection which we feel will be critical to future networks. Each of these are in varying stages of reaching international standards and receiving widespread user acceptance. During the next five to ten years, they will play a key role in influencing the direction of network evolution.

Signaling System 7 (CCITT-SS7)

Signaling System 7 is an out-of-band signaling protocol that is separate from the traffic bearing subnetwork it supports. The objective in using separate channels is to facilitate the transmission of subnetwork control information. The use of SS7 significantly speeds up call processing and provides greatly increased control signaling capabilities. The major carriers are all currently implementing SS7 to some degree.

SS7 will allow carriers to offer advanced services and enables some of the ISDN-type services, such as MCI's Digital Reconfiguration Service and Two-Way Access Service.

Fiber Distributed Data Interface (FDDI)

High speed, high-bandwidth fiber optic links are becoming the transmission media in many networks. Optical fiber is being utilized by all national network carriers (AT&T, MCI, US Sprint) for long lines, and its use is migrating into local distribution by carriers such as Southern Bell. Fiber technology will eventually appear on the desktop. Its lower cost for bandwidth will result in dramatic reductions in costs of digital transmission. The economy and feasibility for the transport of large volumes of data will be greatly enhanced with the wide spread introduction of fiber.

FDDI is a standard under development which will provide the spcifications for a 100 Mbps fiber network. It will allow interoperable high speed fiber networks. However, the FDDI standard does not currently address the management aspects; and FDDI will not gain wide acceptance until this happens.

The key issues with fiber are how long it will take for it to be economically feasible to put it in everywhere, will there be protocols which can support the higher speeds which it allows for, and will it be manageable.

Integrated Services Digital Networks (ISDN)

Integration of operational networks into one seamless and manageable network which supports all of the required applications is a major trend in the communications industry today. ISDN introduces the necessary technology to accomplish the integrated delivery of data, voice, video, facsimile and other services in one user interface with transmission speeds of up to 64 Kbps. The integration of these diverse services into a single telecommunications interface has the potential to be a key factor in the future.

ISDN service is not universally available today, but should be in the 1995 timeframe. It is currently being implemented and tested by the carriers and network equipment providers. There are those who feel that the transmission speeds available under the initial ISDN offerings will not be adequate. The introduction of new transmission media (fiber) and B-ISDN (Broadband-ISDN) will enable speeds from 384 Kbps to gigabits per second.

Open Systems Interconnection (OSI)

OSI is gaining widespread vendor and user acceptance in the USA, although its progress there has been much slower than that occurring in Europe. Therefore, many feel that it is not a flexible network architecture, but users have embraced it as a solution. OSI products will be prevalent and available due to the users demands on their vendors. Forward thinking users perceive OSI as the key to integrated, manageable, and transparent internetworking.

The survivability of OSI will depend on how well it can be adapted to the availability of the very large transport pipes (up to the gigabit range) and if integrated management can be achieved. OSI management is one of the most active areas of research and development today and will be commercially available within the next two years.

One of the problems in using the OSI model in designing systems is that it is difficult to design and implement systems when the abstraction that is to be designed is not fully understood by the industry. For example, one problem with moving to OSI is that there need to be gateways that connect OSI networks to TCP/IP networks. Most implementers are interested in intercepting the transport layer of OSI and converting it to TCP for delivery by a TCP/IP network. This interception of the transport layer violated the OSI model for transport layer which says that the transport layer is not to be intercepted but must be end-to-end. This interception of the transport layer for the conversion from OSI to TCP diluted the functionality of the transport layer in general and can cause problems of more than a conceptual nature in the communications system. Care must be taken in the future not to allow this dilution of functionality to cast a shadow on the original intent of the OSI model.

Open Distributed Processing (ODP)

Within JTC1, there are efforts underway to define standards for Open Distributed Processing. This work is concerned with the development of a distributed systems framework together with all the models and tools to specify distributed systems from a number of viewpoints.

The work within ODP is similar to that within OSI in that it is concerned with defining the information structure, flow of information, structure of applications and the interfaces between processes and applications. The ODP work has adopted four viewpoints for which they are defining models: enterprise, technology, information & computation, and engineering. It is expected that the standardization of many aspects of building distributed computer applications will help to solve many of the problems discussed in this report.

Network Management

Network management, as a technology, is a relatively new field of interest. Networks have, of course, been "managed" for years, but without the benefit of standards and management capabilities built into products. The increasing focus of the users and OSI standards efforts on network management has changed all of this. In the past, management has been primarily tactical in nature with very little emphasis on strategic planning. The increasing focus on network management is changing the way it is viewed to include a much broader range of functionalities including strategic planning and others.

Interoperable network management is going to become a reality within the next five years, primarily because of the influence of an implementors' group - the OSI/Network Management Forum. The reality of the implementations will be that

OSI Management standards will be the basis for the exchange of data from one vendor's network management system to another vendor's network management system. There will be little effort and few R&D dollars spent on building network components with built-in OSI Management capabilities. The OSI standards will only be enforced at the interface between network management systems, not between network management systems and network elements.

The vendors are focusing on establishing the required components of an interoperable solution, while at the same time, retaining their control of the network management operations of any given customer. From a user's perspective, however, there is little value derived solely from the implementation of network management systems that are merely interoperable. This ability to exchange network management data is really just the *starting* point for solving the problems of the operator of today's complex networks. Consider a typical network with multiple network management systems, each supplied by a different vendor with a different user interface. [One recent survey of network operators revealed that over 50% of all networks have more than one network management system.] The implementation of interoperable management data exchange protocols allow these network management systems to exchange data. This data exchange does not necessarily create a management solution. The real value of interoperability for the operator will lie with the applications that are built to run on top of the interoperable interface and provide *network management solutions*. Due to the very strong focus for managing campus networks as a cohesive entity, all discussions of enterprise management issues are applicable to campus networks as well.

There has been little effort spent on establishing the user requirements for network management. There have been many surveys of user needs conducted primarily by trade publications and analyst groups, but this information is not being funnelled into the standards and implementors' groups which are specifying the network management standards. In many cases, vendors are compelled to keep their products functionally equivalent to their competitors, even if the functions provided are not the right ones. For example, a recent analyst survey finds that graphical user interfaces are not a priority for the network operators According to this report, network operators feel that graphics is not required in order to meet their tactical needs; that graphics is basically an "upper management toy".

Initial attempts at developing integrated network management systems have not resulted in full command and control capabilities through a single, top-level system. Each of the announced commercial architectures require terminal access to lower-level management systems in order to completely control the network elements. The job of managing networks still requires highly skilled personnel and the ability to move between multiple vendors' languages and styles of user interfacing.

Network management integration needs to be built into each component of the network as an integral functional capability. This would allow for different vendors' network elements to be managed by another vendors' network management system. This was the original intent of the OSI management model, but vendors are not willing to give up network management control of the elements that they provide. (The marketing leverage is obvious.)

Many problems with the progress toward OSI management are due to the approach of the standards efforts as opposed to the resulting architectures and products. These include the lack of a detailed and achievable workplan by JTC1, duplication of efforts by standards and implementors' groups, and lack of understanding of user requirements of interoperable network management.

In spite of these problems, interoperable network management, loosely based on OSI management concepts and components, will become a reality and should be widely implemented within the time frame of the "future" as defined in this paper, 1995-2005.

Network Performance Analysis

In order to achieve acceptable network performance, the ability to perform quantitative design must be greatly improved. This involves devising and evaluating strategies for blocking, routing, and flow control in the subnetwork as well as in the layers of the end systems. Performance evaluation will become an important part in the design and implementation of campus networks.

Performance evaluation and prediction generally falls into two categories: measurements and modeling. When a system is instrumented and operational, performance can be evaluated using tools such hardware and software monitors. For systems in design phase, modeling techniques can be used for performance evaluation and performance prediction. In the last two decades, it has been demonstrated several times that performance can be evaluated or predicted to some degree of accuracy by queueing models which can be solved either by simulation or analytical methods. Simulation is the most general and powerful technique for studying and predicting system performance. However, the high cost of running the simulation programs and uncertain statistical accuracy, makes analytical methods more attractive. Compared to simulation, analytical methods are more restrictive, but have the advantage that it is less costly to compute numerical results. Moreover, they can be implemented very quickly, thus it is very easy to give interpretations to the relationships between model parameters and performance measures. Analytical methods have proved useful in modeling a variety of computer systems and computer networks in the last two decades. They are flexible enough to represent adequately many of the features arising in such applications.

Computer Technologies and Developments

"System" Architectures

It may appear that architectures are being developed for "every possible" aspect of the computing system — interconnection, communications, management, interprocess communication, distributed processing, etc. That is basically true, and this activity is not the result of everyone latching onto the latest "buzzword." Recognizing the basic meaning of "architecture" — *the rules and conventions by which the pieces of a system relate to and interact with other components of the system to provide the component services required to produce the overall system service* — then it should be recognized that the process of defining all of the architectures required for distributed computing systems is just beginning. All of the activity under this title at this time is a recognition that we must have some well established plans to guide and govern the design and implementation of distributed systems.

Perhaps, the main problem that we have encountered in the development of all of these architectures is that we do not yet know our complete list of needs in this area. A secondary problem that has also appeared is that there is, thus far, no well-established theoretical basis for the design and development of architectures — each one makes up its own rules of "architecture design." The development of a good basis for the development of all architectures would be a great advance in this area. (That would also have an impact on many other areas in addition to distributed computing.)

<u>Developer Toolkits</u>

Many of the areas for which vendors, third parties, and users will be developing software will be governed by the adoption of international standards. For an area which has an international standard specifying message formats, protocols, or interfaces, it will become very expedient and help ensure ease of integration to use a developer's toolkit when producing code and/or products.

We believe that the following are candidates for toolkits. For this discussion a toolkit can be either

- Source code which must be ported to operating environment
- Binary code with a well-defined API (Applications Program Interface)
    - "APIs give developers a way to address user's demands for friendlier, more sophisticated programs while putting an unprecedented range of functions and services at their beck and call." [Hindin]

Toolkits will be available (and already are in some cases) for

- CMIP/CMIS (The OSI Common Management Information Protocol and Common Management Information Services)
- X.11 Windowing System
- Full OSI and ODP stacks

However they are not yet available on a wide variety of platforms and interoperation between two kits of various vendors is not yet fully achieved.

Client/Server Computing

Client/server computing involves the physical separation of applications and data between or among computers. The major applications of this technology will be in departmental computing and cooperative processing on LCNs.

Client/server models are being developed by the major software and computer vendors. The application of these models is becoming very widespread (including network management) and includes SQL data base applications, etc. An example of the utilization of this model is a campus network with departmental and/or regional databases that are logically viewed as one or more databases . End system applications are the clients in the model and they issue SQL queries to the server applications which then find and return the data in a standardized format to the requesting client. The location and the details of the network are transparent to the client.

Client/server models will play a major role in the development and functional aspects of network applications in the next few years. There will be impacts on the development of database applications and any environment where central data servers can be utilized with distributed processing and access points.

Transmission Speeds

Technologies are being developed to enable transmission speeds in the 100 gigabit range. Current applications and those under development do not yet require these large transport pipes. The opportunity to have such large transfer capabilities will surely foster the development of applications that use them; however, there are no proven methods for managing these very large pipes. A good argument for the need for higher transmission speeds has been presented by Lidinsky. Figure 10 from [Lidinsky] shows the relationship between bandwidth required and response time vs. transmission unit size.

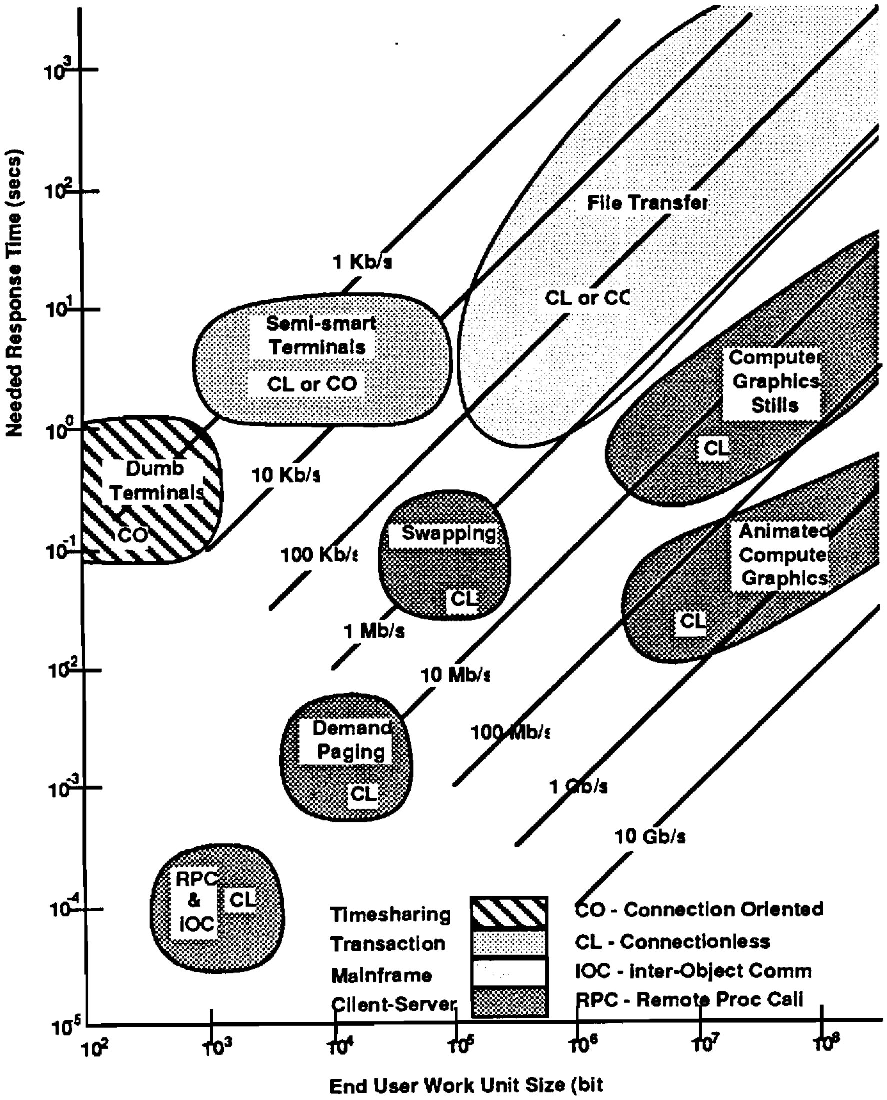
Whereas, our present transmission speeds are limited to effective rates of less than 5 Mbps, future development such as FDDI and SONET, make it reasonable to consider the lower right corner of this figure.

Figure 10

Future Campus Networks

Computing Response Time Requirements

From [Lidinsky]



Standardized and "Friendly" User Interfaces

Standardized user interfaces must be developed for interacting with local application programs and for using communications capabilities to access applications distributed throughout an internet. A user should be able to perform most requests for services easily and systematically.

Advances in this area are essential to overcome the present limitations referred to previously in this report as "The Knowledgeable User" or "Elitism." User interfaces must become forgiving, uniform and intuitive for all levels of users. There must be something that "insulates" the user from changes in technology, such as changes in processors, and from changes in the services offered or the manner in which they are implemented. The novice user must be gently guided through a difficult request.

This need for standardization becomes extremely acute in networked systems, especially local computer networks, where there is so much volatility in technology, services, and implementation.

Windowing

A very popular "standardized" user interface at the present time is "X-Windows," also known as X.11. This interface, which is approaching ANSI Standard status, is the result of a project to do exactly what is described in the previous paragraph — provide a consistent and highly usable user interface. Emphasis on this technology is currently quite high; and it is well-recognized that this interface ,which was initially developed for local computer networks and is based on the client-server model of computation, has applicability to all forms of networking

Operating Systems — File Systems and Other Common Services

A discussion of these topics might have been placed under the topic "Computer Technologies and Developments"; however, they have been given a major heading of their own to highlight their importance. What is being discussed in this paragraph are the basic, common-user services which are required to make effective utilization of the computing system.

There might be some confusion in the distinction between the "tool-kits" discussed above and "operating system services." There could certainly be some argument about which topics belong in which paragraph; the important point is to be sure that they are all covered.

The distinction made here is that "tools" are low-level software support that assists in the development and implementation of software, e.g., distributed, interprocess communication (IPC), connection establishment, etc.; "services," on the other hand, are capabilities that the user might see, e.g., file transfer, electronic mail/message handling, reliable transfer, virtual terminal, etc.

Successful networking requires that compatible and usable services be provided on a variety, if not all, of the network platforms. Some differences in the implementations and exact features of the services provided can be "masked" by a smart user interface, e.g., "X-Windows" discussed above; however, a technique such as that can only go a limited distance in making the network services appear consistent to the user. At some point, it will be necessary to ensure that the services themselves are compatible and implemented in a compatible manner.

Planning for Future Networking on the Georgia Tech Campus

The Georgia Institute of Technology (GIT or Georgia Tech) is in the process of planning for the next 3 to 5 years growth of the current campus network. The major issues facing the Georgia Tech network planners today are described in this section.

The Basic Problem — Integrating Multiple Constituencies

There is a problem on the GIT campus as to how to best integrate the two (or more) constituencies of computer users: PC users (DOS, etc.) and the high powered workstation users (UNIX, etc.). The defining characteristics of the groups is not totally based on choice of operating system. Another factor is the use of computer tools. There are users who use a small set of tools on an unchanging platform for specific utility, and users who utilize the power of the computer for a rapidly changing set of uses. This is not to say that one of these two is better or more necessary than the other, but that there are two categories of uses that computers are put to that must both be supported by the networks of the future. New technology can put more tools into the stable tool bin of the PC type user and can give more power to the PC for the UNIX type user to be creative with. For example, consider the NeXT machine with the Postscript display and DSP chip standard.

A "Standard" Campus File System

The Andrew File System (AFS) is currently the choice of the Georgia Tech network planners for a network operating and file system for the future. AFS will provide a consistent address and name space for the campus on several different platforms including the IBM mainframes, DEC VAX, IBM PC's, SUN workstations, NeXT computers, and Macintosh computers. This includes most of the platforms that are currently in use on the Georgia Tech campus. This system allows for a singly rooted tree for the directory structure for all machines on the campus. It provides access lists to control access from users to the files on various systems. It provides (through Kerberos) security for the access. The key words here are *single name space* for multiple platforms with *security*. Research is beginning now into just how well AFS will operate in a fully functional and operational environment.

Applications including electronic mail, news, and file transfer and remote access to files are another issue that must be addressed in the future Georgia Tech network. Providing the underlying file system (AFS) is a good start to supporting these applications from a technical operations perspective, but not from a users point of view. There are several widely accepted user interfaces for mail reading and at least two major ones for mail transfer. OSI is standardizing on another which will hopefully become widely accepted. This new mail standard, X.400, is currently the target for the campus as the standard for all mail transfer. There are few implementations available now, and these do not run on all platforms, so some custom work must be done to integrate this standard into the existing environment. A standardized, common directory service is also a necessary part of any mail system, especially were multiple systems must be in use concurrently for address translation between these systems. Georgia Tech has plans to implement X.500 on the campus in the next 6 months to a year. File transfer options on campus currently include FTP from the TCP protocol suite, KERMIT from the public domain, and the OSI FTAM. File transfer becomes less of an issue on the campus with the introduction of AFS. For off-campus access, FTAM will probably be the choice. Some of the motivation for the choice of FTAM is that it is the choice of the government (GOSIP).

The Campus Communications Infrastructure

The underlying communications infrastructure must also be changed to accommodate the growth and change. At this time, it is believed that Ethernet over fiber is the Georgia Tech choice. Fiber is the media of choice for the foreseeable future, but Ethernet must be able to go over it. It is apparent that FDDI is the next foothold in the datalink over fiber realm. Georgia Tech is taking steps now to install FDDI between the North and South interconnect buildings as a minimum and to expand this to the major buildings (5 of these) in the next 1 to 2 years. Fiber to the desktop is desirable but, for financial reasons, will probably not be viable for the next 3 or 4 years. Fiber in new installations is not much more expensive than Ethernet cable, but interfaces for workstations that run fiber are not currently available, and software which will run over these interfaces is rare. Also, the amount of the usable bandwidth that can be utilized by a workstation running over fiber is very small. Most workstations cannot utilize even the 10 Mbps bandwidth available now on Ethernet; however, as the power of workstations is used to provide the user with the interfaces that hide the complexities of the computer network, fiber will probably be the only way to support this to the desktop.

Possible Future Campus Roles for ISDN

ISDN is a technology that appears to have many potential uses on the campus. Dormitories have, in the past, been wired with either modems for use over the existing phone lines, or some type of data over voice system which required the users to purchase equipment that could not be used anywhere else after his/her stay in college. (The student can sell his special data-over-voice modem back to the Institute Bookstore.) ISDN is a possibility to replace this technology with one which will allow much more flexibility and the possibility of taking the equipment elsewhere when one leaves the dorm. ISDN lines to dorm rooms (and homes) will be competitive in the near future to a comparable amount of service from conventional lines (one ISDN line provides two separate calling ID's on the two B channels which are identical in circuit switched mode to two conventional telephone lines with the added plus of calling number identification and common channel out-of-band signaling) with the added feature of packet switching being available on the B channels in addition to circuit switching. It is apparent that the D-channel packet capability of ISDN basic rate interface (BRI) lines is limited beyond the common channel signalling that it was designed for, but packet switching on B channels could provide much better access to campus machines than is possible even with leased lines today. A point-to-point protocol, such as the one described in the Internet RFC 1134 "The Point-to-Point Protocol: A proposal for multi-protocol transmission of datagrams overpoint to point links," would be useful in sending data across B channel circuit switched digital service. Alternatively, the X.25 packet handler at the central office could be used to provide X.25 packet service from the user in the dorm room or home to the campus machines connected to X.25 packet switches and either the local carrier or public data networks. The fact that ISDN utilizes standard telephone loops (copper) means that anywhere a phone could go (within reason) an ISDN line could go, providing digital networking capability to that point. This doesn't come free, however, and cost could slow its introduction.

Network Management on the Georgia Tech Campus

Network management is the one area that has been overlooked in the past on Georgia Tech's campus. This oversight has caused many problems which are now very evident in the existing network. There are times when broadcast storms ravage the campus network, and the network is completely unusable for tens of minutes. This is unacceptable in a user service industry, which networking is. There are also times when naive users bring up workstations with previously used internet addresses. This causes problems with the existing station using this duplicated address. There is currently no effective method to locate the sources of these problems and then segment the network to limit their effects. SNMP (Simple Network Management Protocol from the TCP/IP community) is currently being installed as a means of monitoring the health of the network and the resources that provide network services; however, SNMP will not address and handle the problems described above. Therefore, the current architecture of the network is being modified to allow a network manager to restrict problem to small areas of the network so that "repair" can take place without affecting the rest of the campus.

Summary

This report has identified and highlighted the goals of future campus networks, the current problems of such networks, and some of the problems and/or limitations that will be encountered in pursuing the future goals. Within this summary, we will offer some opinions on the directions in which we feel campus networks will evolve and the amount of commercial success that various technologies will achieve. It is important to realize that success within the commercial world and widespread implementation within the academic and research worlds are not equivalent measures. A commercial success means that there is sufficient user demand and that the users are willing to pay for the technology.

General Goals and Objectives of Future Campus Networks

Restating our vision of the future, it is seen that it centers around achieving two major goals (Figure 11).

- Access to all network resources should be easy and uniform — they must be accessible by even a novice network user; and
- Network resources must be manageable in an integrated and systematic way to enable network managers/operators to satisfy user requirements.

Figure 11

Future Campus Networks
Primary Goals and Objectives

An integrated network with access to all network resources
- **Easy, simple, and intuitive**
- **Uniform, straightforward**
- **Reliable, repeatable**

A manageable network
- **Integrated**
- **Systematic**
- **Comprehensive**

Characteristics of "Campus Networks of the Future"

Our vision of future networks is shaped by all of the previous discussions of interoperability, manageability, user requirements, and developing technologies. The composition of the envisioned networks, as summarized in Figure 12, include:

- Transmission Systems
  - High performance processors (possibly providing multiple MIPS) at the mainframe, server and workstation level
  - High speed, high bandwidth backbone circuits
  - High speed, high bandwidth LANs at termination points
- Distributed Applications/SW Developments
  - Interoperability standards for software
  - Client/server models prevalent for software
  - Transparent interaction between software operating on different processors
  - Remote execution enabling distributed applications
  - Multi-tasking, multi-session workstations located on the desk
  - Global directory services
  - Consistent and uniform user application interfaces
  - Standardized application-program interfaces (APIs) and toolkits

Figure 12

Future Campus Networks

A Summary of Their Characteristics

- **High-speed, high-bandwidth transmission**
  - **LANs**
  - **Backbone circuits**
  - **Internetworking**
- **High-performance processors**
  - **Mainframes**
  - **Workstations — multi-tasking, multi-session**
  - **Servers - files, printing, and processing**
- **Software models**
  - **Consistent and uniform applications interfaces**
  - **Client/server prevalent**
  - **Transparent interaction between processors**
  - **Transparent interoperability**
- **Network Services**
  - **Extensive and powerful programming tools**
  - **Global directory**
  - **Network management — for user and manager**

- Network Management
  - Network management services available to network user
  - Highly automated and sophisticated, integrated network management systems
  - Interoperability standards adopted for network management

Typical Campus Network Configurations and Their Characteristics

Figure 13 depicts what we feel will become a typical campus network configuration. All of the characteristics listed in the previous section will apply (Figure 14). The technologies which can be used within each of the levels of the network and our predictions as to when they will be widely available are given in Figure 15.

The communication infrastructure of the networks can be viewed as consisting of three components:

- Wide Area, Backbone Networks
  - Public and Private
  - Probably "conventional" store-and-forward packet switching
  - High speed, i.e. DS-1, trunks
- Campus Backbone
  - Mostly private
  - May make use of public MANs
  - Very high speed 100 Mbps or greater
- Local Area Networks
  - Distribution and interconnection of workstations
  - Access to mainframes
  - Probably medium to very high speed, 10-100 Mbps
- Network Management
  - Integrated
  - Standards-based
  - Interworking with Public WAN

Of course, there are many network applications and services that reside above the communications infrastructure and provide functions to the users. These will include among other capabilities:

- Distributed operating system;
- Distributed file system;
- Global naming plan and directory service;
- Network mail service;
- File transfer service;
- Network management.

Figure 13

Typical Subnetwork Configuration

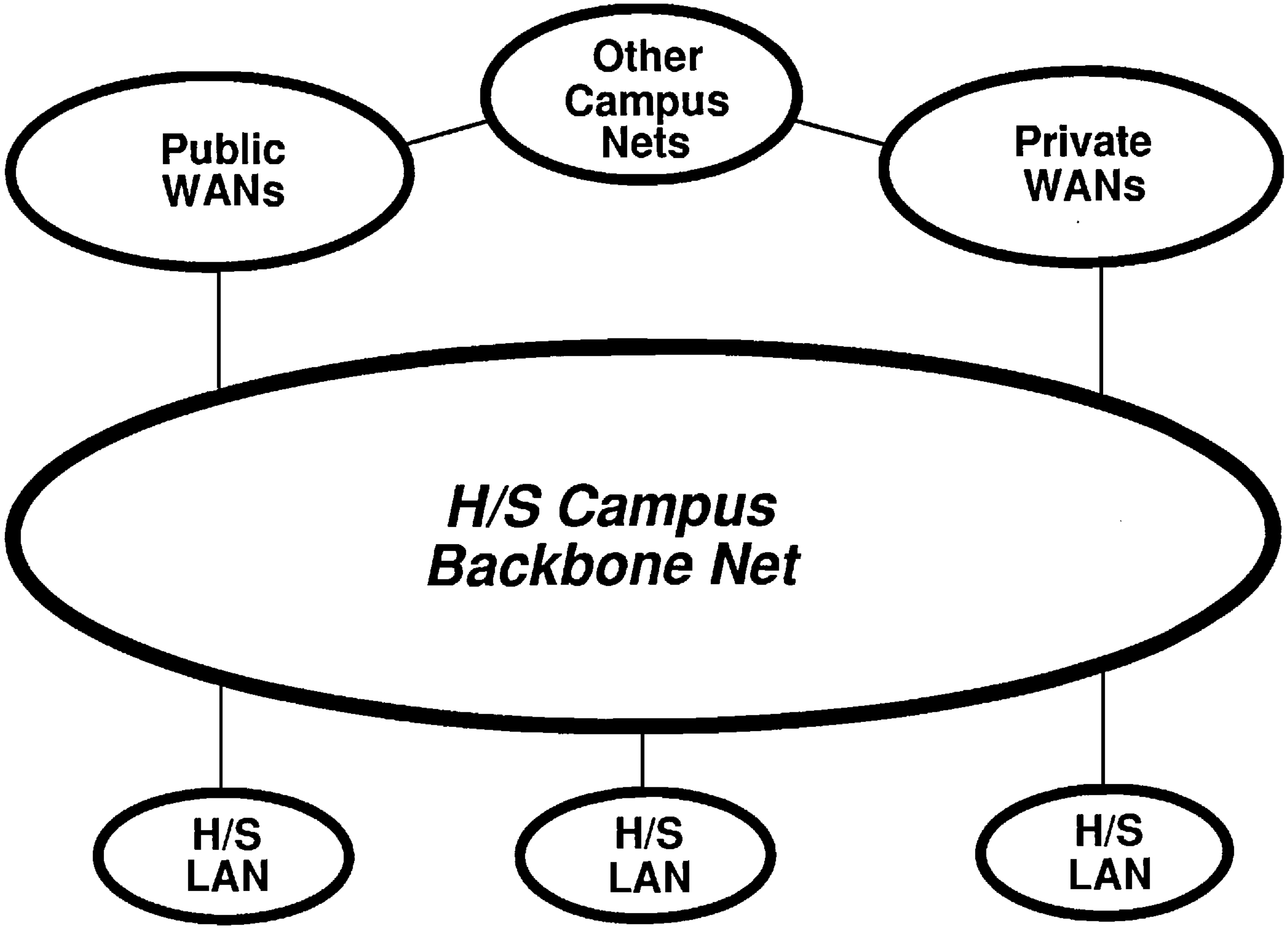
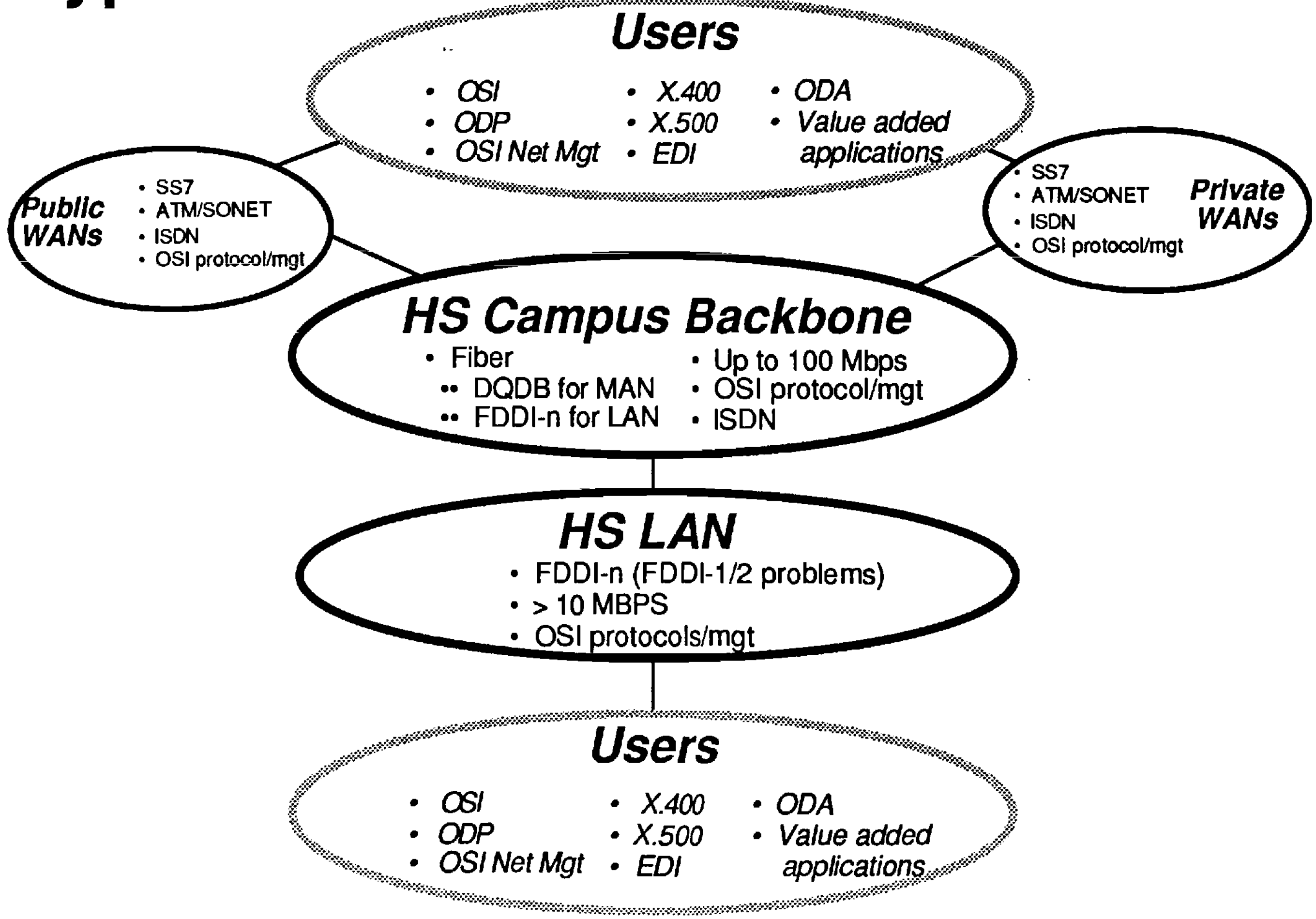


Figure 14

Typical Future Network Characteristics



Predictions for Industry Acceptance

We feel that it is impossible to predict with a high degree of accuracy the timing of the development, general availability, affordability, and adoption of all of the technologies discussed in this paper. Without the benefit of additional research (*and a crystal ball*), we are only able to use our instincts, knowledge of the industry and past history to offer some predictions. The chart in Figure 15 lists the newly emerging and somewhat well-understood (*but not yet prevalent)* technologies. Our predictions for when their development, including standards and technical understanding, will be complete enough for widespread implementation and whether they will gain acceptance within public and private networks are given in the body of the chart.

Figure 15

Predictions

		Adopted/Utilized In	
Technologies	**Developed**	**Public**	**Private**
N-ISDN	E90s	? in U.S.-Y in Europe	? in U.S.-Y in Europe
B-ISDN	M90s	Y	?
SS7	now (initial)	Y	?
FDDI	M90s (transport now there)	N (topology & compatibility problems)	Y (in spite of limitations; mgmt not avail yet)
OSI	Now	Y	Y (for internetworking)
ODP	M90s	Y	Y (for basic interoperability)
OSI Net Mgmt	E90s	Y	Y
SNMP	Now	N	Y (will be replaced by OSI)
X.400	Now	Y	Y
X.500	E90s	Y	Y
Integ Net Mgmt	M90s	Y	Y
SONET	M90s	Y	Y ?
Dist File Systems	M90s	N	Y
Dist Oper Systems	M90s	N	Y
Networked EMail Apps	M90s	N	Y

E = Early
M = Mid

A Research Agenda To Get To The Future

The computer industry will need little motivation to continue with the development of higher-speed transmission system for LANs and campus networks; work is proceeding on the 100 Mbps FDDI systems and the 16 Mbps token passing ring (IBM) is already reality. Actually, user needs and the natural motivation of the "technology tinkerers" will keep this aspect of development moving at top speed for some time to come. There is similar high interest and high levels of activity in the area of network management. However, it is feared that these areas are being pursued for their technological interests only — we are in grave danger of failing to really meet the true *user needs.* [1]

Research activities are needed very quickly to address and answer the concerns posed in the section of this report called "Factors Limiting Advances in Campus Networks." Prototype networks must be put together and experiments performed to determine the best management techniques and systems architectures which provide the most useable and efficient services. The lack of ability to answer that series of questions limits our ability to predict and map a course to the future as it could be.

[1] One of the authors (PE) can not help but draw a comparison between the current frenzy of activity in this area under the banner of "answering user demands" and activities some years ago in the area of data communications. An entire industry segment, the "Specialized Common Carriers," MCI, etc., was being argued for and formed on the basis of "filling a critical unmet *user need*;" however, few bothered to to learn what the user truly required *and was willing to pay for*— only the computer techies were surveyed and asked how much data communications would they like to have. When corporate management was asked what it really was going to require and what it was willing to pay for, the survey results were dramatically different.

Citations, References, and Suggested Readings

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