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On-Premises Digital Communications Upgrades With Emphasis on Fiber Optics

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U.S. DEPARTMENT OF COMMERCE
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for Communications and Information

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PREFACE

Distributed data processing and office automation have become virtually the status quo for all Federal agencies within the past few years. Unfortunately for users, as well as for automatic data processing (ADP) and communication managers, this proliferation of terminal equipment has typically far exceeded the capabilities of existing building wiring and communication systems to interconnect on-premises user work stations with each other and with external networks. This report documents efforts of one group of Federal employees to better understand the mutual problems associated with on-premises communication upgrades and to analyze alternative potential solutions.

The report is submitted as partial completion of a series of studies being conducted by the Institute for Telecommunication Sciences (ITS), National Telecommunications and Information Administration (NTIA), for the Office of the Manager, National Communications System (NCS), Technology and Standards Office, Washington, D.C., under Reimbursable Order 5-40033.

Certain commercial names are identified in this report to specify and describe some of the necessary information. Such identification does not imply exclusive recommendation or endorsement of the companies or products by NTIA or NCS. The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official NTIA or NCS position or decision unless designated by other official documentation.

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EXECUTIVE SUMMARY

The Fiber Optics Task Group (FOTG), chaired by the Institute for Telecommunication Sciences and sponsored by the Office of the Manager, National Communications System, was founded under the aegis of the Federal Telecommunications Standards Committee, which is responsible for development of Federal Telecommunications standards. (Federal standards are published by the General Services Administration.) The Task Group was formed, in July 1984, in recognition of numerous and major problems confronting Federal communication managers in on-premises upgrades of obsolescent building wiring and communication systems. Fiber optics was seen as a potential solution for at least some of these problems.

The agenda of the 11 meetings to-date of the FOTG has been devoted to the effort to share, among participants, experiences and requirements of individual agencies and to learn about state-of-the-art products from manufacturers and suppliers, often prior to public announcement. Most agencies active in the FOTG have given presentations on their requirements and their experiences in meeting them, thereby creating a catalytic, interactive environment in which all have benefited. Presentations by industry representatives have been given by technical personnel well versed in systems technology. This has offered agency planners the opportunity to interact directly with these key people and, in several instances, has assisted those agencies engaged in advancing their on-premises communications capability. In similar fashion, industry has acknowledged benefits from learning more about the specific needs of Federal agencies. Presentations and discussions have never been limited to optical fiber implementation, but, in accord with initial goals, emphasis has been placed on potential applications of the technology.

The intent of this report has been to summarize and organize this FOTG learning experience into a format that will assist not only the agencies making the experiment possible, but also other agencies who will face similar on-premises communications upgrades. The espoused goal of developing definitive Federal guidelines for such upgrades has not yet been realized. Content of the report may serve to explain why: not only is fiber optics technology undergoing major evolutionary developments (in standards as well as systems hardware/software) for on-premises applications, but basic building-wiring

architecture, encompassing all types of transmission media (and how they are employed), is being reevaluated and considered for standardization.

The development of guidelines for on-premises upgrades has, in itself, become an evolutionary process as the result of the complexity and scope of interrelated technical areas, all involving new technologies, about which the communication manager must make decisions. This wide scope is reflected in the subjects chosen for the major section headings of this report, no one of which can be treated truly independently in analyzing on-premises upgrade solutions: local area networks (LANs), digital PABXs, optical fiber considerations, and building-wiring distribution systems.

The interrelationship of the four areas is indicated by recent and current experience of agencies participant in the FOTG. For example, within the 2 years since inception of the Task Group, one agency (the Library of Congress; see Section 4.4.1) has delayed selection of a very high-capacity LAN, but has begun installation of a hybrid (optical fiber/twisted-wire pair) building-wiring distribution system designed to be transparent to future LAN and state-of-the-art PABX choices.

Another agency (the USDA, see Section 4.4.2) was unable to get bids on overall optical fiber implementation to meet its needs, and has begun installation of one of the largest LANs to date, employing a coax/broadband CATV approach to handle voice, video, telemetry, and a broad range of data requirements.

Standards development (see Sections 4.3.1 and 4.3.4) is proceeding at a very high level of activity in the areas of building distribution systems, LANs, optical fiber LANs, and optical fiber systems components. This work is underway in numerous working groups, including those of the Electronic Industries Association and the Institute of Electrical and Electronics Engineers, and Accredited Standards Committees of the American National Standards Institute. A particularly concentrated series of efforts is underway pertaining to fiber optics, a standards arena that has received some criticism in past years for moving too slowly. The user who is concerned with keeping abreast of developments in the above several subsets of on-premises communications is advised to follow these standards activities; primary sources are indicated in the report.

On-Premises Digital Communications Upgrades With Emphasis on Fiber Optics

Joseph A. Hull and A. Glenn Hanson[1]

The Federal Telecommunications Standards Committee, chaired by the Office of the Manager, National Communications System, has established a Fiber Optics Task Group, one purpose of which is to develop guidelines for Federal agencies planning to use fiber optics in on-premises communications upgrades. This report describes the key technical elements under consideration in the Task Group. These technical elements include local area networks (LANs), digital private automatic branch exchanges (PABXs), building-wiring distribution architecture, and the application of optical fiber waveguides in the implementation of these on-premises systems. Each of these technical elements is undergoing rapid technological change.

This report develops some fundamental principles necessary to do tradeoff analyses required to make decisions regarding cost versus early technological obsolescence. Some examples of commercially available technology representing the present state of the art are included. Brief summaries of technology readiness, as presented by several key industry representatives to the Fiber Optics Task Group, are provided.

Key words: building-wiring distribution systems; digital PABXs; fiber optics on-premises upgrades; office automation; optical fiber LANs; OSI Reference Model; PBXs

1. INTRODUCTION

In the spring of 1985, it was predicted that American business would invest $141 billion in computers and communications equipment during the calendar year (Modern Office Technology, 1985). Most of this continuing investment will be in on-premises systems that automate routine office chores, boosting productivity and reducing costs. Similar impending investments by the Federal Government involve the systems integration of voice, data, facsimile, video, and other electronically encoded information streams needed to allow central planning, control, management, billing, and maintenance.

The availability of microcomputers and work stations in government agencies has brought about an unprecedented level of distributed files and information requiring electronic means for transportation to and from central

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central files, central applications programs, expensive peripherals, etc., may enhance efficiency and promote cost-effective operation. The competitive environment, however, has promoted incompatibility and lack of interoperability, since suppliers generally desire to capture an agency's business through the required use of proprietary terminals and equipment.

Today's communication manager faces tasks of formidable proportions: industry studies suggest (Irwin, 1982) that 80 percent of an organization's data communications occurs within a common building location. The recognition of these facts has created the burgeoning interest in local area networks (LANs) (Hull, 1985). The remaining 20 percent, however, also presents new challenges to the on-premises system designer/operator, who must plan for interfacing increasingly higher capacity user requirements with equally burgeoning new service offerings of long-haul networks.

The U.S. telecommunication marketplace has changed significantly over the past 3 or 4 years, chiefly as a result of Federal policies to promote competition, with the goals of resultant improved services at lower cost. The need to contain costs for telecommunication services (e.g., lowest cost routing for a particular user requirement) makes it necessary for Federal agencies to use many different long-haul networks, for example, the Public Switched Telephone Network (PSTN), Public Data Networks (PDNs), specialized common carriers, and private networks. For an optimum mix of these telecommunication services (i.e., to meet requirements of performance, cost, and efficiency), it may be necessary for an agency or department to interface with a dozen or more carriers (private communication, Herb Mendelsohn, U.S. Department of Agriculture). In addition to cost-containment objectives, major agency concerns are those of end-to-end compatibility and interoperability.

A significant effort is under way to bring about these needed efficiencies, cost savings, and provision of new services through a new procurement of long-haul Federal telecommunication services (Bushelle, 1986). The goal is to replace the present hardware-based FTS (Federal Telecommunications System) with FTS 2000 (Federal Telecommunications Services).

International standardization bodies have been very active in an attempt to bring about the definition of a limited number of user/network interfaces (Cerni, 1984) that may help considerably in meeting the objectives of end-to-end interoperability and compatibility. A primary example of this is the work on ISDN, the Integrated Services Digital Network (ITS Staff, 1983). The ISDN may lead to a few universal user/network interfaces that will force interoperability through common protocols and power/voltage levels.

Optical fiber communication will play an important role in on-premises networks (Galuszka, 1985) and may eliminate the restrictive 4-kHz transmission link represented by a voice circuit in present local loop, switching, and common-carrier multiplex systems. Common-carrier lightwave transmission systems will provide enormous capacity, available at the user/network interface, compared with present wire-line and microwave relay systems. Some agencies are preparing to take advantage of this potential, in system upgrades, by specifying optical fiber "internal trunking" implementation on the user side of the user/network interface. A very significant by-product of optical fiber technology is the potential solution to well-known electromagnetic interference problems, including crosstalk, electromagnetic pulse (EMP) effects, and lightning-induced noise.

This report will discuss some current competing approaches to on-premises communication systems. These include LANs, on-premises wiring distribution systems, digital private automatic branch exchanges (PABXs), and mixes of these. Emphasis will be placed on several pertinent characteristics of optical fiber transmission media for the support of new on-premises communication systems (or for the upgrade of such systems) in light of this discussion. The report reflects the work of an interagency Task Group formed to study these problem areas, as discussed below.

1.1 Background of the Fiber Optics Task Group

In recognition of the potential benefits of optical fiber distribution systems, from the standpoints both of immunity from electromagnetic interference and of suitability for the transition to higher digital bit rates, the Federal Telecommunications Standards Committee (FTSC), chaired by the Office of the Manager, National Communications System (NCS), established an interagency Fiber Optics Task Group (FTSC/FOTG, hereafter referred to in this report as the FOTG), near the end of fiscal year (FY) 84.

The purpose of the Task Group was to act as a focal point to disseminate information on fiber optics to Federal agencies contemplating on-premises upgrades, to determine broad requirements of Government users, and to approve technical contributions that would encourage Federal users in the transition to optical fiber systems as soon as economically practical, considering the expected long useful life of optical fibers. It was felt necessary to give special guidance to Federal users in these areas because the type of local distribution would affect overall telecommunications quality and could determine the ease of the evolution to newer digital systems, such as Integrated Systems Digital Networks, that would have potential benefits with respect to NSEP (National Security Emergency Preparedness) communications. The cardinal question driving formation of the working group was: what realistic steps could be taken to assist Federal agencies in this technological transition?

Discussions between the Institute for Telecommunication Sciences (ITS), which was asked to assign an individual to chair the FOTG, and NCS, prior to organization of the FOTG, led to an agreement that creation of Federal Standards addressing optical fiber implementation of on-premises distribution might be highly desirable, but was undoubtedly premature because of ongoing technology evolution. In view of this, the primary FOTG goal was established: development of user-oriented, informal Federal guidelines for on-premises upgrades, leaving open for future consideration the possibility of evolution of these guidelines into mandatory Federal Standards.

A fundamental premise upon which formation of the FOTG was based is that a data base adequate for formulation of such guidelines did not exist. Guidelines development requires both an in-depth empirical understanding of user requirements and a considerable knowledge of the technology and how it is applied in various vendor offerings--from the user's vantage point. To further this knowledge and understanding, the following agenda was established for Task Group working meetings:

- exchange information on emerging optical fiber technologies and their potential on-premises applications, including cost vs. performance capabilities;
- collect and discuss requirements from Federal offices on systems that might use fiber optics;
- create a mechanism by which the Government requirements can be conveyed to vendors and to voluntary standards-developing organizations; and
- develop guidelines for use by Federal agencies that wish to consider optical fiber intrafacility systems, keeping in mind cost tradeoffs.

The FOTG, chaired by an ITS staff member, has held a total of eleven 2- or 3-day working meetings, during fiscal years 85 and 86, devoted to fulfilling these goals. To promote information exchange, numerous commercial firms, including carriers and manufacturers/vendors of LANs, PABXs, building-wiring systems, and systems components were invited to give technical presentations to FOTG participants, who represent 13 civil and Department of Defense (DoD) agencies. Emphasis was on state-of-the-art intrafacility systems, and much proprietary, preannouncement information was released to attendees (upon signing of appropriate nondisclosure agreements). The importance of ISDN digital interfacing was stressed by several firms. Although the content of presentations was not limited to systems using fiber optics, emphasis was placed on the growing applications, advantages, and availability of optical transmission.

Many FOTG participants represent agencies that face immediate, major updating of intrafacility communication systems. These include the Library of Congress, Department of Agriculture, Department of Health and Human Resources, and Veterans Administration. Others are analyzing near-term requirements. Attendees have been encouraged to describe individual agency needs, as well as potential solutions offered by vendors. The FOTG thus represents an interactive forum for comparing current, mutual problems and collecting representative agency need requirements.

The FOTG has, as the result of vendor/user interactions, achieved considerable exposure in the private sector, making major potential suppliers more aware of Government requirements, as well as expediting industry information transfer to the agencies. This exposure also applies to the standards arena; the NCS, ITS, and virtually all other FOTG member agencies are active in the FTSC. Many also participate in Working Groups of EIA, the Electronic Industries Association, and U.S. national standards committees accredited by ANSI, the American National Standards Institute. The FOTG chairman has established liaison with these and other domestic standards organizations and has kept the Task Group advised of pertinent activities.

One proposed Federal Standard (pFS) has originated within the FOTG to date: pFS-1070, "Standard Optical Waveguide Fiber Material Classes and

Preferred Sizes," a reformatted version of EIA-458-A.[2] The pFS was prepared by ITS, reviewed by the FOTG, and submitted to the FTSC, which approved it in late FY 1985. Section 4.3.1 below discusses the 1986 status of pFS-1070 in relation to other work on fiber size standardization.

1.2 Purpose and Scope

The purpose of this report is to present background and rationale for the ongoing development of guidelines for Federal agencies that are planning, or engaging in, on-premises upgrade of communication systems and/or building-wiring distribution. Of particular interest in this study is the application of optical fiber communication systems and/or media in such upgrades. The goal is to summarize the basic technologies required in the upgrades, independent of terminal equipment. The intended audience includes Federal communication managers, designers, and agency executives who may wish to keep abreast of state-of-the-art technologies pertinent to their needs and procurement actions.

The scope of the report is necessarily broad in the number of problem areas addressed; the intent of the authors has been to summarize the FOTG learning experience in such a way as to provide useful tools for the on-premises upgrade decision-making process.

1.3 Structure of the Report

The remainder of Section 1 will summarize some options for on-premises upgrade as an introduction to the in-depth discussions of following sections. Section 2 will provide some general material on LANs, a status review of commercially available optical fiber LANs, and a proposed set of questions that Federal agencies may wish to ask LAN vendors. Section 3 presents fundamental principles of digital private automatic branch exchanges (PABXs), a survey of several commercially available PABXs, and a discussion of important items in evaluating such digital PABXs. Section 4 presents a chronology of the application of optical fiber waveguides to telecommunications and LANs, a simple method of evaluating the bandwidth adequacy of optical fiber waveguides based on manufacturers' published performance, some considerations for recommending

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[2] The EIA has officially deleted the "RS" (for "Recommended Standard") prefix from all EIA standards.

the use of optical fiber in an on-premises upgrade, and two examples of ongoing Federal agency upgrades. Section 5 provides an overview of commercially available building distribution (wiring) systems. Section 6 presents a summary of the report and some conclusions on status of technology pertinent to on-premises systems. Sections 7 and 8 contain, respectively, reference and bibliography lists.

1.4 Some Options for On-Premises Upgrade

Communication and data-processing planners are swamped with options for connecting devices and getting information from one point to another. The primary set of options includes the choice of cable or wiring installations for a major building or campus upgrade, or new site implementation. The choice of cabling (twisted-wire pair, coaxial cable, or fiber optics) is critical since installed cable will remain in place for 10 to 15 years or longer, and may prove to be the limiting factor in future office automation developments. The EIA Bulletin 15 (1983), "EIA Engineering Bulletin for Provision of Premises Wiring for One and Two Line Voice Telephone Systems," sets forth requirements to be followed by nontelephone-company personnel for connection to the public telephone network.

Recognizing the need for broader recommendations to meet automated office requirements, a new standards activity has been started under the auspices of EIA TR-41.8 to produce guidance for users who are planning wiring for new buildings or for rewiring old ones. The work will cover the use of both copper and optical fiber in such upgrades, addressing requirements for data and voice. Project approval has been given by EIA and a new ad hoc working group has been formed, designated Building Wiring for Commercial Enterprises. The primary intent of this new on-premises-wiring group is to establish a standard for wiring installations and practices so that equipment vendors can design products that will work with the installed wiring. A draft standard is scheduled for completion by December 1986.

On-premises wiring generally consists of a number of subsystems, such as work area (including wall connectors), horizontal distribution, backbone or riser, campus, and administrative (which includes detailed records of wiring location and how it is identified). Although the specific details of installations will vary with user requirements, and the number and locations of wiring closets (intermediate distribution frames) will vary with building designs, the overall wiring system will generally conform to this subsystem hierarchy.

At present, optical fiber is used primarily in the closet-to-closet, or riser, installations and interbuilding trunks. Agencies may wish, however, to extend the capabilities of their premises wiring by extending the fiber to work areas if the anticipated growth in transmission capacity and distance or the need for protection from electromagnetic interference (EMI) can provide justification for the additional costs. The difference in transmission-line cost between optical fiber and high-quality copper media is frequently lost in the overall installation costs. Currently, the fiber option to the work area is hard to justify because of the cost of terminations (connectors) and the paucity of terminals requiring the wide bandwidth of fiber.

A recent article (Patrick, 1985) summarizes five of the most popular copper cable options:

- Quad-wire: conventional unshielded PABX telephone cable, typically 24- or 26-AWG (American Wire Gage) TWP (twisted-wire pairs);
- EIA-232-C-based unshielded 4-wire, 22-AWG TWP cable;
- RG-58 coaxial cable;
- standard Ethernet™ cable, a specially developed coaxial cable; and
- the IBM Cabling System approach, using IBM Type I (TWP cable containing two shielded 22-AWG pairs) from wiring closets to central processing unit, and Type 2 (same as Type 1, but including four unshielded 22-AWG pairs for telephony) from work area to wiring closet.

Patrick estimated wiring costs based on a distance of 85 ft (26 m) from the workplace to an intermediate distribution frame and 65 ft (20 m) from this intermediate distribution frame to the main distribution frame. The approximate costs, including wire, connectors, and labor, range from $50 to $200 per workplace. If building codes require special insulation such as Teflon™, the estimated cost of the wiring could be tripled. Other assumptions made in this article were: telephone wire between wiring closets or wiring closet to PABX is bundled in 25- to 300-pair cables; labor costs for installation are prorated to the number of stations; and the Ethernet™ costs assume that a main cable is routed through each user (10-ft by 10-ft) area. This paper does not include cost estimates for optical fiber installations.

2. LOCAL AREA NETWORKS

Local area networks (LANs) are among the most publicized developments in the on-premises communications arena. According to draft Federal Standard 1037A, Glossary of Telecommunication Terms, (1986), a LAN is

> A nonpublic telecommunication system, within a specified geographical area, designed to allow a number of independent devices to communicate with each other over a common transmission topology. NOTE 1: LAN's are usually restricted to relatively small geographical areas; e.g., rooms, buildings, or clusters of buildings, and utilize fairly high data rates. NOTE 2: A LAN is not subject to public telecommunications regulations.

This definition agrees well with the following:

> The LAN is distinguished by the area it encompasses; it is geographically limited from a distance of several thousand feet to a few miles and is usually confined to a building or a plant housing a group of buildings. In addition to its local nature, the LAN has substantially higher transmission rates than networks covering large areas. Typical transmission speeds range from 1 Mb/s to 30 Mb/s. LANs do not ordinarily include the services of a common carrier. Most LANs are privately owned and operated, thus avoiding the regulations of the FCC or the State Public Utility Commission. LANs are usually designed to transport data between computers, terminals, and other devices. Some LANs are capable of voice and video signaling as well (Black, 1983).

This section of the report presents those attributes of LANs that a communication manager must know to work through the process of:

1) determining the need for a LAN in the work environment,
2) developing the necessary criteria to determine the type of LAN to request, or interpreting an engineering study commissioned to define communication needs, and
3) determining the appropriate questions to ask LAN vendors.

This section is not designed to be an in-depth tutorial since such information is readily available in recent publications (Black, 1983; Flint, 1983; Cheong and Hirschheim, 1983; FOC/LAN 1984; Stallings, 1985). A helpful document for Federal managers may be the Navy publication CAA-83007, Handbook For Local Area Network Analysis and Selection in Navy Organizations, January 1984. This document was prepared for the Naval Data Automation Command, Washington, DC 20301 by the Federal Computer Performance Evaluation and Simulation Center, Washington, DC 20330.

2.1 Physical Elements of LANs

The physical elements most often used to make up a LAN are listed in Table 1, and their characteristics are summarized below. These physical parts should not be confused with the Physical Layer of the Open Systems Interconnection Reference Model (OSI-RM). (See Section 2.4 below.)

Consideration of the physical elements of a LAN is important to agency planning. This is analogous to having the tracks, stations, and management of a transportation system developed before one selects the trains to be used; the trains and traffic loads may continuously change, but the rights-of-way should remain relatively fixed once they are in place.

2.1.1 Transmission Media

The transmission media for LANs are widely discussed and debated at present. For applications where distributed terminals operate at bit rates of 64 kb/s or less, the drop connections to the terminal would normally utilize twisted-wire pairs (TWP) for economic reasons. In fact, the building cabling systems recommended by both AT&T (1985a) and IBM (1985a) utilize TWP for the individual terminal connections. Extensive work has been done (see for example, IBM, 1985b) in developing the distribution systems for buildings so that future modifications to accommodate LANs of various topologies (or different configurations) can be made without further installation of basic wiring to the office areas. (See Section 5 below.)

Table 1. Physical Elements of LANs

Transmission Media	Control Devices
Twisted-Wire Pair	Central
Coaxial Cable	Distributed
Optical Fiber Cable	
Interface Devices	Management Devices
Passive	Configuration
Active	Monitoring
Access Devices	Gateway/Bridge Devices
Passive	Network
Active	Subnetwork

The shared transmission media for high-speed LANs normally are either coaxial cable or optical fiber. However, the high-bandwidth potential of TWP is undergoing evaluation. Laboratory tests by Hewlett-Packard, begun in the spring of 1986, indicate that Manchester-modulated digital signals can be transmitted over a 300-ft (91-m) distance at a bit rate of 10 Mb/s, using unshielded 24/25 AWG TWP, yielding a BER (bit error ratio[3]) $\leq 10^{-9}$. (Private communication, technical input from Brice Clark, H-P, to EIA ad hoc Working Group TR-41.8, June 2, 1986.) More will be said below about the requirements and advantages of these transmission media.

2.1.2 Interface Devices

The physical interface devices include the wire closets, splice cabinets, connectors, couplers, taps, tees, and other passive means by which the terminal drops, the shared transmission media, and the terminal and control devices are interconnected. In most LAN applications, additional active media access units are employed to permit the sharing of the wideband transmission medium. These active devices depend upon both the type of media access and the virtual or direct circuit to be established between the user interfaces on the network.

2.1.3 Access Devices

Access devices range from simple passive terminal plugs located at convenient positions in the work-area environment to permit the attachment and disconnection of terminals, to sophisticated active integrated-circuit modules that serve as protocol converters, address sensors, and other functional elements.

2.1.4 Control Devices

Control devices are required to do a range of tasks. These include simple flow control between, for example, a work station and printer via the LAN, file servers that permit access to central files by several users, and the multi-tiered constraints on access to files or disks (e.g., departmental utilization

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[3] "Bit error ratio," according to FED-STD-1037A (1986), replaces the previously used term "bit error rate."

of the LAN where central files for the entire agency are served by the LAN). Such control devices may be distributed in each work station or may be centralized at the data processing center. They may take the form of physical devices (e.g., printed circuit boards at the work stations) or software (e.g., that used to check passwords required for access).

2.1.5 Management Devices

Since LANs are generally privately owned, it is very important to have management devices that will allow the initial configuration of the network (i.e., how many users, and where) as well as reconfiguration when new users come on line and former ones leave. In many cases, this configuration and reconfiguration should be done centrally. Monitoring of the network is necessary a) to detect faults and errors, b) to provide other performance features, and c) to provide billing information, if the cost of the network is to be shared among subelements of the agency.

2.1.6 Gateway/Bridge Devices

If it is desirable for terminals on one LAN to communicate with terminals on another LAN, it is necessary to have a gateway or bridge device between the LANs. Gateways are used to communicate among LANs that have different protocols. Therefore, a gateway would be required for general networking of several LANs having different protocols. Communication among LANs that use the same protocols is accomplished via bridges. Thus, several independent LANs of the same type could be connected via bridges, and communication among compatible terminals on separate LANs would then be subnetwork communications insofar as the overall facility network is concerned.

2.2 Characterization of LANs

A primary reason for local area network installation is to provide connectivity at bit rates much higher than that available using private automatic branch exchange switches. Transmission rates on the shared media of the LAN might be characterized as: low (<2 Mb/s); medium (2-10 Mb/s); high (>10 Mb/s). A recent NTIA publication (Glen, 1985) has provided a tutorial on LANs and has summarized the status of LAN standardization activities in the

United States. LANs may be characterized in many ways. One set of characteristics is shown in Table 2.

2.2.1 Bandwidth Sharing

Coaxial cables have been used in cable television distribution systems for several years. Bandwidths of the order of 300 MHz are available on the cable systems. Many TV channels are modulated, each on a different radio frequency (rf) carrier, and transmitted (using intermediate amplifiers as appropriate) to all receivers attached to the cable. Different channels may be selected at the receiver stations by tuning the receiver to the desired rf carrier. Similar techniques are used in broadband LANs using the available CATV cables and components. The rf carriers are modulated with the digital bit stream from the transmitting station and received at the intended receiver

Table 2. Characterization of LANs

Bandwidth Sharing Technique
- Broadband
- Baseband

Topology
- Ring
- Bus
- Star
- Tree

Access Methods
- CSMA/CD (Probabilistic)
- Token-Ring (Deterministic)
- Token-Bus (May be Distributed)
- Polling (Deterministic)
- Hybrid (Probabilistic or Deterministic)

Connections
- Logical Link
- Connectionless Oriented (Datagram)

Other
- Speed
- Distance
- Single or Multiple Function Usage
- Types of Interfaces
- Quality of Service

station. Since the broadband technique does not constrain the channels to digital input signals, anything from teletypewriter to TV signals can be accommodated. The carrier transmission is analog in nature.

Digital pulses may be transmitted directly on the shared transmission media without being modulated onto an rf carrier. The baseband approach permits high bit rates on wideband media such as coaxial cable or fiber optics. The bandwidth is shared by sending the data in short bursts and timesharing the media. It takes about 1 s to transmit 1000 bits at 1200 b/s but only 20 μs if the 1000 bits are transmitted at 50 Mb/s. The time occupancy for a 1000-bit packet can be made very short, and the LAN can transfer a large number of such packets representing many users.

Broadband systems in general share the wide bandwidth of the LAN by creating separate channels, which are essentially analog in nature. Baseband systems in general share the wide bandwidth of the LAN by packetizing digital information and timesharing the wideband medium.

2.2.2 Topology

In a typical on-premises communication system, a LAN can be configured in one of several topologies. Several LANs employing different topologies may be used in a facility to accommodate special requirements of different user groups. Cabling systems are generally planned to permit changes in topology as new requirements arise (IBM, 1985a). The basic configurations, namely ring, bus, star, and tree, are well known and widely discussed in the literature (e.g., FOC/LAN 1984; Flint, 1983; Cheong and Hirschheim, 1983).

Bus topologies are favored for coaxial cable implementations and are the most widely used. Only a few aspects relating to optical fiber implementations and to performance issues will be discussed here. (See Section 4 for additional discussion of optical fiber implementation.) The ring topology allows point-to-point links between nodes. Each node acts as an active repeater; therefore, this topology is favored for high-data-rate optical fiber LANs (Burr and Carpenter, 1984). Star topologies are used in some optical fiber implementations (FILAN, 1984) where star couplers are used passively to distribute the information from one station to n stations. Tree topologies might be thought of as concatenated star topologies. These have been developed for optical fiber implementation (Lee, et al., 1984).

2.2.3 Access Method

The most widely implemented access method at present, and the first to be standardized by the IEEE 802 committee (Glen, 1985), is the carrier sense multiple access/collision detection (CSMA/CD) method. This is the Ethernet™ protocol. In this technique, a station listens before attempting to transmit its message on the shared medium. If there is no signal (carrier) present, the station begins its transmission. The station continues to monitor the shared transmission medium and if it detects its own transmission, it will continue to transmit. If it detects a message other than the one transmitted (or a message that is garbled by a collision with another signal), it ceases to transmit immediately and waits a predetermined time before attempting to transmit, assuming that no signal is present at that time. The actual acquisition of the medium, and thus the transmission time, is probabilistically determined. For many applications this uncertainty, which may be only milliseconds, is quite acceptable. For other applications, such as precision control of machines, this uncertainty is not acceptable and other access methods must be employed.

In token passing, a station can transmit only if it has captured the token (a specific byte or bit pattern). In a token ring, each station receives and regenerates all traffic on the shared medium. If the message has the address of the receive station appended, it is sent to the station's receive system. When a station has a message to transmit, it waits for the token to be received. It captures the token, and thus the medium, and transmits its message. As soon as the message is complete, the station regenerates the token and transmits it on the line to the following stations. Ring LANs are generally unidirectional in transmission, although counter-rotating rings are popular for protecting the LAN from a single point of failure. Since a station captures the shared medium when it removes the token, access to the medium is deterministic. The token access approach may also be used on bus LANs. In this way, a bus may simulate the ring approach by assuring that opportunities for access occur in a sequential manner around the connected stations. A bus may also allow a distributed approach by assigning priorities along with sequencing requirements to the attached stations. In optical fiber implementations of token LANs, it may be desirable to provide an optical bypass for each station to cover those times when one or more stations are not active. This is particularly true for ring configurations where each station serves as an active repeater.

Polling access methods differ from token methods by requiring a central controller to make decisions regarding which station will be allowed to transmit or in what order the stations will transmit. This method requires query and response between the controller and attached stations to determine whether messages are waiting. The method (FILAN, 1984) also allows the controller to determine that the intended receive station is ready to receive a message and whether the receive station has sufficient buffer space to store the message. This access method is also deterministic, since the controller prevents collisions from occurring on the shared medium.

In some intrafacility implementations of multiple LANs that communicate to a central source (as well as among terminals attached to different LANs), it may be necessary to have combinations of the above access methods. The result would be a hybrid system. Such systems would require gateways and may provide either probabilistic or deterministic access in the various subnetworks.

2.2.4 Connections

In most baseband implementations of LANs, a logical connection between the sending and receiving stations is established via addressing protocols attached to the message. This logical link permits the appropriate dialog(s) to be carried out. In some broadband installations, messages are transmitted to the headend or controller of the network where the message is translated to a different carrier frequency and broadcast to all receivers on the network. Only the receiver with the proper address should record the message even though it is available to all. This is one type of datagram service. (Datagram message services do not have a means of acknowledgment from the receiver to the sender; the network is responsible only for transmitting the message.) Store and forward methods may be used in some instances where immediate delivery is not necessary, for example in electronic mail applications.

2.2.5 Other

In some LAN networks, the speed of data transfer, or throughput, is of importance to the user community (e.g., for file or database transfer). In baseband systems, the maximum data rate determines the bit interval time on the network; however, the delays caused by access techniques, depending on the number of stations seeking to use the shared media, may affect the throughput of the network. Mathematical models are available (Stuck and Arthurs, 1985; Rosenthal, 1985) to predict the maximum throughput as a function of the number of users who wish to use the network. A typical Ethernet-type LAN with a bus rate of 10 Mb/s may be limited to 3 Mb/s or less when a significant number of users attempt to access the network at the same time.

Coaxial cable LANs typically require repeaters if the length of the cable exceeds about 1 km. Current multimode optical fiber cables extend this length to between 3 and 5 km. Future single-mode optical fiber cables in LAN applications will probably extend the distances to 30 km. Current optical fiber bus-type LANs are restricted to about eight stations, if present passive taps are used on the shared medium (Hull, 1985). Future single-mode systems using CAD (channel and drop) directional couplers may remove this restriction (Gordon, 1985).

Simple LANs that permit multiple work stations to access a central file, an expensive printer, or other shared resource(s) are generally single-function networks. A network that interconnects multidiscipline applications such as machine shop controls, CAD/CAM (computer aided design/computer aided manufacturing) systems, engineering work stations, teleconferencing, and database or spreadsheet applications would clearly be a multifunction network. Special engineering design may be required to make such multifunction networks serve the needs of a Federal agency.

LANs may be adapted to serve many different types of interfaces, which might include, for example, telephones, computers, video, microprocessors, and printers. Specific tradeoff factors between the use of PABX and LAN technologies for intrapremises communications will be addressed later in this report.

A primary need for LANs has arisen in connection with data communication applications for high-quality transmission. Typical digital voice communication systems (e.g., PABXs) may allow BER of the order of 10^{-3}. In optical fiber LAN systems, typical BER is specified as 10^{-9} and actual systems may provide BER $< 10^{-10}$. Accordingly, LANs may provide much higher quality service than typical PABX systems.

2.3 LAN Applications

The need for LANs comes about when a significant number of terminals or users desire to transmit information at rates much higher than that normally handled by user-premises telephone switches. Such user stations could be connected together with direct transmission media; however, when the number of such stations exceeds a few, the fully connected work station concept becomes impractical. Some current applications of LANs are depicted in Table 3.

2.3.1 Office Automation

Much attention has been given to the development of methods for the interconnection of office terminals and the creation of system architectures that permit the development and growth of such systems (Cypser, 1978; Tanenbaum, 1981). Cypser describes the Systems Network Architecture developed by IBM. Tanenbaum describes other architectures and relates these to the seven-layer Open Systems Interconnection Reference Model. (See Section 2.4 below.)

In its simplest form, office automation develops the means for interconnecting personal computers or workstations. Such interconnection will allow communication by electronic signals among the workstations, and via telecommunication with remote workstations. Interpersonal communications within an office environment may be extended by the use of video services for

Table 3. Applications of LANs

- Office Automation
  - Personal Computers (Workstations)
  - Electronic Mail
  - Video Services
  - Resource Sharing
- Intrafacility Services
  - Remote Batch
  - Transaction Applications
  - Interactive/Conversational
  - Message Switching
  - Bulk Data Transfer
  - Video Conferencing
  - Videotex
  - Surveillance
  - Telemetry

teleconferencing and/or image transfer. In the future, optical recording of library resources with the capability of remote access may become a reality (see Sec. 4.4.1 below). Another important reason for employing LANs in an office environment is to permit all of the work stations to share expensive resources such as laser printers or hard disks. Derfler (1985) discusses the specific problems associated with small offices that use personal computers. These office automation applications apply readily to small offices or departments of a Government complex. However, many agencies prefer to plan such automation approaches from a central vantage point and thus assure more interoperability and accessibility.

2.3.2 Intrafacility Services

The intrafacility services identified in Table 3 cover an extremely wide range of information transfer requirements. The remote batch requirements may result from the need to transmit aggregate data from several workstations (say at the end of a workday) for processing or scientific problem-solving on large central computers. Transaction applications may be represented where large data bases are interrogated by many users. An advantage of having several users share common files or working documents is the ability to work in an interactive and conversational way (e.g., in the editing of a report or the preparation of a document). Message switching may add the convenience of message storing and retrieval. This is similar to electronic mail. Bulk data transfer from large computer files to peripherals may lead to very high data rate requirements. For example, Task Group X3T9.5 of ASC X3[4] is developing a set of standards on the Fiber Data Distribution Interface (FDDI) that specifies operation at 100 Mb/s or greater (Joshi and Iyer, 1984). Video conferencing can require data rates from 56/64 kb/s (stop-scan voice channel bandwidths) to 90 Mb/s (full-motion video). Videotex generally requires the transmission of still images and text, and therefore the bandwidth requirements can be adapted to voice-channel transmission.

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[4] Accredited Standards Committee X3, "Information Processing Systems", is an ANSI-accredited committee.

Surveillance implies remote video transmission requirements. For full motion surveillance the bandwidth requirements range from a few megahertz (analog) to 90 Mb/s for digital color TV. Telemetry applications generally refer to alarms, meter reading, etc. These require only narrow bandwidths from 75 to 300 Hz. Many of these intrafacility services may share the bandwidth of a LAN and save the redundant wiring that would otherwise be necessary.

2.4 OSI Architecture for LANs

One of the major features of a well-designed LAN is the ability to interconnect a wide variety of dissimilar equipment. This attribute is known as open systems interconnection. Two international standards organizations, the International Telegraph and Telephone Consultative Committee (CCITT) and the International Organization for Standardization (ISO), have developed detailed documentation on an Open Systems Interconnection Reference Model (CCITT, 1985a; ISO, 1983) that defines seven layers, as indicated in Figure 1. The OSI-RM provides a systematic framework for the development of services and protocols necessary to effect communications. This model represents an architecture by which data application programs can communicate (interact) via common-carrier-provided systems in an internationally recognized way.

The principles that ISO used to define the seven layers of the OSI-RM architecture include the following (Tanenbaum, 1981):

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

Communication systems designed in accordance with this layered approach consist of a set of functional processes which, taken together, provide the application or user with the means to conduct an interprocess dialog over

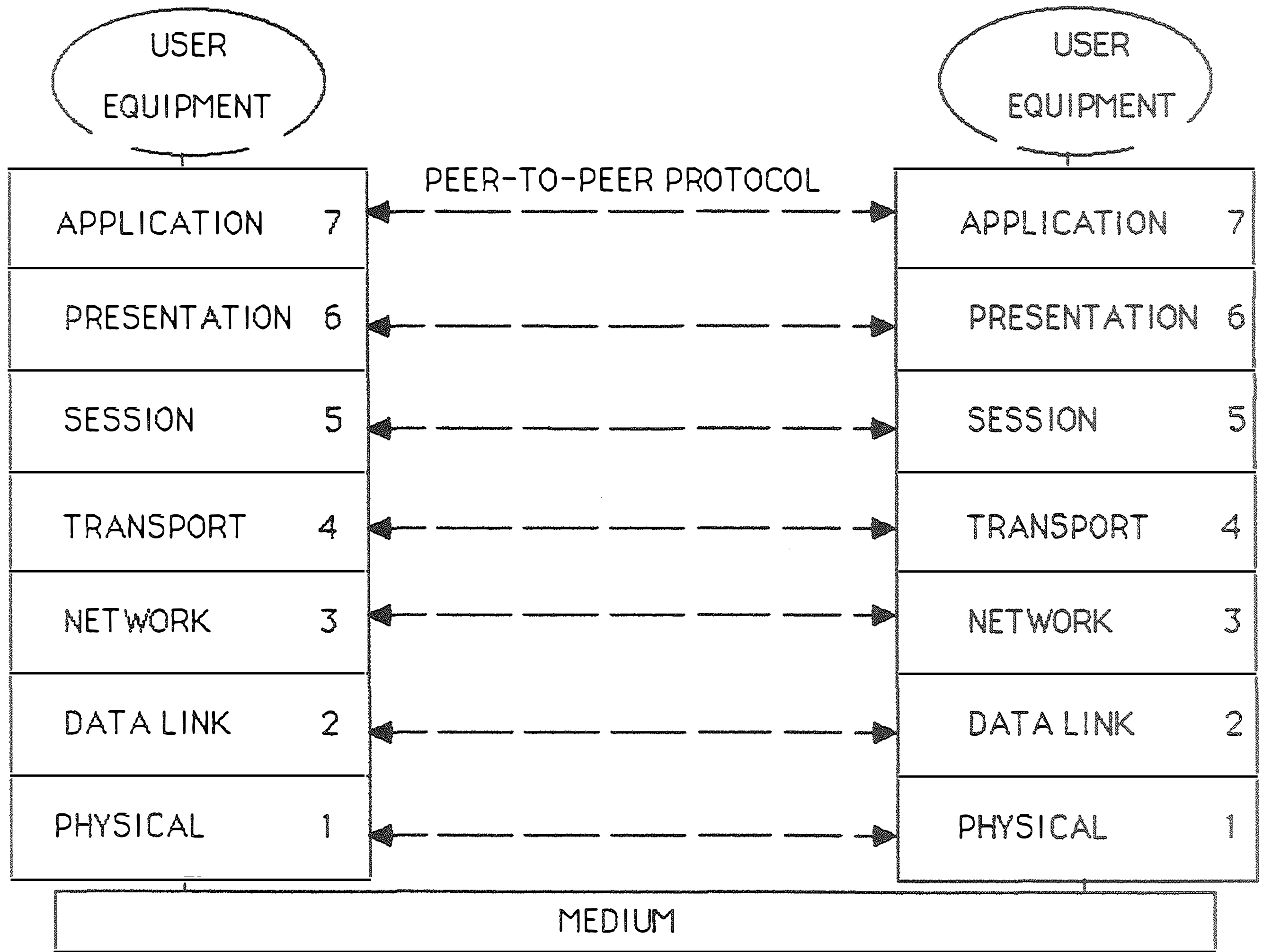

Figure 1. Open Systems Interconnection Reference Model.

distance. This layered architecture embodies structure, symmetry, and peer protocols.

The structure is defined in a way that collects similar or related functions together to form a layer. The set or subset of this functionality invoked for a particular instance of communication is called an entity. Layers are defined so that there is a clear interface between them. This allows a layer to be redesigned without redesigning the entire system.

The OSI-RM architecture requires that for each functional entity invoked in one system there is a functional counterpart in the connected system. Data and control can flow (architecturally) "down" one system and "up" the other system with the assurance that the functionality to handle the dialog will be present.

The dialog between peer entities takes place by using a set of rules governing the exchange. The set of rules is embodied in a protocol. Because the dialog controlled by the protocol is between "peer" entities, it is called a peer protocol.

Each layer performs a set of functions necessary to provide a defined set of services to the layer above it. A layer, in turn, requests and utilizes the services of the layer below it. Each layer isolates the implementation details of the layers that exist below it from the layers above it. The isolation of layers permits the characteristics of a layer to change without impacting the rest of the model, assuming that the services provided and requested do not change. Each layer has interfaces with the layer below and the layer above. Service requests, data, and other parameters and control information are transferred across these interfaces. Each layer also has a peer-to-peer protocol relationship with the corresponding layer in a connected system.

The seven layers of the OSI architecture have been given names that are indicative of the functions performed at that layer. These are defined by Tanenbaum (1981) as follows:

Application Layer: (7) Directly serves the end-user by providing the distributed information services to support the application process, application management, and system management.

Presentation Layer: (6) Provides the services to allow the application process to interpret the meaning of the information exchanged. Translation and formatting of information is performed at this layer.

Session Layer: (5) Supports the dialog between cooperating entities, binding and unbinding them into a communication relationship.

Transport Layer: (4) Provides end-to-end control and information interchange with the level of reliability that is needed for the application. The services provided to the upper layers are independent of the underlying network implementations.

Network Layer: (3) Provides the means to establish, maintain, and terminate switched connections between end systems. Included are addressing and routing functions. An additional global sublayer may also be provided to ensure a consistent quality of service on connections traversing more than one network. The interface between this layer and the transport layer provides services that are independent of the underlying media.

Data Link Layer: (2) Provides the synchronization and error control for the information transmitted over a physical link.

Physical Layer: (1) Provides the electrical, mechanical, functional, and procedural characteristics to activate, maintain, and deactivate the physical connection.

Local area networks may be designed to conform to the OSI-RM. In fact, one of the first decisions of the IEEE 802 standards committee was to work in terms of the OSI-RM (Myers, 1985). The two lower layers of the OSI-RM map onto three layers of the local area network reference model (LAN-RM) as shown in Figure 2 (from Meyers, 1985). Levels 3 through 7 of the OSI-RM are outside the scope of the LAN model except to the degree that the logical link control layer has to interface to the network layer (symbolized by the vertical bars at the top of the LAN model). Much work has been done by this committee as well as by the ASC Task Group X3T9.5 to develop sophisticated standards (Glen, 1985) for LANs based on the principles of the OSI-RM.

Two types of specifications are provided by the standards developed in accordance with the OSI-RM, namely: service specifications and layer specifications. The first specifies the services provided by a layer to the next higher layer. The second specification describes a way of implementing a particular layer. In the IEEE 802 standards, the logical link control is common to all of

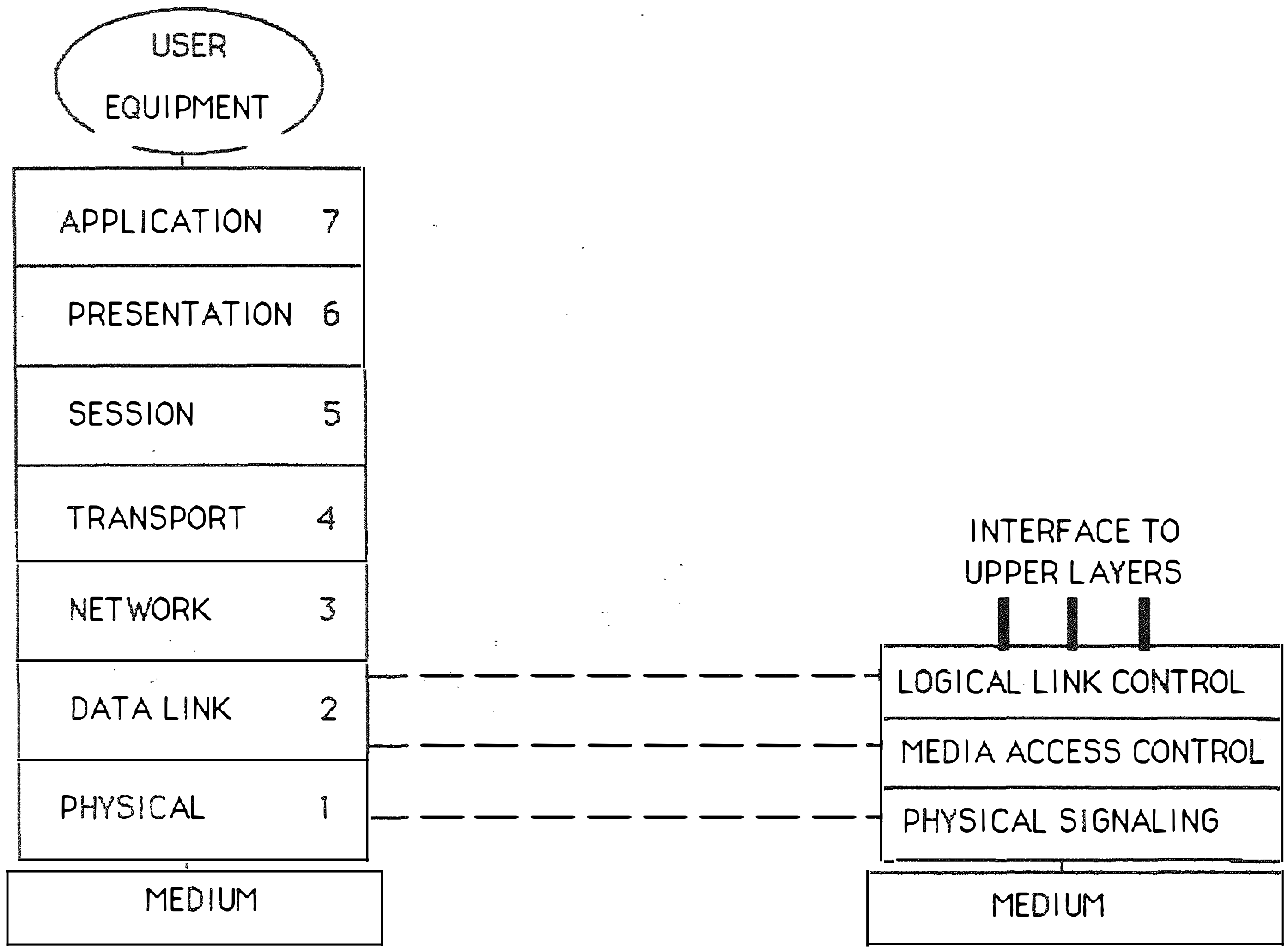

Figure 2. OSI-RM mapping to LAN-RM.

the standards, but at the media access control and physical signaling layers, two general approaches encompassing three methods are provided. The two approaches are CSMA/CD (carrier-sense multiple access with collision detection) and token passing. Token passing includes both token bus and token ring techniques. At the media access layer, means are specified for accessing three media: twisted-wire pair, coaxial cable, and optical fiber.

Local area networks developed in conformance with these standards should permit the interconnection, and promote the interoperability, of a wide set of user equipment. Since the ISDN interface standards are also developed in conformance with the OSI-RM, the framework for interconnecting LANs via the long-haul networks of the future should be facilitated.

2.5 Nontechnical LAN Characteristics

Several nontechnical characteristics of LANs, summarized in the following sections, are important to consider when choosing a vendor. This list of nontechnical characteristics is not exhaustive, but it may serve to initiate planning and discussion. The extent to which these characteristics are important will vary from agency to agency.

2.5.1 Reliability and Flexibility

The reliability of a large LAN used to support an entire complex is particularly important since any downtime results in disruption of normal work flow, and may also result in loss of critical data. Physical moves and the reorganization of working units make the flexibility or reconstitution of the LAN and its work stations a priority consideration.

2.5.2 Vendor Support

Vendor support to assist in maintenance, restructuring, and upgrade of the LAN is important. Training of the agency personnel who must manage the LAN, as well as the users who must adapt to the special constraints and options of the LAN, should be part of the nontechnical requirements of the procurement process. The ability of the LAN product to be vendor-independent, especially for the types of work stations and equipment to be attached, may avoid the commitment of an agency to any one vendor's products. The reputation and stability of the LAN vendor is an important consideration for large installations.

2.5.3 Management and Control

Central control and management is an essential requirement for LANs in a large building complex or agency-wide system. Central control, accounting, fault-finding and fixing procedures, maintenance testing, record keeping, repair of equipment, and other procedures should be possible from a central point where the LAN can be managed and controlled. A vendor/agency policy for extending the capabilities of the LAN should be developed at the outset. Documentation from the vendor regarding the LAN--its capabilities, its fault-location procedures, repair, etc.--as well as appropriate logs and records to be kept by the agency, should be secured and maintained by the control personnel. User friendliness of the interfaces will greatly facilitate adding new users and equipment to the system as needs grow.

2.5.4 Modular Growth

Most agencies cannot precisely predict future needs, even 5 years into the future. Thus, provision for extending the LAN through modular growth is important. Possible extensions and resultant installation requirements should be considered at the time of purchase of an on-premises LAN upgrade. This growth factor coupled with the potential changes inherent in technological evolution make it necessary to consider the reputation and stability of the vendor.

2.5.5 Security and Integrity

The security and integrity of the LAN system are of great concern when several departments such as personnel, payroll, accounting, engineering, data processing, and others share the same LAN resource. Particular files must be protected from access by unauthorized users, who may be authorized network users, to assure interdepartmental privacy and integrity.

2.6 Commercial Optical Fiber LANs

It is beyond the scope of this report to document all commercial developments in optical fiber LANs. However, a worldwide survey (Bergman, 1984) of commercially available optical fiber LANs indicated that more than 50 products were available. The countries surveyed were the United States, Canada, England, France, West Germany, Italy, and Japan. The LANs available in the United States are shown in Table 4. In addition, at the time of this survey, several companies were developing optical fiber LANs, as shown in Table 5.

Another survey (Horwitt, 1984) that was not restricted to optical fiber LANs shows only nine companies that advertise fiber implementation. In a more recent survey by Datapro Research Corporation (Datapro, 1985), 35 companies responded to requests for information on LAN systems that are capable of serving many types of end-user equipment. These companies offered 52 LAN systems. Of these 52 systems, there were 12 offerings that can utilize optical fiber media in the backbone of the network. These optical fiber LANs were available from nine of the companies. These surveys indicate that much of the expected growth of optical fiber LANs has not materialized as of this writing.

A paper by Finley (1984) provides insight into the performance and technology comparisons of several competing optical fiber LANs. He concludes, in part:

> Optical-fiber technology for LAN applications is maturing rapidly and there are now a number of commercial optical fiber LANs available. Active-ring topologies using token-passing access methods and having a very high degree of fault tolerance are in the forefront, with several intriguing alternatives, such as Hubnet and D-Net, whose influences are yet to be seen. Passive and active star-coupled CSMA/CD bus configurations are also available, which are useful if compatibility with Ethernet-like components is desired. Several high-speed buses have been implemented.

The potential of future high-speed buses is illustrated in a paper by Bergman and Eng (1984), which reports a laboratory demonstration of an optical fiber ring LAN that permits the simultaneous transport of packet and real-time traffic at multigigabit data rates. The concept reported here is feasible only at gigabit data rates. Other attributes include low-gigabit hardware complexity (within the state of the art), high channel efficiency, well-matched interfaces for low-speed user systems, and the support of subnetworks and data storage applications.

Local area networks are emerging at a rapid pace at this time. It does not seem reasonable to make recommendations to Federal agencies on any of the topologies, access methods, media, or other technological characteristics.

Table 4. Optical Fiber Local Area Networks in the United States

Name/Company	Access Method	Topology	Nodes
Fibernet II/ Xerox	CSMA/CD	Active Star	1000
FO Net 1/ Codenoll Ungerman-Bass Siecor	CSMA/CD	Passive Star	1000
Net 100/ Siecor	not avail.	Point to Point	not avail.
Two-Way Bus/ Bell Labs Albanese	not avail.	Loop	13
D-Net/ TRW	Locomotive	Open Ring/Star Bus	not avail.
NASA-ITT	TDMA	Passive Star	16
API Net/ Am. Photonics	Circuit Switch	Active Star	34
Pro NET/ Proteon	Token	Ring	255
Agora/ Aetna Telecom.	Dynamic TDM	Star	>1000
RCA	Token	Hybrid Star	not avail.
Leeds and Northrup	Token	Ring	480
Mitre Net	not avail.	Point to Point	not avail.
Mitre Corp.	not avail.	Bus	not avail.
LANFOTS/ Martin Marietta	TDM	Fragmented Star	64
Novanet/ L. Livermore Labs	not avail.	Passive Star	not avail.
Illinet	Token	Ring	not avail.
Foxring/ Tandem	Token	Ring	not avail.
S/Net/ Bell Labs	not avail.	Bus	225
Unilan Fiber Optics/Applitek	UniLINK	Tree/Bus	not avail.
Desnet/ Destek Group	CSMA/CA	Bus	350
Ringnet/ Prime Computer	Token	Ring	not avail.

Table 5. Optical Fiber Local Area Networks under Development in the United States

Name/Company	Access Method	Topology	Nodes
Systems Dev. Corp. Burroughs	CSMA	Bus or Ring	---
Proteon	Token	Ring	---
Data Pipe/ Network Systems	TDM (self timing)	Folded Bus	256
Agora Aetna Telecom.	Dynamic TDM	Star	1000
IBM	Token	Ring	200
Wangnet/ Wang Labs	Reported to be developing optical fiber version of Wangnet		

By the time this report is available to the agencies, there will undoubtedly be new offerings. The IBM Token Ring announcement (Nelson-Rowe, 1985) in mid-October 1985 was expected to set the de facto standard for the industry. This announcement, however, did not include provision for optical fiber, and the LAN will support only personal computers at this time. (See Section 5.3 below for updating on IBM's 1986 announcement on fiber implementation.) The IBM Token Ring is supported by the IBM Cabling System. Third-party developers will most likely utilize the interface definitions for this token ring to adapt it to many needs (Mier, 1986).

Much work is under way by AT&T Information Systems to adapt PDS, the Premises Distribution System (AT&T, 1985b) to support the modern office environment. One approach is their AT&T Information Systems Network (ISN), which is a centralized-bus architecture using a short bus, consisting of backplane wiring in a cabinet to provide contention resolution (Acampora and Hluchyj, 1984). The PDS integrates the capabilities of LANs and PABXs to provide connectivity for both on-premises and interpremises communications.

For agencies planning large LAN implementations, current documentation and knowledge of commercially available local area network systems are required.

One can keep abreast through a subscription service as well as through the normal process of requiring vendors to submit complete documentation on products that they offer. The following list of questions (after Black, 1983), edited and revised by the FOTG, may be helpful in evaluating LAN products for any application. This list is provided to assist Federal agencies in establishing a technical working relationship with vendors or consultants.

- What is the user base (how many networks have been installed)? Can users be reached for comment?
- Given that many LANs are new, with limited numbers of users, what are the results of Beta test sites (i.e., customer prototyping the LAN)?
- How many stations are supported?
- What types of stations are supported (word processors, printers, etc.)?
- What types of software packages or functions are available?
- Are security features such as encryption and password log-ons available?
- What are the performance statistics, given varying stations and varying traffic loads?
- What is the cost and effort of adding stations to the network?
- Does the LAN use layered protocols?
- Are widely implemented U.S. standards used in the architecture (e.g., EIA-232-C, EIA-232-D, EIA-449)?
- Does the vendor have products or plans to support the OSI seven-layer model?
- What are the fail-safe and backup capabilities?
- Is the net subject to single-point failure?
- What is the maximum distance allowed, and what are the costs involved in extending cable distances?
- What is the maximum drop length of work stations to backbone cable, and does this fit with the user's building or plant layout?
- Is the network transparent to other vendors' products? If not, which vendor products are supported, and at what cost?
- What is the network protocol?

- Is the network broadband or baseband?
- What is the service/maintenance plan?
- Is documentation adequate?
- Does the vendor have a realistic and attractive plan to use the LAN for office automation?
- Does the vendor plan to integrate its LAN with other communication products? If so, will the network be transparent to the user?
- What is the cost of the network?

3. DIGITAL PRIVATE AUTOMATIC BRANCH EXCHANGES

Any planning of major on-premises communications upgrades will require the consideration of digital PABXs. The PABX technology is undergoing the same rapid evolution as that discussed previously for LANs. The same office-automation driving force has fueled the development of digital data-switching PABXs and has provided a stimulus to develop integrated data/voice PABXs. The increased competition in customer-premises equipment since divestiture is reflected by the multivendor products available.

The evolution of PABX technology is inherently linked to the transition from analog to digital switching. Fundamentally, digital switching differs from analog switching in that the channels to be switched carry only binary bits. These bit streams comprise digital data and/or some form of digitized voice, typically pulse-code modulated. This does not mean that all PABXs handle the bit streams in the same way or that there is a high degree of compatibility. On the contrary, digital PABXs generally require the use of proprietary telephone terminals to assure operation of the proper functions and features offered by the on-premises and/or interpremises switches. It is beyond the scope of this report to analyze the many variations among currently competitive offerings. This section offers some fundamental principles of PABXs and provides references for those readers interested in further information.

3.1 Introduction

On-premises switching has been accomplished by analog PABXs and by Centrex-CO (central office) switches for many years. The circuit to be switched consisted of a 3.2-kHz bandwidth analog voice signal or digital data signals transmitted as quasi-analog tones generated by a modem. The present most popular upper limit of digital input bit rate over the public switched telephone network using modems to generate quasi-analog signals is 9.6 kb/s, although modems that operate to 19.2 kb/s are available. The bandwidth of the PABX channels is still the nominal 3 kHz.

FED STD 1037A (1986), Glossary of Telecommunication Terms, defines a PBX[5] (and PABX) as:

> PBX, Abbreviation for private branch exchange. 1. A private telecommunications exchange that usually includes access to the public switched network. 2. A switch serving a selected group of users and subordinate to a higher level military establishment switch. 3. A private telephone switchboard that provides dial service on a subscriber's premises and serves only those stations with local and trunked communications. NOTE: A PBX operates with only a manual switchboard; a private automatic exchange (PAX) does not have a switchboard; a private automatic branch exchange (PABX) may or may not have a switchboard.

The basic architecture of digital PABXs is shown in Figure 3. The three functional elements required to connect lines to lines, lines to trunks, and trunks to trunks are the terminal interface unit, the switch matrix, and a control unit. Practical digital PABXs are much more complex since they must provide additional functions and features to support the growing sophistication of office environments. For example, service circuits are required to provide supervision and signaling.

The basic switching functions required to provide the connectivity, alluded to above, are supervision, control, signaling, and provision of network paths (Keiser and Strange, 1985). The basic switching environment to be discussed here includes only circuit switching and not the virtual circuit environment represented by packet-switched networks. The following discussion can apply to central office switches as well as PABXs in terms of the switching functions that are performed.

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[5] There is a growing trend in the literature to revert to use of the term "PBX" for designation of all switches because all current models are automatic; i.e., inclusion of the "A" is considered by many to be unnecessary.

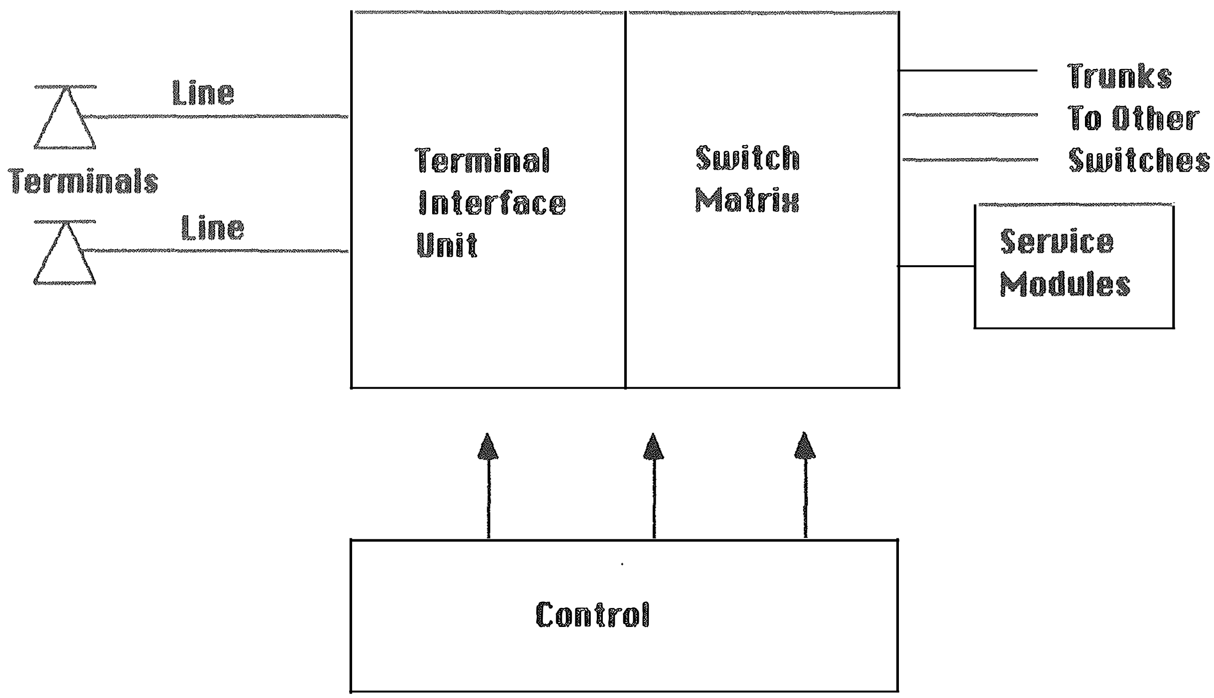

Figure 3. Architecture of digital PABXs.

3.1.1 Supervision

Supervision involves recognition of the busy or idle condition of circuits (lines and trunks) connected to the switching system. A transition from idle state to busy state is recognized as a demand for service requiring response by the switching system. The inverse transition from busy to idle is recognized as a disconnect-requiring action by the switching system to restore all associated connections to idle state. This function involves all of the functional elements of the switch as represented in Figure 3.

3.1.2 Control

The control function must first recognize and then respond to a request for service. The system control then prepares the system to receive the digits of the called numbers (address) and returns dial tone. The address digits are interpreted by the control function to determine the equipment terminations required to set up the call. The control function then examines the availability of a path through the switching system network to the equipment termination representing the destination. If a path is not found, the caller is informed by a busy signal (tone). If a path is found, the system control establishes a path to the called line or to a trunk termination to anotherswitching system. Ringing is applied to the called line. When the called line is answered, causing a transition from idle to busy state, ringing is discontinued. When the transaction is completed over the connected circuit, transitions from busy state to idle state are detected, and system control causes the network path to be released.

Current state-of-the-art PABXs are designed around stored program common-control systems. In these systems, both the generic operating program and the local data base information are stored in memory. These state-of-the-art concepts utilize different design technologies with different characteristics and capabilities. All such common control systems perform substantially the same functions described here.

In the actual physical hardware of these systems, considerable heat is concentrated into small areas represented by read-only-memory and random-access-memory chips, requiring environmental controls to maximize the service life of components.

3.1.3 Signaling

Supervisory signaling transmits the busy or idle state of lines or trunks to the control functional element. Address signaling is the transmission of the digits of the called station to a switching system or from one switching system to another. Call progress signals are transmitted to the caller to provide information relative to establishment of a connection through the telephone network.

The PABX signaling is also referred to as customer line signaling or interoffice signaling. Interoffice signaling may be either in-channel or common-channel signaling. In-channel signaling uses frequencies or time slots within the bandwidth of the information channel. Common-channel signaling transmits signaling information for a group of channels by encoding the information and transmitting it over a separate channel, using digital time-division techniques.

3.1.4 Network Paths

Each switching system has a network of paths used to connect lines to lines, trunks to lines, and trunks to trunks. The switching system also provides access to peripheral equipment such as tone generators and digit receivers. Digital signal paths can be separated from each other by either space or time.

3.2 Digital Switching

Digital switching has technical, economic, and operational advantages over analog switching. The switching speeds are generally faster and the transmission quality is improved. Signal processing is less complex and more accurate. When the digital switch is combined with digital transmission systems, there are advantages of cost and transmission quality. Digital PABXs have the advantages of the reduction in floor space requirements, efficient use of distributed control, increased line and trunk capacities, and reduced maintenance requirements. New services may be provided to the customer via these advanced technology systems. Administration is simplified with the interfacing of computerized service-order procedures.

The revolutionary advances in solid-state technology in the last decade have radically reduced the cost of digital switching systems. The development of large- and very-large-scale integrated circuits has enabled powerful microprocessors and coder/decoders to be designed. The cost of semiconductor memories has continued to drop as larger and larger memories are placed on single chips. These advances in solid-state technology, and the radical decrease in costs of such devices, is the primary factor in the development of cost-effective digital switching systems.

3.2.1 PABX Classification

For convenience of categorization, four generations may be identified at present. One breakout of the four generations is shown in Table 6 (Glen, 1985). Note that digital PABXs may be considered to be in both third and fourth generations. Most third-generation switches fail the test as a fourth-generation switch in the area of fully distributed control and switching.

To switch analog voice using the digital switches represented in the third- and fourth-generation PABXs, it is necessary to convert the voice to a digital format. In third generation switches, this may be done at the line card (terminal interface) of the switch or at the telephone instrument. The cost of the codecs (voice encoder/decoder) used to do this A/D (analog-to-digital) and D/A (digital-to-analog) conversion influences the conversion location. Early versions used analog transmission to the PABX cabinet and then concentrators to reduce the number of codecs required. When the switch was designed to interface with the standard T1 (1.544 Mb/s) trunks, the channel concentration was 24:1 before the A/D conversion. Other codecs used lower concentration ratios such as 3:1 or 4:1. However, for automated office applications, it is desirable to do the A/D conversion at the telephone instrument so that the line can be shared directly with data.

Thus, in many third-generation switches, a single physical input for both voice and data is available at the telephone instrument. The digitized voice signal is generally in a format that can be accepted at the line card of the switch, moved through the switch to the line card on the called side, and then moved to the codec at the called set. The data signal is mapped into a bit stream that can be handled in the same way, and voice and data are multiplexed together between set and card. (There is no assurance that any two PABXs use the same mapping technique.) At the line card, one physical port can be used

Table 6. PABX Generations

Generation	Control	Switching	Loops
First	Mechanical	Analog	Analog
Second	Stored Program	Analog	Analog
Third	Stored Program	Digital	Digital or Analog
Fourth	Distributed/ Stored Program	Distributed/ Digital	Digital

for both voice and data, with time-division multiplexing separating the signals for switching to different destinations.

3.2.2 Distributed Digital PABX

Fourth-generation PABXs provide distributed control as well as distributed switching. This is particularly useful for multi-tenant buildings or for multiple departments of a single agency that occupy different floors or different buildings. The distributed control allows for separate billing, specific feature allocations, and local switching, for example. All such remote (satellite) units are interconnected so that any set can talk to any other set on the system without the need to utilize the public switched telephone network (end office).

A simplified diagram of a distributed PABX system is shown in Figure 4. In this hierarchical system, the main PABX interfaces with the "outside world" and provides the connectivity for network services as well as centralized attendant functions. The satellite units may serve a specific building, department, or other operational unit and provide connectivity via the main PABX to all other stations within the overall complex. If the satellite units are located at long distances from the main PABX, the interconnections may require dedicated tie lines.

Figure 5 shows a block diagram that is representative of the AT&T System 85 communications processor switch (AT&T-IS, 1983). The System 85 is representative of a fourth generation PABX that permits distributed switching/stored program control, integrated voice/data on single lines,

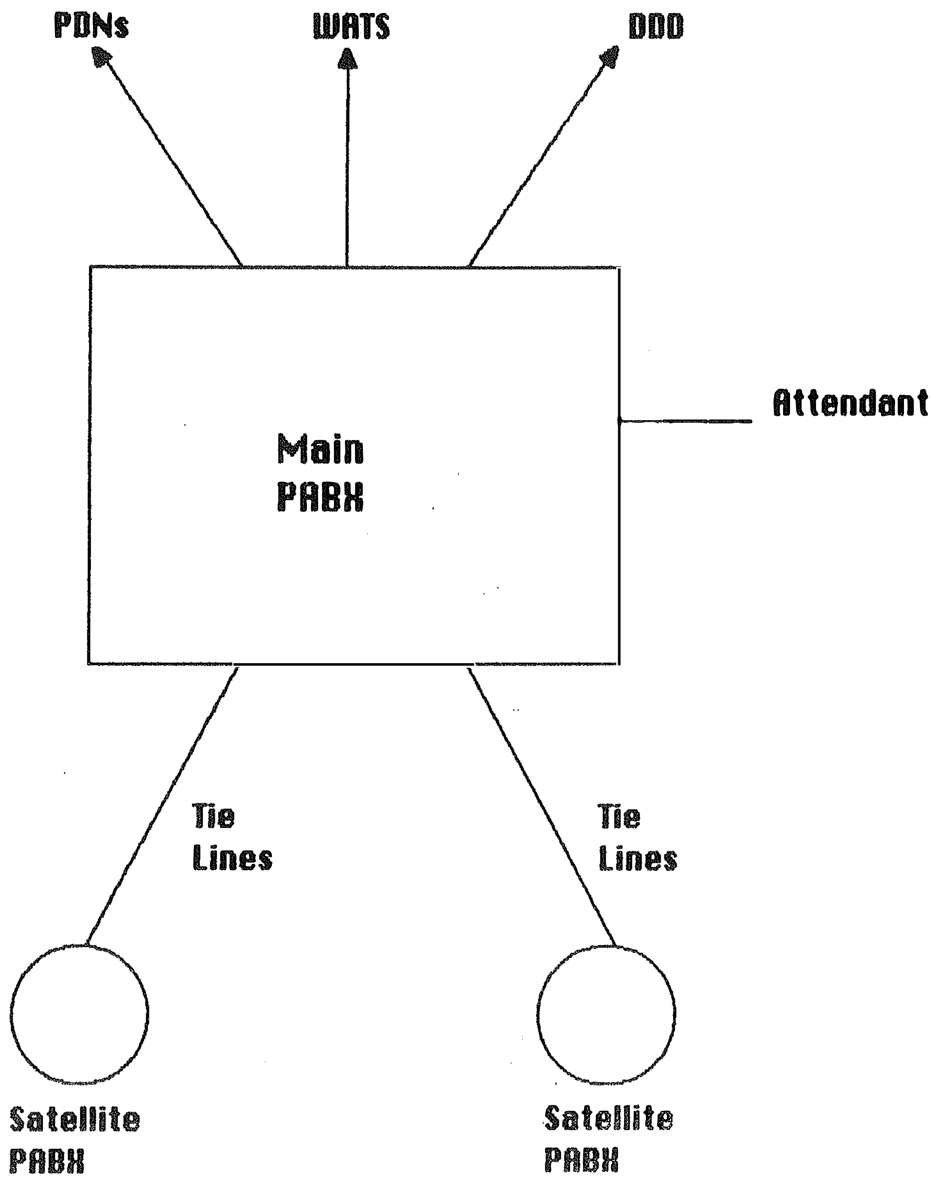

Figure 4. Block diagram of distributed PABX.

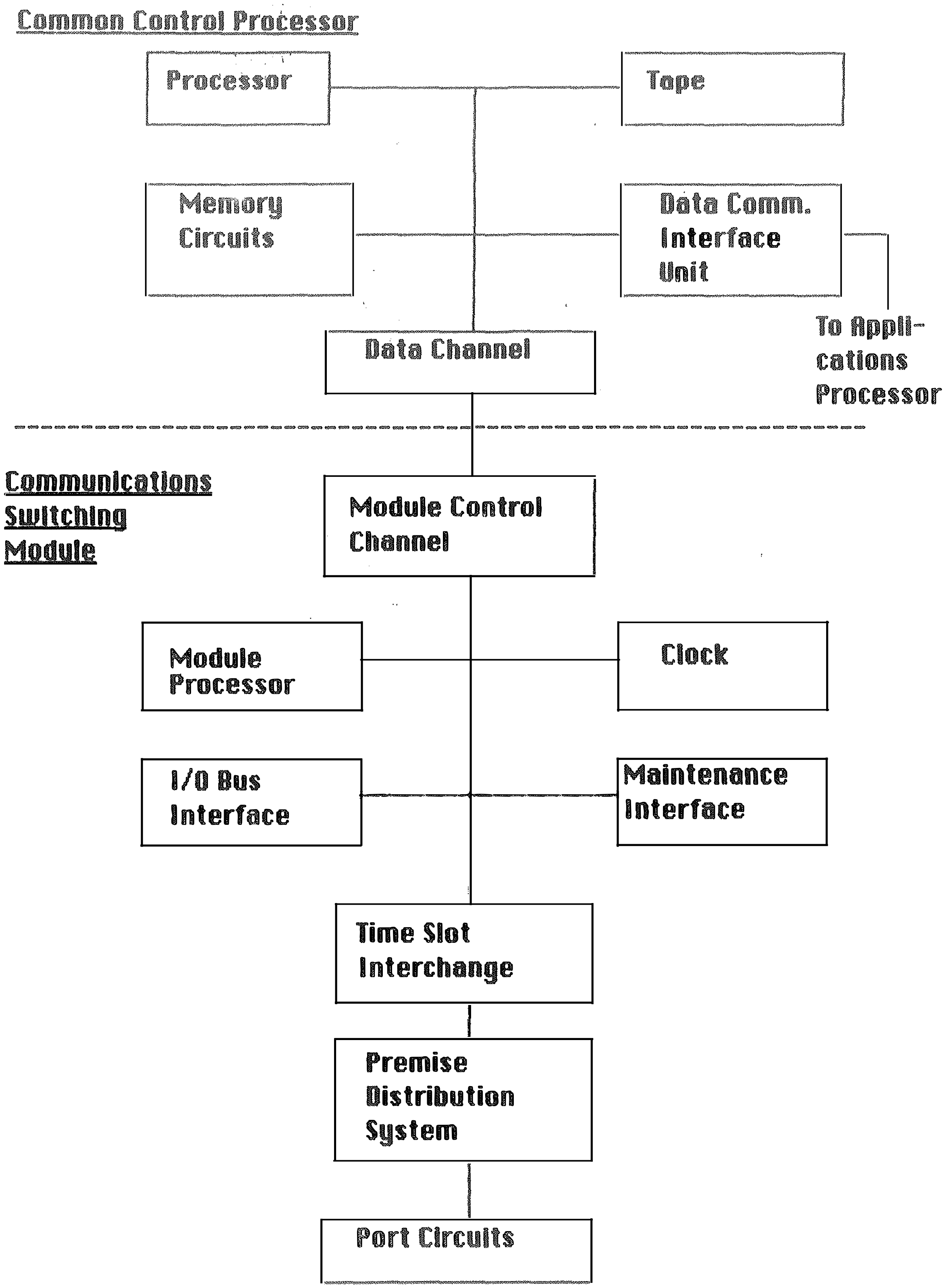

Figure 5. System 85 communications processor.

flexibility, sophisticated features and services, and extensive growth potential. Large-scale integrated circuit technology is utilized throughout the system. The primary elements of this system are the common control processor and the communication switching module. A digital communication protocol is used to multiplex digitized voice and high-speed data from a digital work module.

The common control processor consists of a proprietary (301C) processor, a memory system, a tape system, a data communications interface unit, and input/output channels. The call processor performs the highest level of call processing, administrative, and maintenance functions. It acts as the master controller for the distributed microprocessors controlling specific functions within the switching module. The tape cartridge unit is used to back up system programs and data information.

The data communications interface unit (DCIU) provides a packet-switched interface between the control processor and applications processors. For example, the DCIU passes the called station number from the communications processor to the applications processor on calls forwarded to a message center. This allows the applications processor automatically to display the called party's information (messages, itinerary, etc.) to the appropriate message attendant.

The communications switching module consists of the module control complex, the time slot interchange (TSI), and port facilities to interface to extensions, terminals, and trunks. The System 85 digital network uses T-carrier-compatible pulse-code modulation (PCM) in transmitting voice signals. The TSI is a programmable unit that performs intra-module switching by placing each active port's voice and data samples on a time slot in a time-multiplexed channel. The TSI establishes connections between ports by rearranging the order of time slots in the channel. The TSI is directed by the module control processor.

The module processor communicates with the 301C main processor over the data channel. It increases the 301C's capacity by off-loading real-time, intensive switching functions. For example, dial tones are provided to requesting terminals, and the module processor receives and acts upon dialed digits. It handles both incoming and outgoing service requests.

Port circuits are interface circuits connecting the system to terminal equipment and other circuits such as central-office trunks.

The software structure is designed to complement the distributed control architecture and is partitioned into a hierarchy of layers. The lower layers of software are permanently stored in nonvolatile read-only memory (ROM). This firmware controls microprocessors dedicated to specific, real time, intensive tasks such as port scanning or data line control. The middle layers of the software manage the operation of many dedicated microprocessors at the lower layers to form the logical building blocks of the stored-program controlled communication system. The upper layers of the software structure operate primarily with the 301C control processor to provide the sophisticated features and functions visible to the user.

The applications processors couple to the 301C processor through the DCIU to provide integrated voice/data services. Examples of these services are message center and call detail recording and reporting.

The integrated on-premises network supported by the integrated voice/data switch described above is designed to provide present and future information network capabilities. These new integrated networks will permit simultaneous real-time voice, video, and data transmission.

3.2.3 Data PABX

It has been suggested (Dhawan, 1984) that user communities requiring all of the features described in the previous section may be few and far between, and if diverse features are required, some management questions will also arise. For example, the data processing manager may not be qualified to provide proper guidance for the telephone network and/or teleconferencing, but he/she may not be willing to relinquish the data communication management function to a telephone communication manager. An alternative solution may be to continue traditional use of a voice-only PABX and to handle data distribution by means of a data PABX.

The local computer-access application requires a way to connect many terminals to a host or hosts. Dhawan asserts that this can best be done by using a data-PABX approach. The data-PABX-based network consists of two major functional elements: switching and management, and distribution. The data PABX, which consists of a control element, a switching unit, and communication interfaces, can perform the switching (making and breaking connections) and management functions. The distribution may consist of dedicated physical links (e.g., twisted-wire pair) for each terminal or computer port. This distribution element provides a transparent path between a communication device and the data PABX. No link-level protocols are required, provided the error rate in the local environment is acceptably low (typically $<10^{-6}$). The proximity of terminals and hosts (typically <300 meters) allows inexpensive node connections. (A line driver or local data set may be required to extend beyond the EIA-specified 50-foot [15-m] limit.)

The data circuits in a local computer-access network normally have a longer hold time (connection duration) than voice telephone connections. The data PABX can be designed for low connect rates (few connect or disconnect requests per unit time). Processing within the switch can be performed with a uniprocessor architecture. This leads to simpler software and implied greater reliability.

Data PABXs typically support star networks, but will support almost any other topology as well. Interconnection of data PABXs may be made by high-speed (coaxial or optical fiber) local links or by statistically multiplexed wide-area links including packet-switched public data networks.

3.3 Summary of Commercial PABX Characteristics

There are approximately 30 vendors vying in the U.S. PABX market. Four of these vendors (AT&T, Northern Telecom, Rolm, and Mitel) had 70 percent of the 1985 PABX market, based on the number of lines sold (Feldman, 1986). The distribution of the market share is shown in Table 7. Another study (Bruu, 1986) reveals a slightly different distribution of market share. Five vendors have 80 percent of the 1985 PABX market. NEC displaced Mitel in the fourth position.

Table 8 summarizes the technical characteristics of ten PABXs from the top nine manufacturers in Table 7. Together, these manufacturers held over 90 percent of the 1985 market. The first characteristic covers the minimum and maximum number of lines and trunks for each PABX. This is followed by traffic characteristics. The prevalent traffic terminology, according to manufacturers, is that the switch is "nonblocking" or "essentially nonblocking." For example, a single-stage switch is strictly nonblocking because a desired

Table 7. Distribution of the 1985 PABX Market in the United States (According to Lines Sold)

Vendor	Share(%)		Vendor	Share(%)
AT&T	30	[27]*	GTE	2.5
NTI	15	[22]	Harris	2
Rolm	15	[16]	ITT	1.5
Mitel	10	[7]	UTC	1.5
NEC	6	[8]	Ericsson	1
Siemens	4.5		Hitachi	1
Intecom	4	[5]	Toshiba	1
Fujitsu	3		Others	1.5
			Total	100

* [ ] indicates market share in subsequent study as indicated in the text.

connection can be made between two users by selecting a particular crosspoint connection. The blocking arises when crosspoints are shared. In a three-stage switch, individual arrays are nonblocking and the desired path can be set up at any time with idle links between each stage. Blocking is based on the sharing of links and the probability of each one being busy. All of the PABXs in Table 8 are nonblocking up to the listed minimum number of lines or a lower limit.

The central processors have 8-, 16-, or 32-bit capacity with 16 bits being most common. All are stored-program controlled.

All the switches are digital and they all employ time-division multiplexing (TDM) and pulse-code modulation (PCM). Only the Mitel employs space-division multiplexing (SDM) as well. The Rolm CBX II uses linear PCM with a 12-kHz sampling rate. All other PABXs use North American, CCITT-recommended mu-law PCM with 8-kHz sampling.

All of these PABXs are capable of handling data, with or without modems. The data rates are contingent on the particular interfaces and the modems available. PABXs designed for interfacing with optical fiber transmission

Table 8. Summary of PABX Characteristics

	AT&T SYSTEM 75	AT&T SYSTEM 85	ERICSSON MD110	GTE(c) OMNI	INTECOM IBX S/80(g)	MITEL SX-2000(g)	NEC NEAX2400	NTI MERIDIAN SL-1	ROLM CBXII	SIEMENS SATURN III(g)
CONFIGURATION										
Min/Max Lines	-/800(b)	300/32,000	400/12000	d)	100/12,000	200/4000	64/23,184	e)	48/10,000	-/992
Min/Max Trunks	-/200	0/6000	To 1000	d)	100/14,000	8/350	64/23,184	e)	-/1280	-/512
TRAFFIC										
Nonblocking (a)	Yes	Yes	Yes	Limited	Yes	Yes	Yes	No	Yes	Yes
No. of Simultaneous Calls	236	7636	8192	d)	6000	128	11,592	e)	5760	496
Traffic Limit (CCS)	7200	As Req.	36/Line	d)	36/Line	--	30/Port	e)	--	36/Line
Call Attempts (BHCA)	180	30K to 52K	1800	d)	30,000	--	--	e)	10,000	10,000
CONTROL										
Processor (Bits)	16	16	8	d)	32	16	16	16	16 or 32	16
SPC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Main Memory (Max)	2 Mbyte RAM	8 Mbyte RAM	3 Mbyte RAM	--	4 Mbyte RAM	4 Mbyte RAM	--	--	--	1.5 Mbyte RAM
Auxillary Memory (Max)	--	32 Mbyte RAM	--	--	83 Mbyte Disk	1 MByte RAM	--	--	16 MWord RAM	--
SWITCHING TECHNOLOGY										
Analog or Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital
Multiplexing	TDM	TDM	TDM	TDM	TDM	TDM, Space	TDM	TDM	TDM	TDM
Modulation	PCM	PCM	PCM	PCM	PCM	PCM	PCM	PCM	PCM, Linear	PCM
Sampling Rate/sec	8K	8K	8K	8K	8K	8K	8K	8K	12K	8K
DATA SWITCHING										
Simultaneous Voice/Data	Yes	Yes	Yes	Yes(Packet)	Yes	Yes	Yes	Yes	Yes	Yes
Without Modem	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
-Interface	RS-232-C, RS-449	RS-232-C, RS-449	RS-232-C, V.35	Async/X.25	RS-232-C, RS-447, V.35	RS-232-C	RS-232-C, RS-449, V.35	RS-232-C, RS-422, V.35	RS-232-C	RS-232-C
-Max. Rate (Kb/s)	19.2, 64	19.2, 64	19.2, 64	19.2, 64	57.6	9.6, 19.2	19.2, 56, 64	19.2, 56, 64	64	19.2
With Modem	Yes	Yes	Yes	Yes	--	Yes	N.A.	Yes	Yes	Yes
-Max. Rate (Kb/s)	f)	f)	4.8	19.2, 64	f)	9.6, 19.2	N.A.	f)	4.8	4.8
Packet Access	X.25	X.25	X.25	X.25	X.25	No	X.25, X.75	X.25	X.25	No

a) Either Nonblocking or Essentially Nonblocking

b) Enhanced Version; 400 Lines Standard

c) Uses Packet-Switched Voice and Data

d) Depending on Model.
Model: Lines, Trunks, Simultaneous Calls, CCS, BHCA

SI:	200,	64,	72,	5,184,	2,400
SII:	1,024,	400,	192,	13,824,	7,200
SIII:	2,048,	800,	384,	27,648,	14,400
SV:	50,000,	25,000,	--,	1.2×10^{5},	--

Processor: 8 bits for SI, SII, SIII.
16 bits for SV.

e) Depending on Model.
Model: Lines, Trunks, Simultaneous Calls, CCS, BHCA

SL-1S:	32/140,	6/20,	45,	1,200,	3,600
SL-1MS:	80/400,	16/60,	180,	7,200,	3,600
SL-1N:	140/1500,	10/150,	360,	15,840,	5,700
SL-1XN:	800/ 5,000,	80/500,	1,900,	92,400,	10,500
SL-100:	3000/30,000,	30/20,000,	30,000,	--,	200,000

f) Function of Modem

g) Smaller Model(s) Available.

media alone are not currently available, but optical fiber is used along with copper transmission media in many current installations.

3.4 PABX and LAN Comparisons

Precise technical distinctions between functions provided the user by LANs and PABXs (especially fourth-generation data/voice designs) are becoming increasingly blurred. The Reference and Bibliography Sections of this report give numerous sources of in-depth information on characteristics of LANs and PABXs. The following summary of "generic" comparisons, paraphrased from Data Decisions (1984), may be of use in preliminary evaluations of which approach appears to be most practical for a given application, prior to detailed engineering analysis.

PABXs and Digital Data Switches:

Primary advantages:

- Very large user populations can be supported without loss of performance.
- Cost of the switch itself is normally lower than LAN alternatives for networks with a large number of ports.
- Integration of a switch into an existing directly cabled environment is easier than integrating a LAN.
- Central control of the switch tasks allows implementation of password and other security mechanisms.
- Network features, such as logical user addresses, password protection, and closed user groups, are more likely to be available.

Primary disadvantages:

- Single point of failure.
- Extra cost of cabling (connecting) each device to the switch when (1) users are widely separated, or (2) building codes and structures require unusual installation practices.

LANs

Primary advantages:

- The cost of a small network is much lower than for data switch networks.
- Cabling costs are almost certain to be lower than for data switches except where all users are located in the same area.

- Supported data transfer rates are much higher than those available with all but the most expensive switches.

- Many cable systems are designed so that the failure of a component other than the cable itself will affect only a small number of users.

- Some cable networks permit sharing of the cable with CATV, facsimile, surveillance video, or even digital voice applications.

Primary disadvantages:

- Lack of standards (although this is being remedied).

- Lack of central billing and accounting information.

- Per-port costs and shared facility costs.

4. OPTICAL FIBER CONSIDERATIONS

Much has been written since the early 1970's extolling the virtues of optical fibers; the effort will be made in this section to minimize academic tutorial presentation[6], and to relate data and background information to perceived LAN requirements. An obvious omission is the lack of detailed discussion relative to cost considerations. This is deliberate because of the authors' joint conviction that cost comparisons between systems using dielectric and metallic transmission lines must be made on an individual-system basis. For example, initial decisions on "glass vs. copper" may be made (superficially) based solely on relative cable costs. This risks ignoring two potentially crucial factors associated with cost. The cost of either cable type may prove relatively insignificant compared to (a) installation labor and (b) hardware and software for optimized, competitive systems.

Another cost-analysis factor that is becoming increasingly important and difficult to assess is systems obsolescence. This has become a tripartite dilemma: budget/procurement cycles have become more lengthy; technology is advancing at a frenetic pace; and costs--for <u>any</u> system type--are escalating.

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[6] For the reader concerned with in-depth background on optical fiber technology, the following texts are recommended: Gowar (1984), Kao (1982), and Palais (1985). Lacy (1982) is written for the senior technician, and AMP (1982) and H-P (1983) provide thorough designer's guides. The Bibliography section of this report provides additional suggested literature.

Many new (or updated) on-premises systems may become technologically obsolete before the end of the planned life cycle.

Building-wiring plant, the system "skeleton," is a key ingredient of all such installations, and can be extremely costly to replace. The selection of the building-distribution transmission medium can make the difference between early obsolescence of a total system and the opportunity to upgrade that system by replacement of "black boxes." Here the fiber optics option warrants consideration.

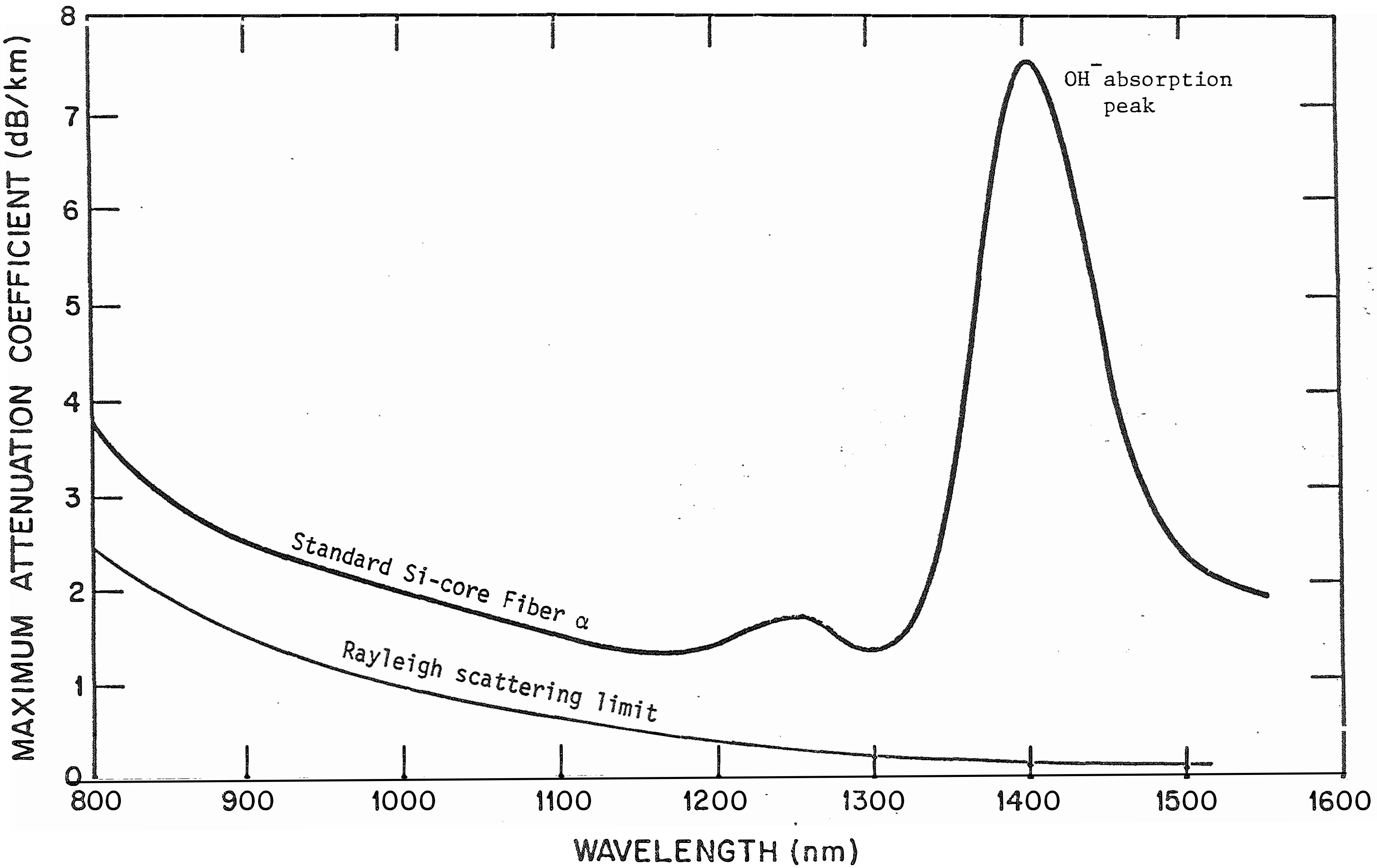
During at least the next several years, as optical fiber technology continues to mature, the communication manager will be faced with decisions on building-wiring architectures partly based on answers to the following questions. For a specific installation, can the use of optical fiber prolong the life cycle; for example, by providing excess capacity (for today) to accommodate almost certainly increased future requirements? If initially more expensive than wire lines, can the difference be justified on the basis of long-term planning?

4.1 Why Fiber Optics?

Why fiber optics (for communications)? The question was asked often in the early 1970's, following successful fabrication of the first "low-loss" (20 dB/km) silica fibers by Corning Glass Works. (Prior fibers, made of optical glasses such as borosilicates, evidenced typical losses of 850 to 1000 dB/km.) The Corning breakthrough capitalized on a theoretical prediction of Dr. Charles Kao (Kao and Hockham, 1966) that current high losses were the result of impurities, such as those resultant from fabrication processes, rather than being representative of intrinsic optical material properties.

Succeeding fiber production by Corning and many others, using ultrapure materials and sophisticated manufacturing techniques, has resulted in attenuation approaching the theoretical Rayleigh scattering limit illustrated in Figure 6. Bandwidth of the improved fibers has steadily increased, to the gigahertz-kilometer range (for single-mode fibers). Cabling techniques, optical sources and detectors, connectors, and interfacing electronics have kept pace.

This technological progress has answered (at least for long-haul telecommunications) the first of two subsets of the question: "Why fiber optics?"



Notes: 1. Hydroxyl ion (OH^-) absorption band at 1400 nm can be almost totally eliminated, but at extra production cost.

2. Lower curve is for ultimate lower attenuation limit imposed by Rayleigh scattering, which varies with λ^{-4}.

Figure 6. Attenuation vs wavelength for typical, low loss, silica-core optical fiber.

This might have been expressed as, "Will it work?" voicing not-uncommon skepticism concerning practicality of using the new transmission medium in the real world of communication systems. Was it destined to remain a laboratory curiosity, or could (and would) the fiber be supported by cost-effective, efficient systems components? The second, and now often-forgotten constituent of the question (again, at least for the long-haul community) was, "Who needs it?" The current, all-pervasive use of fibers for long-haul cable transmission to handle the insatiable capacity/growth requirements of the present decade gives an empirical answer to this part of the question regarding who needs it. But, "Why fiber optics for LANs?" As in the case of long-haul carriers 10 years ago, it is important to ask why, and to evaluate both "Will it work?" and "Who needs it?" Before making this evaluation, the following sections briefly examine how well fiber is working and why it is needed in those applications where it is most used today (in long-haul trunking), look at local distribution, and then draw some parallels in terms of on-premises applications.

4.1.1 Long-Haul Trunking

Optical fiber transmission is indeed successful for long haul, having become the preferred cable medium worldwide. It is now considered by some to be cost-effective, compared to point-to-point satellite transmission, beyond the 500-mile (805-km) radius previously acknowledged to be serviced more economically by satellites (Byrne, 1985). It is working in long haul because the overall technology applicable to long-haul transmission has matured, and is now definitely more efficient and less expensive than wire lines, primarily because fiber permits repeater spacings of tens of kilometers.[7] In comparison, twisted-wire-pair cable repeater spacing for the pre-divestiture Bell System has long been established as 600 ft (183 m). In the United States, competition for the long-haul market includes major carriers such as AT&T Communications, MCI Communications Corp., Lightnet, Fibertrak, U.S. Sprint, RCI Corp., Electra Communications Corp., Indiana Switch, Inc., Norlight, and Walker Telecommunications Co. In addition, a nationwide consortium of seven regional optical fiber networks, called National Telecommunications Network, has been formed (Corman,

[7] The first use of optical fibers in telephone networks was for interoffice trunking, because no repeaters were required.

1985; Kessler, 1986). Several technical journals (e.g., Lightwave, 1985) have reflected concern over possible near-term overcapacity in trunking, but growth continues unabated.

The 10-year-ago "chicken-and-egg" problem of commercial hardware availability vs. emergence of a viable market has been empirically resolved, at least for long-haul. But this resolution has come about concurrently with the perceived requirement for vastly higher long-haul communication capacity. Not unexpectedly, the answers to "Will it work?" and "Who needs it?" have been inextricably linked.

4.1.2 Local distribution

Within the past few years, speculation on the possibility of fiber penetration into the telephone company local loop has aroused at least as much interest as that in long-haul transmission a decade ago. That speculation has recently turned from "if" to "how fast," according to reports (Ryan, 1985) from a mid-June 1985 symposium "Fiber in the Local Loop," sponsored by Lightwave. According to Ryan, fiber clearly is going to dominate the local loop, but the details, such as how long this will take, the primary driving forces, and "what it will do when it gets there" are less apparent. Some highlights from his article are summarized below, updated by more recent articles by Bruhnke and Richards (1985) and Fogg (1985), on announced plans of several operating companies as they proceed toward fiber cable implementation.

- **Pacific Bell:**

Has an "early ISDN" targeted bit rate, for delivery to all homes, of 144 kb/s. Following this, they plan large-scale video transport to the home, requiring a minimum DS-3 (44.736 Mb/s) rate, possibly several hundred Mb/s. Their short-term plans include the use of embedded copper-cable plant (23 million copper-cable pairs, "about half of which work"), to provide ISDN basic 64-kb/s channels to the 52% of customers who are within 12,000 ft (3600 m) of Class 5 end offices. Service can be provided to a radius of 9000 ft (2700 m) with 26-AWG pairs. They "can see the ability" to enhance the outside plant to a 12,000-ft range for the early ISDN target of 144 kb/s.

Long-range plans are to retire all toll-network copper cable by the year 2005 and to have an all-fiber network in place by the year 2025. These schedules could be accelerated in some cities by economics of conduit congestion; estimates for the San Francisco area, for example, show 40% of conduits to be congested. Manhole sizes have doubled since the 1960's.

• Southern Bell:

Has ceased installation of copper wires >26 AWG, using fiber cable as the replacement, and is planning early installation of all-fiber--single mode--networks carrying voice, data, and video to the home. Long-range goals include providing control of house security, life-support systems, heat and air-conditioning, utility meters, and CATV.

The company is putting effort into promoting manufacture of in-house E/O (electro/optical) converters, planned to sell for approximately $1500, the cost of which would be included in home mortgages.[8]

• Illinois Bell:

Has installed Novalink, a point-to-point "high-speed" optical fiber urban network, in the Loop district of Chicago. The system offers tariffed, unswitched, custom-designed services, with fast cutover promised. The network uses star architecture; the 144-fiber backbone cable is single mode, while nodes and spurs are multimode. According to a company spokesman, use of single mode throughout, considered technologically desirable, would have resulted in an estimated $2000/terminal additional cost to customers.

Installed in advance of customer orders, the network terminates in places like "strategic manholes" that facilitate trunk tapping to customer premises, for basement access or entire building "wiring," as services are ordered.

• **New York Telephone:**

Is using a different strategy (compared to Illinois Bell) in fiber use for ISDN transition in metropolitan areas. Their "serving area multiplex (SAM) sites" concept calls for widespread use of remote digital switches in loop locations, allowing some Class 5 end office switching functions to be moved, over fiber, closer to customers. A SAM site could be a large building, several city blocks, or a business or educational campus. [A "metropolitan area network?"]

The SAM approach "will cap the growth of voice-frequency copper systems," facilitating changeover to ISDN. First SAM trials, with full-scale local switching "sometime next year," will be at Rockefeller Center.

Fiber's role in SAM "isn't always important." The company finds fiber often too costly for loop applications, but is convinced it can be more economic "with optimum use of digital switches and remote channel banks." Bandwidth demands of 100 MHz-km are modest, permitting use of step-index or "low-quality graded-index" multimode fibers.

• **New York's Teleport Communications:**

Is competing with New York Telephone, "using different strategies" to serve New York City with a mix of voice and data services. They claim single-mode fiber offers the best economics, and are laying single-mode cable in major buildings in Manhattan and neighboring boroughs and cities. The company began operation in April 1985, and had over 100 miles (160 km) of fiber installed by October 1985, serving a large customer base including several major carriers. This included a 22-mile (40-km) link, part of which is buried under the

[8] The May 1986 edition of Lightwave announced that this Southern Bell project has been cancelled not because of technical difficulties, but because of disagreements with real estate developers.

Verrazzano Narrows, connecting Brooklyn, Manhattan, and Staten Island. "High-speed" access (45, 90, and 560 Mb/s in network trunking) is being provided to a satellite earth station "farm" on Staten Island. The standard digital interface is DS-1; the DS-3 rate is also offered as a "more economic option," along with dedicated fiber lines.

Indeed, it does appear only a question of how soon before fiber takes over the local loop; "what it will do when it gets there" (to the user premises) will depend on what we as users want it to do--for us.

4.1.3 On-Premises Applications

Why fiber optics? The "will it work?" part of the old question has been at least partially answered: optical fiber LANs are commercially available and in use. Some employ fiber throughout, while (most) others use fiber only for high-capacity, multiplexed network segments. Voice/data building wiring plans employing fiber to various degrees are supported and being implemented by major suppliers (e.g., AT&T and IBM). Here, also, the available options range from (a) fiber all the way from external (network) interconnect to individual work stations, to (b) fiber use only for interbuilding trunks and intrabuilding vertical risers, with twisted-wire pairs employed for horizontal distribution, servicing work stations. The latter option is still prevalent, accounting, for example, for over 90 percent of AT&T-IS installations as of early 1986 (private communication, Hank Dorris, AT&T-IS). Some coax is being used.

Thus, vendor literature implies that fiber "will work," now, for on-premises applications. From 1985 procurement experiences of some agencies participant in the FOTG (private communications), however, some hurdles exist today for lightwave implementation of large-scale, on-premises upgrades. "Large-scale," in these cases, means installations requiring more than 2000 work stations, a size as yet achieved by few optical fiber LANs (or, in fact, by few LANs using any transmission medium). For one such large procurement, no bids on lightwave implementation to the user work area were received. (See Section 4.4.2, below.) A primary systems problem for large, connection-intensive LANs appears to be the present nonavailability of efficient, low-cost, mass-produced optical taps. Another problem is connectors, including wall outlets; although optically efficient connectors are available from multiple vendors, cost is not yet compatible with those for metallic cables. In spite of these constraints, however, one agency (the Library of Congress;

see Section 4.4.1 below), with projected very high-capacity requirements, is installing a hybrid cable containing TWP, as well as optical fibers to accommodate future needs. Because of current unacceptably high costs of optical wall-outlet receptacles, the fibers will be coiled temporarily within outlet boxes in some locations until such time as receptacle purchase is affordable.

One very large LAN installation by a commercial user is reported by Telephone Engineer and Management (1986). Southwestern Bell has installed more than 144 km of multimode fiber to serve more than 2000 data work stations in its new St. Louis, Missouri, headquarters. The maximum fiber run of 1200 ft (366 m) is designed to permit a performance upgrade to 200 Mb/s, permitting future transmission of video teleconferencing. Present maximum transmission rate is 10 Mb/s for asynchronous data over an optical Ethernet logical-bus network, and 2.5 Mb/s for synchronous data over a separate network. The Belden 85-μm core/125-μm cladding fiber is distributed over the entire 44-story, 1.5-million-square-foot building. Copper wiring is used for a separate but interconnected digital Centrex™ system for voice.

This "plan-ahead" approach for on-premises upgrades is in accordance with recommendations of major proponents (e.g., AT&T and IBM) for wiring new buildings to accommodate growth requirements. (See Section 5 below.) The philosophy is reflected in the title of a journal article on building wiring: "PABXs are for 7 years; cables are forever" (Sustar, 1985). For data LANs, the need to wire for the goal of "forever" may be more pressing.

Lightwave technology works, but it is still in a process of evolution, and has not matured, in all respects, to meet the needs of on-premises applications as well as it does for point-to-point networking. Then why consider it--now? We must address the second part of our question, and answer better "who needs it?"--by examining how lightwave may assist in solving intrafacility problems.

Earlier in this report, the authors have stated that cost comparisons will not be addressed in depth because of the strong dependence on specific, individual systems requirements and subsequent design. Yet, obviously, as seen in the Library of Congress example (see Section 4.4.1 below), cost considerations will permeate every facet of every agency's evaluation of all technology tradeoffs. In these evaluations, i.e., in looking at competitive systems using various transmission media, it must be borne in mind that systems cost must be weighed against potential obsolescence. The "who needs it?" question for fiber must not be answered in terms of only current requirements, but must be extrapolated to answering needs of at least 10 or 15 years from now. Long-haul carriers are planning ahead by installation of capacity often far in excess of immediate requirements. And, as seen above, local operating companies are following in like manner, extending that capacity to the user/network interface (rapidly becoming the ISDN interface) and, often, using fiber.

4.2 Optical Fiber System/Link Characteristics

This section discusses some fiber attributes applicable to on-premises needs. None of these "benefits" of optical fiber transmission may be new to the reader; perhaps, however, the comparisons with coax and twisted-wire pair technology may provoke thought.

4.2.1 Bit Rate x Distance Requirements

Discussion of capacity in the above sections suffers from a sin of omission: the term has not been defined. Digital capacity, maximum throughput for a given signal quality, for any transmission line is constrained by two parameters: bit rate (P) and distance (L). Transmission limits are determined by the product of these parameters; for all metallic conductors, this limit is expressed as bit rate x (path length)^2, or PL^2. (This does not apply precisely to some short-length systems where excess loss occurs.)

For multimode optical fibers, this product is linear with distance, and is expressed as PL. The allowable figure of merit (see below) is generally much higher than the bandwidth-length characteristic specified on manufacturers' data sheets. This discussion and those immediately following apply to limits imposed by pulse distortion and do not consider attenuation, which must be addressed separately. The two distinct phenomena are properly attributed to either the distortion-limited regime or the attenuation-limited regime. The reader will note that the term "bit rate" rather than "bandwidth" is used here; the distinction is important. "Bandwidth" is used in manufacturers' data sheets to describe fiber performance (e.g., BW of 300 MHz-km). (Note that the use of the term "bandwidth" here is a characterization of fiber performance based on the fact that the product of frequency and distance is constant where the frequency is defined as indicated below.) The term, BW, and values quoted for it, however, are not directly applicable to specification of digital performance. For multimode optical fibers, bandwidth is related to digital bit rate (Hull et al., 1983) by the simple relationship:

$$P_{max} = 1.3\ B_{f(3\ dB)}\ \text{Mb/s} \qquad (1)$$

where P_{max} = maximum NRZ (non-return-to-zero) digital (pulse) rate, and

$B_{f(3\ dB)}$ = the measured 3-dB bandwidth in Megahertz. [That is, $B_{f(3\ dB)}$ = BW (from manufacturer's data sheet)/length (km) of fiber.] This assumes a Gaussian-shaped impulse response function.

This is based on a figure of merit (Fm) derived (Hull et al., 1983)[9] for expressing a first-order approximation of optical fiber performance in terms of bit rate x path length product:

$$Fm = PL, \qquad (2)$$

Where Fm is a constant which is a characteristic of the particular fiber,

P is the maximum required (or allowable) digital bit rate, and

L is the corresponding maximum allowable (or required) path length.

Note: Fm is derivable from the manufacturer's BW characteristic by chosing L = 1 km:

$$Fm = PL = \frac{1.3\ \text{BW (MHz-km) (1 km)}}{1\ \text{km}} = 1.3\ \text{BW}\ \frac{\text{Mb-km}}{\text{s}}\ . \qquad (3)$$

[9] The transfer function of an optical fiber may be taken to be the output optical power as a function of modulation frequency for a fixed input power. The frequency at which the output power, A (f), is reduced to 1/2 of its amplitude at zero frequency is called $B_{f(3\ dB)}$ (optical), the 3-dB bandwidth (Hull and Hanson, 1984, p. 116). (Note that this characterizes a particular fiber length and, in practice, the value for $B_{f(3\ dB)}$ is multiplied by that length to obtain the BW characteristic published on manufacturers' data sheets.)

The figure of merit approach is very straightforward, works, and is useful, but its use must be qualified:

a) It applies only to the distortion-limited regime.

b) It addresses effects of multimode distortion (also called "intermodal" and "modal" distortion), which is a major contributor to pulse distortion (broadening), consequent intersymbol interference, and resultant higher bit error ratio because of receiver inability to distinguish between binary "0's" and "1's".

c) It is a primary transmission-line characterization that does not take into consideration other system parameters that may, and usually do, contribute in a similar manner to performance degradation. Other primary systems parameters include transmitter and receiver rise times, and material dispersion, which results from fiber refractive index wavelength-dependence. (Different wavelengths travel at different velocities and have different arrival times, producing pulse broadening. Spectrally broad LEDs, as compared to monochromatic--or nearly monochromatic--lasers, contribute appreciably to this degradation.)

With these qualifications, how are the expressions for bandwidth/bit-rate conversion and figure of merit useful? They are helpful for comparisons of various types of transmission media and for preliminary systems design. The figure of merit is used as a "common denominator."

As an example of a straightforward design calculation, assume the planning of a high-speed optical fiber LAN, implementing the draft Fiber Distributed Data Interface (FDDI) standards.[10] The draft physical layer standard specifies a maximum bit rate of 100 Mb/s and a total path length, for a ring topology, of 200 km. For an (arbitrary) fiber bandwidth of BW = 300 Mhz-km, what would be the maximum spacing between regenerative repeaters (based solely on modal distortion)? From (3) above, the manufacturer's fiber specification is converted to Fm by:

$$Fm = PL = 1.3 \ BW \ \frac{\text{Mb-km}}{\text{s}}$$

$$= 1.3 \ (300) \ \frac{\text{Mb-km}}{\text{s}} = 390 \ \frac{\text{Mb-km}}{\text{s}} .$$

[10] As of late 1985, a series of Draft Proposed American National Standards was being written by ASC (Accredited Standards Committee) Task Group X3T9.5. Probably the first to be completed will be "FDDI Physical Layer Protocol (PHY)," draft document X3T9.5/83-15.

Therefore, for the example above, the maximum acceptable value for path length, L (in this case, the unrepeatered distance) is the figure of merit divided by the digital bit rate:

$$L_{max} = \frac{390 \text{ Mb-km/s}}{100 \text{ Mb/s}} = 3.9 \text{ km.} \qquad (4)$$

This can be achieved by using a laser (ILD) source, which produces minimal material dispersion. This is, however, but one input into the systems calculation of acceptable maximum path length. How about material dispersion effects when using an LED source, which is the most cost-effective choice today? A rule of thumb[11] for maximum bit rate on a material-dispersion- limited, graded-index-fiber/LED system is 161 Mb/s for a 1-km path length. These assumptions are made: no modal distortion, NRZ (non-return-to-zero) transmission, 1-dB intersymbol penalty, infinite modulation bandwidth for the LED, and an LED at 850 nm with 40-nm spectral width (a typical value).[12] The use of these values (instead of those derived from fiber manufacturer's bandwidth data) as preliminary inputs for repeater spacing, gives:

$$Fm = PL = 161 \text{ Mb-km/s},$$

and, for the FDDI 100 Mb/s rate, the maximum path length between nodes is:

$$L_{max} = \frac{161 \text{ Mb-km/s}}{100 \text{ Mb/s}} = 1.61 \text{ km}$$

(rather than 3.9 km).

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[11] Private communication from a 1985 IBM presentation to the FOTG. Approximate confirmation can be calculated using the derivations of Hull, et al. (1983).

[12] Use of an LED at 100 Mb/s is hypothetical; few presently available LEDs are rated for bit rates this high, but the draft FDDI standard does specify an LED source.

What is the import? Use the figure of merit for fiber comparisons and preliminary approaches, but apply an overall systems analysis to see what degradation is added by source and receiver as well as the transmission line. Reports by Hull et al. (1983) and Hull and Hanson (1984) present simple, first-order equations for analyzing link performance in terms of the aggregate of all such individual contributions.

Bit Rate x Distance Requirements: a LAN example

Ethernet design calls for use of coaxial cable, with the following basic specifications:

- 10 Mb/s backbone transmission,
- 50-ohm coax,
- maximum 0.5 km between repeaters, limited by:
  - a) cable crosstalk,
  - b) cable attenuation (20 to 125 dB/km for typical cables), and
  - c) pulse distortion.

Substituting optical fiber for coax, and using the above assumptions for a material-dispersion-limited LED/graded-index fiber system, the path-length limits are considerably different:

a) crosstalk does not exist,

b) attenuation is as low as a few dB/km for current systems, depending on operating wavelength, and

c) pulse distortion, assuming the above "rule of thumb" for material distortion limit, permits extension of the distance between repeaters from the 0.5 km of coax to:

$$L_{max} = \frac{161 \text{ Mb-km/s}}{10 \text{ Mb/s}} = 16.1 \text{ km},$$

compared to the recommended 0.5 km limit for coax.

Bit Rate x Distance Requirements: a DTE/DCE Example

The ubiquitous EIA-232-C DTE/DCE[13] interface standard (EIA,1981), based on use of nominal 24-AWG twisted-wire pair for interchange circuits, recommends (in an appendix) a maximum 4000-ft (1.2-km) path length at a data rate not to exceed 90 kb/s for balanced transmission.[14] This point is at the knee of the 232-C bit-rate x distance curve, at which pulse distortion still dominates; at longer distances, attenuation is the primary limiting factor for TWP.

Again substituting fiber for the metallic transmission line, and using the above worst-case "rule of thumb" assumptions for a material-dispersion-limited LED/graded-index fiber system, the maximum bit rate at 1.2 km is:

$$P_{max} = \frac{161 \text{ Mb-km/s}}{1.2 \text{ km}} \approx 134 \text{ Mb/s.}$$

4.2.2 Electrical Isolation Problems

Electrical grounding has long been a problem for communication systems as well as for power systems, in terms of protecting both personnel and equipment. Today, power-system grounding is typically well taken care of as the result of numerous national and local electrical codes. Responsibility for communication-system grounding, however, is spread among equipment manufacturers, system designers, and manufacturers, and, ultimately, users, who must (at least for the present) bear the final brunt of assuring themselves that proper procedures are employed (a) to ensure against equipment damage and (b) to assure optimal systems operation.

It is important to realize that "overkill" in methods used to protect equipment may result in defeating optimal systems design, and therefore, operation. One example of this may be illustrated by referring again to the bit-rate/distance curve of the EIA-232-C appendix. The maximum recommended bit rate of 10 Mb/s for balanced operation is a "conservative limit," as stated in

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[13] Data terminal equipment/data circuit-terminating equipment

[14] The EIA-232-C appendix states that, "using good engineering practices," these limits can be exceeded for TWP. They can--especially when using shielded cable--but still represent severe constraints on applications employing high data rates.

this appendix, based on constraints imposed by signal rise and fall times. The maximum distance of $\approx$15 m (at the maximum bit rate), however, was established based not on signal-propagation quality, but on an independent criterion (which is not reflected in the text of the standard): electrical isolation (private communication).

Members of the EIA working group who prepared the standard had experienced equipment damage resulting from ground-potential differences (with potentially very high currents) when DTE and DCE equipment were connected to ac outlets supplied by different power transformers that did not share a common Earth ground. In an effort to minimize such damage, the committee decided to recommend the 15-m limit, based on the assumption that ac outlets within this distance typically will be supplied by a single transformer. Users who meticulously follow this recommendation will be afforded some protection, but only at this extreme of the "how far--how fast" curve. And they will probably sacrifice system performance by not addressing separately the problems of electrical isolation and performance. The EIA-232-C document has been revised and incorporated into EIA-232-D. There is no distance limitation implied other than the requirement that "the effective shunt capacitance of the receiver side of an interchange circuit, including the capacitance of cable, shall not exceed 2500 picofarads."

The considerable increase in path lengths that may be realized, using EIA-232-C generator and receiver specifications in conjunction with careful analysis of TWP propagation characteristics (based on an analogous "figure of merit" characterization of the TWP), has been detailed in a 1984 contractor report by ITS: Guidelines for Engineering U.S. Army Satellite Earth Terminal Interconnect Facilities, Rpt. CCC-CE-TS-84-01, Hdq., USACEEIA, Ft. Huachuca, AZ (limited distribution).

Use of all-dielectric optical fiber cables for interchange circuits totally eliminates electrical isolation problems and the related needs for isolation-circuit implementation, because of the absence of electrically conducting paths. Conversion of the interface signals into a serial bit stream permits efficient utilization of a two-fiber optical cable, replacing the typical 25-conductor metallic ribbon. During 1985, EIA Working Group FO-2.2

continued progress in development of such an interface standard.[15] A proposal was introduced into FO-2.2 by Texas Instruments for a chip specification to perform the requisite electrical/optical conversions for optical interchange circuits. The manufacturer has offered to make the patents available, contingent upon adoption of the coding technique within the proposed standard (private communication).

4.2.3 Freedom from Electromagnetic Interference

Concern for signal degradation resulting from electromagnetic interference (EMI) associated with metallic transmission lines has grown as digital data rates have increased, concurrent with requirements for virtually error-free transmission. These problems can become acute--indeed, intolerable--in the on-premises environment, particularly in upgrading older buildings, as the result of overcrowding of conduits and the not unusual maze of power and communication cables in crowded work areas.

One cure for this is the recommendation by some building-wiring vendors to use shielded TWP cables for critical data requirements. A primary disadvantage of this approach is mechanical: the shielded cables are stiff, with increased bending radii, and consequently, they are difficult to install properly in some environments (private communication to the FOTG, Herb Mendelsohn, USDA). Cost is also increased appreciably.

All-dielectric optical fiber cables are immune to EMI.

4.2.4 Electromagnetic Pulse Effects

Nuclear electromagnetic pulse (EMP) is a short-duration, high-intensity electromagnetic field that may detrimentally affect numerous components of communication systems. System hardening against EMP is a complex technological field beyond the scope of this report. The reader who may anticipate needs for systems design and/or procurement involving EMP hardening is directed to a recent handbook on the subject (Ghose, 1984), which was prepared for an audience including "...system designers, managers and users of equipment who

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[15] EIA-232-C/Fiber-Optic Synchronous/Asynchronous Interface Draft Specification, FO-2.2 Project Number 1796.

may be concerned about nuclear effects on their systems and how to harden against such effects...." (from the handbook's foreword).

One fact pertinent to this discussion, especially in regard to inter-building on-premises wiring, is that all-dielectric optical fiber cable is immune to EMP effects. This is not true, however, for cables employing metallic strength members and/or metallic sheaths, which, like all-metallic cables, can conduct damaging electrical currents to terminal equipment. For such installations, terminal shielding and grounding procedures similar to those for cables employing metallic conductors must be used.

4.2.5 Lack of Obsolescence

Designing building wiring for future needs has been emphasized throughout this report, especially in this section on fiber optics, and details pertinent to specific discussions will not be repeated here. All communication managers are acutely aware of their burgeoning data requirements and the fiscal necessity of not replacing a newly installed but outgrown system prior to the end of its anticipated life span. A primary emphasis of major vendors (e.g., AT&T and IBM) who advocate various "total" on-premises wiring systems is on the economy of wiring buildings to meet long-term requirements. This wiring architecture approach is based on the widely held premise that those major future systems upgrades, which will result from technology evolution, will most strongly affect system "black boxes," which are replaceable without disturbing an adequate wiring installation.

The elusive problem is that of defining an adequate wiring installation--ideally adequate to accommodate such upgrades into the next century. Complicating the solution to that problem is the fact that optical fiber communication is today in the forefront of technology evolution, an evolution involving the basic transmission medium as well as some of the black boxes. By the end of the present decade, this evolution may permit the on-premises system designer/user the clear-cut options on wide use of optical fiber that are now available to the long-haul and local-distribution supplier. Meanwhile, tradeoffs are inevitable in the search for an optimum and affordable transmission network that will not be obsolete when ISDN becomes ubiquitous.

4.3 System Tradeoff Factors

The user who is considering optical fiber transmission for part or all of an on-premises installation is confronted with some systems tradeoff decisions that are unique to the optical regime. These decisions are pertinent whether the communication manager plans to design the system or will be evaluating competitive designs of vendors. Such decisions may affect potential upgradability as well as near-term capabilities. One of the most contested issues in 1985 (continuing into mid-1986) within both U.S. supplier and standards communities was that of fiber sizes for LAN-type applications.

4.3.1 Fiber Sizes

Standardization of a single size for multimode fiber core and cladding diameters, for on-premises applications, would considerably simplify systems design and procurement, as well as promote maximum effectiveness of interoperability and interconnectability of lightwave systems. Efforts to accomplish such standardization have been underway in several U.S. standards organizations for the past few years, and have resulted in proposals (and some standards) for a lesser number of sizes for graded-index multimode fibers. A stalemate continues to exist, however, on the selection of a single set of values. Because of current emphasis on multimode transmission for LAN-type applications, single-mode fibers have as yet received minimal attention in these arenas. For similar reasons, this report concentrates on graded-index multimode fibers.

Based on observations made by the authors of this report while participating in working group meetings of various U.S. standards bodies, the present lack of consensus reflects not only unresolved engineering evaluations of performance tradeoffs, but also two other pragmatic factors:

(1) Reluctance of fiber manufacturers to abandon designs for which they have tooled up, in many cases have installed (or sold) in large quantities, and whose performance they can defend in terms of one or more of the pertinent technical tradeoffs (which will be discussed further below).

(2) Reluctance of user agencies, including the DoD, to relinquish advantages of backward compatibility with installed systems.

By comparison, international agreement has been reached on specifications for long-haul use of fiber. The CCITT, which began work on optical fibers in 1976, is responsible for international standardization of optical fibers for use in public telecommunication networks. The CCITT has adopted single-size specifications for both multimode and single-mode fibers. Recommendation G.651, "Characteristics of 50/125-μm multimode graded-index optical fibre cables" (CCITT, 1985b), specifies these single values for core/cladding diameters, which replace a multiplicity of sizes formerly used internationally. These included, among others, 32/100 μm, 50/100 μm, 50/125 μm, 60/125 μm, and 62.5/125 μm (Bonaventura and Rossi, 1984).

Recommendation G.651 specifies other fiber parameters, including numerical aperture (NA), tolerances on geometric characteristics, baseband response (dispersion and modal distortion), attenuation coefficient, and spectral operating regions (of "around" 850 and 1300 nm). The document does not recommend specific applications, stating, "This fiber can be used for analogue and digital transmission." Bonaventura and Rossi (1984) conclude it can, therefore, be used in the junction network of large metropolitan areas, and in short-and-medium-distance trunks, where indeed its use is found today. (Prior to the rapid acceptance of single-mode fiber, multimode fiber was also used in the first-generation intercity trunking, such as the AT&T Northeast Corridor.)

This CCITT multimode Recommendation states in a prominent footnote: "It should be clearly understood that the selection of only one set of fibre values in this Recommendation does not preclude the preparation of other Recommendations for different fibre designs." A single-mode specification has been subsequently prepared: Recommendation G.652, "Characteristics of a single-mode optical fibre cable" (CCITT, 1985c). The 125-μm cladding diameter of the multimode fiber Recommendation has been adopted in G.652, and the mode field diameter (of 9 to 10 μm), rather than core diameter, has been specified along with other pertinent parameters such as operating wavelength (optimization at "around" 1300 nm, but permitting use at ≈1500 μm). According to Bonaventura and Rossi, the CCITT is considering the need to standardize a third fiber type, optimized "for the local network (user/local exchange links)," presumably for public network access to user premises, at the ISDN NT-1 interface. (For a description of the ISDN interfaces, see Hull et al., 1983.) Should this further standardization take place, it may be of considerable interest to on-premises planners because of availability at their external interconnect points of not only the rapidly emerging ISDN channel capacities, but also of a standard fiber interface.

Standardization of fiber sizes for on-premises applications has lagged that for long-haul for both technical reasons and vested interests of manufacturers and owners of early systems, as discussed above. The vested-interest aspects are best left to the marketplace; the technical considerations involve basic distinctions in requirements between long-haul trunking and building-complex "wiring." In weighing performance tradeoffs for long-haul transmission, maximum bandwidth in conjunction with maximum repeater spacing has been of primary importance, resulting in adoption of the relatively small 50-µm-core multimode fiber.

For local area networks, often with lower bandwidth/distance product requirements than those of long-haul trunking (and, perhaps most important, a broad system-to-system diversity in overall design requirements), tradeoff priorities are not so straightforward. Fibers with core diameters of from 50 µm to a few hundred micrometers are available, offering the user a variety of options, and a plethora of decisions, involving a number of interrelated parameters, whose values usually change with fiber size. The experienced communication manager may choose not to design a system but to leave such decisions to prospective vendors, having specified the system's performance. This approach simplifies matters, but may or may not ensure an optimum system, and buys nothing in terms of future compatibility in systems expansion.

What are the system tradeoffs as a function of fiber core diameter? The following results are typical when increasing core size:

- Improved optical source input-coupling efficiency,
- Lowered losses for connectors, couplers, and splitters,
- Decreased maximum bandwidth,
- Increased microbend losses, and
- Higher cost for equivalent cabling (because more glass is used).

Buckler (1984) reports laboratory research on comparative fiber performance, for LAN applications, of four core/cladding diameters: 50/125 µm, 62.5/125 μm, 85/125 μm, and 100/140 μm. (His company espouses 62.5/125 μm.) Results of the analyses indicate:

- 50/125 μm is not suited for an "LED-driven local network" because of low source-coupling efficiency and bending sensitivity (and therefore is not further considered by him).

- 62.5/125 μm (with a Δ--refractive index difference--of 2%) is "by far" the most upgradable in terms of bit-rate/distance product, and offers better power throughput than either 80/125 μm or 100/140 μm--except for relatively short path lengths (see comparisons below).

- 85/125 μm (with a Δ of 1.6%) offers better power throughput than 62.5/125 μm for paths under ≈1 km but is the least upgradable fiber, and is also "very susceptible to installation, environment and aging sensitivities."

- 100/140μm (with a Δ of 2%) offers the best power throughput of all three fibers for paths under 4 km, but at the expense of cost, bandwidth, handling ease (minimum bend radius and stiffness), and lowered future upgrading potential (compared to 62.5/125μm).

Presentations on building-wiring distribution systems were given to the FOTG during 1985 by AT&T-IS, IBM, and Siecor FiberLAN, the major proponents of the three contending sizes of multimode fibers for on-premises applications.[16] Recommendations of these vendors were as follows for core/cladding diameters:

- AT&T-IS: 62.5/125 μm,

- IBM: 100/140 μm, and

- Siecor FiberLAN: 85/125 μm.

As of summer 1986, both AT&T-IS and IBM still endorsed the sizes indicated above in meetings of the EIA ad hoc TR-41.8 Working Group on Building Wiring for Commercial Enterprises. (See discussion below.) Siecor FiberLAN has participated in recent working group meetings, but has not voiced a strong stand on the 85/125-μm size. Corning, whose fiber is used in Siecor's cables, announced a new fiber for LAN applications in the May issue of their quarterly publication, GuideLines (1986). The fiber size was stated to be 62.5/125 μm, "...equivalent to the design of other fibers currently on the market...."

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[16] The fourth size discussed above and included in the EIA standard below (50/125-μm core/cladding) is used for some DoD systems, but is not being actively promoted for LAN-type applications.

Table 9 gives multimode, graded-index fiber sizes that are currently specified in domestic standards or are under consideration by standards working groups. Because of the long-haul standardization by CCITT, emphasis of these standards efforts is on various applications for on-premises distribution, including local area networks.

4.3.2 Topology: Limitations of Optical Fiber LANs[17]

In metallic shared-media LANs, the access to the transmission line is through a tee coupler or a tap. These introduce only small losses and reflection on the line. The analogous simple power dividers used as couplers to optical waveguides, at present, incur fairly high loss (i.e., loss ≥10 dB) for both access and exit. In addition, an equivalent trunk insertion loss of about 1 dB occurs at each coupler. Consequently, if one assumes a 30-dB power margin between any driver and receiver on a LAN that utilizes these taps, a maximum of ≈10 couplers could be allowed. (This assumes that a 10-dB loss would be incurred for both access and exit, as well as a total of 10-dB trunk insertion loss.) The number of stations able to share the medium is clearly limited using this passive bus approach.

Most optical fiber LANs utilize topologies that permit point-to-point transmission among active nodes. The ring topology is readily adaptable to optical media since each node is active, and transmission occurs sequentially between nodes. Star configurations make all links point-to-point. Optical star couplers[18] can provide multiple access and broadcast functions (or point-to-multipoint connections) required by certain media access protocols.

The specific limitations and advantages of optical fiber transmission media are discussed in several review papers (Hanson, 1981; Hanson, 1982; and Hussain, 1983). Specific recommendations on design procedures are available (Finley, 1983).

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[17] This section is excerpted from a journal article by Hull (1985), "High data rate fiber optic LANs," Telephone Engineer & Management, June 15, 1985.

[18] An architectural example is Siecor FiberLAN's "Universal Wiring" system, employing optical-fiber (physical) star topology to serve the user work area. Fiber Optic Wiring Centers™ at network nodes, using star couplers, permit configuration--and reconfiguration--to various (logical) topologies, e.g., bus, ring, or star.

Table 9. Status of Multimode Graded-Index Fiber Size Specifications in U.S. Standards Organizations (Summer 1986)

Organization	Core/Cladding Diameter (μm)	NA (Numerical Aperture)
EIA FO 6.6: EIA-458A June 1984	50/125 62.5/125 85/125 100/140	0.19 to 0.25 0.27 to 0.31 0.25 to 0.30 0.25 to 0.30
FTSC: proposed Federal Standard 1070, Standard Optical Fiber Waveguide Material Classes and Optional Sizes	Proposed FED-STD-1070 was prepared by the FOTG during 1985. Because of the impasse at that time (within industry and domestic standards working groups) on selection of a single multimode fiber size, the FOTG decided to recommend the four-fiber "shopping list" of EIA-458A. Subsequently, IEEE 802.3 and 802.6 have each endorsed single sizes, and EIA ad hoc TR-41.8 (see below) is negotiating on a single size. The FTSC has withheld adoption of pFS-1070 pending resolution by the ad hoc EIA working group.	
IEEE Working Group 802.3: Draft Standard 802.3, Sec. 9.9 (for an inter-repeater link), Jan. 1986	85/125 (62.5/125 still under consideration as an option.)	data NA
IEEE Working Group 802.6:	62.5/125	0.29
ASC Task Group X3T9.5: Working Group on the Fiber Distributed Data Interface (FDDI), Physical Layer: Draft Proposed American National Standard, Nov. 18, 1985	62.5/125 85/125	data NA data NA
IEC TC86: IEC Doc 86A, Secretariats 10 and 11	62.5/125 85/125 (50/125 and 100/140 are still under consideration as possible options.)	data NA data NA

Table 9. (cont'd) Status of Multimode Graded-Index Fiber Size Specifications in U.S. Standards Organizations (Summer 1986)

Organization	Core/Cladding Diameter (μm)	NA (Numerical Aperture)
MIL-STD-188-111: Subsystem Design & Engineering Standards for Common Long-Haul and Tactical Fiber Optics Communications	No present fiber size specification. The system document is in process of revision as MIL-STD-188-111A.	
EIA ad hoc Working Group TR 41.8 on Building Wiring for Commercial Enterprises:	Founded in November 1985, this working Group has established the goal of producing, within 1986, a draft standard on architecture and transmission media for wiring office buildings and building clusters. They are addressing both copper and fiber optics cabling. During the June 1986 working meeting, attendees agreed on the desirability of a single size for fiber for on-premises applications and requested the major proponents of various sizes (AT&T, Corning, and IBM) to attempt to agree on a single recommendation. Should this take place, the intent of the ad hoc group is that the proposed EIA standard will endorse this size for all on-premises uses. This includes interbuilding trunking as well as intrabuilding vertical risers and horizontal distribution (to the user work area). It is anticipated that such endorsement will result in revision of pFS-1070 to reflect the single set of fiber dimensions.	

A projection (Gibson, 1984) of the impact of optical fiber media on LANs indicates that costs will be competitive with coaxial cable within the next 5 years. Specific technology advances may be expected in lower loss cables and splitters (with more than six-way division and with increased efficiency). The key hardware technology advances expected to affect LANs are in chips, microprocessors, fiber optics, input devices, and local storage. Software will continue to be a pacing item on the development of LANs.

A listing of commercially available large-scale LANs (Datapro, 1985) itemizes a total of 52 systems. Of these, 12 offer optical fiber as an alternative transmission medium for the system backbone. Only 3 of these 12 offer fiber implementation of horizontal distribution to the user work area. Of the 12 systems, only 2 provide backbone operation qualifying them for the high-data-rate LAN category, somewhat arbitrarily defined as ≥50 Mb/s.

4.3.3 Central Control vs. Distributed Control

The introduction to this report briefly discusses distributed data processing, a topic that has properly received much attention during the past several years. By comparison, the subject of network management of the communication systems required to interconnect distributed data stations has often been paid little attention. Is data network control also to be distributed? If so, how does it work, and what is to be "controlled?" Langford (1983) assigns three aspects to network management:

1) Maintenance: Including fault identification and isolation, accurate diagnostics, simple maintenance, and, for sophisticated systems, fault recovery;

2) Administration: To enable management of growth and change in the network; requires traffic statistics, network configuration data, billing/accounting routines, and procedures to control personnel/work station relocations; and

3) Control: Including the ability to configure and reconfigure the network, and to control user access--in terms of both network priority and database access restriction.

The PABX is the historical example of central control of an intrabuilding communication system. With the feature menus available for today's digital PABXs, almost anything can be centrally managed and "controlled." Many features are inherently similar to functions provided by some LANs: diagnostics, restricted and expedited user access, multiple interfaces to external networks, selection of point-to-point or point-to-multipoint connection, and called/caller "addresses," all utilizing extensive software control. Those PABX features not always considered in LAN management architecture include accounting and billing, which may be of equal importance to the automatic data processing (ADP) manager as telephone billing is to the telephony communication manager.

Like PABXs, LANs do not "run themselves" without a guiding hand, and relatively sophisticated systems management will inevitably be required for efficient operation of the systems being planned for major agencies. When those requirements are for networks of several thousand interconnected work stations, the management problem becomes acute. One writer team (Tschammer and Klessman, 1985) has concluded that a LAN management system "resembles a distributed control system," and treats it thus in a paper entitled, " Local Area Network Management Issues." The paper concludes that such a management system must be designed as an integral part of the communication system, with that system's application requirements and network characteristics in mind. The approach is somewhat (deliberately) restrictive in that it addresses specifically the management of "closed distributed computer systems." The authors define such systems as those usually dedicated to one particular application and designed to meet its special requirements, "often restricted to a closed user group and not open to users and applications from outside." For some Federal agency users, this definition may coincide with requirements for a major LAN installation, while others may find that it more closely matches needs for relatively smaller subsets; e.g., bridge- or gateway-interconnected LANs serving closed user groups within a major installation.

Tschammer and Klessman present a management framework that relates LAN management to the OSI Reference Model architecture, and discuss several methods of classifying management activities, relating concepts to work done by IEEE, ISO, and other international standards organizations.

There is no universal solution; perhaps the only meaningful advice to today's communication manager is not to ignore the crucial need for system management: not to be lured into believing that the best designed building-wiring system--alone--makes an "intelligent" building, or that the highest capacity LAN, without user-tailored system management, can suffice. This concern is fundamentally independent of the systems hardware employed. It is emphasized in this section because of the relative newness of fiber optics; the sometimes considerable technical decisions to be made in its applications could tend to mask the need for carefully defining network management requirements.

4.3.4 Interoperability and Standards Development

As may be expected within any new, rapidly growing technology, there is a proliferation of vendor-specific proprietary LANs, most of which are mutually incompatible, requiring sometimes complex and typically costly gateways for interoperation. These user problems are exacerbated for optical fiber LANs; many components are still undergoing evolutionary development directed toward optimized LAN-type applications, thus adding to the overall systems interoperability issues. Fortunately, numerous standards organizations are active in developing a broad spectrum of standards on LANs, optical fiber LANs, and fiber systems components.

The IEEE has been in the forefront of LAN standards development, having initiated Project 802 in February 1980 with the goal of establishing standards for local area networking, in compliance with the OSI Reference Model, prior to growth of a major market. As of March 1986, 6 such standards, resultant from efforts of the several Working Groups of the 802 Committee, have been jointly approved by ANSI and IEEE, and work on 13 more is ongoing. (Of the latter, all but one deal with various aspects of fiber optics implementation.)

One document that should prove to be of particular interest to the on-premises communication planner is IEEE 802.6 MAN (Metropolitan Area Network) Fiber Optic Installation Guidelines. The document addresses, in depth, a broad spectrum of practical installation techniques for on-premises systems. In draft form in early 1986, the final document will be available from IEEE publication sources.

Several domestic standards organizations have become actively involved in creating standards in various areas of optical fiber communications; many of these standards address LANs directly, others indirectly (e.g., in specification of test procedures). Ongoing efforts are spread among many working groups of the major voluntary standards organizations (and the DoD) and therefore, until recently, have been most difficult for the user to track. In recognition of this difficulty, a U.S. coordinating activity (also covering international projects) was formed in early 1985 under the ANSI Electrical and Electronics Standards Board (EESB). The group is designated the Fiber Optics Coordinating Committee (FOCC).

The FOCC statement of Scope and Functions reads:

> Within the scope of the Electrical and Electronics Standards Board, the Committee shall coordinate national standards activities and U.S. input into international standards activities in fiber optics by bringing together the responsible standards-developing organizations in the field.
>
> The Committee shall:
>
> 1) facilitate exchange of information on ongoing and proposed standards projects,
>
> 2) identify the need for additional standards projects and recommend priorities, and
>
> 3) provide a forum for negotiations among the standards developers to arrive at an agreement on sponsorship, coordination and consolidation of these projects.
>
> The Committee shall recommend appropriate actions to EESB to achieve these objectives. The committee shall not itself develop standards or establish standards developing committees.

Membership requirements of the FOCC:

> Membership shall be open to all organizations, companies, government agencies and individuals who might reasonably be expected to be or who indicate that they are, directly and materially affected by the development and coordination of fiber optic standards.

The magnitude of the combined U.S. and international optical fiber communication standardization effort is reflected by the March 1986 Status Report[19] of the FOCC (updated periodically), which contains 144 pages. Agency membership in the FOCC is highly recommended to those communication managers who are interested in keeping abreast of standardization efforts.

4.4 Agency On-Premises Communications Upgrades

Since inception of the Fiber Optics Task Group, some participant Federal and DoD agencies have reached deadlines for implementation of varying levels of on-premises upgrades, while others are in planning and evaluation stages for future requirements. The Veterans Administration, in analyzing replacement of

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[19] The ANSI staff contact for these Status Reports is C.T. Zegars, ANSI, 1430 Broadway, New York, NY 10018. The above statement of Scope and Functions is included in these periodic reports.

outdated interconnection of two Washington, D.C., buildings, found a high-capacity, optical fiber trunk to be an optimal solution. The Diplomatic Telecommunications Service is designing a fiber-optics-based total upgrade of their Intrasite Data Distribution System, called the Secure Fiber Optics System (SFOS). The SFOS will be installed in all base and field stations.

Two Federal agencies, the Library of Congress and the U.S. Department of Agriculture, have recently contracted for major on-premises communications upgrades of multibuilding sites in Washington, D.C. The former installation will employ hybrid transmission media, including fiber optics, while the latter will use no fiber. Basic requirements and technical approaches of the two upgrades are summarized below.

4.4.1 Library of Congress Upgrade

The Library of Congress (LC) upgrade comprises a mix of requirements including some that are common to growing needs of many large agencies, as well as some that, if not unique, are certainly a first in terms of very high bit-rate distribution to many user work stations. Highlights of these requirements include:[20]

- Interconnection within and among three major LC buildings (Adams, Jefferson, and Madison) in Washington, D.C.;
- Work stations to be interconnected:
  - Telephones: current 4000, with projected increase to 10,000;
  - Data Terminals: current 2000, with projected increase to 6,000;
- Phase I (Adams and Jefferson); target date for completion is November 1992, including 8000 voice/data locations. (Initial work began in late 1985.);
- Minimum systems life for distribution wiring system: 20 years--particularly crucial for Phase I because of the coincidence with major building renovations (installation of some trunk cables requires lifting the marble floor and/or wall slabs);
- Long-range goal: a high-resolution (min. 10 Mb/s) terminal at each telephone location;

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[20] This section constitutes a summary of a presentation on the upgrade given by Manny Bahrami, of the Library of Congress, to the FOTG on February 4, 1986.

- Tentative target date of the year 2000 for completion of an optical-disk data base (begun in 1985) for storage of all books in the LC;

- Evolution of a prototype communication system (currently operating at 180 Mb/s) to access the optical-disk data base, and transport data at the DS-1 rate to cluster controllers situated near user terminals, including those in public reading rooms. The first of these terminals, with 300 x 300 pixel/inch resolution, were installed in reading rooms in 1985; and

- Accommodation of all future systems changes and work station moves by means of changes in controller software, not by "stringing more cable."

After evaluation of many manufacturers' responses to its 1985 RFP (request for proposals) for the initial phase of this major upgrade, the LC decided on installation of a building-wiring system rather than a LAN, per se. The decision was influenced by consideration of current and projected needs, which dictated a transparent "pipeline" throughout the LC, not restricted by requirements of a specific LAN, but compatible with a broad spectrum of systems (including state-of-the-art PABXs), as well as ISDN interface requirements.

The AT&T Premises Distribution System (PDS) was chosen, with custom LC modifications. All existing wiring will be removed from the Jefferson and Adams buildings and replaced with a specially designed PDS cable containing two optical fibers (62.5/125-μm core/cladding), four shielded twisted-wire pairs, and four unshielded twisted-wire pairs. (No coax will be used in building distribution.) Star wiring topology will be employed. Because of current unacceptably high cost of optical interfacing at wall outlets, fibers will temporarily be coiled (in some selected areas) behind receptacle boxes, with the goal of "connecting them at everybody's desk" when receptacle/connector hardware costs become affordable, ideally no later than the Phase I target date of February 1992. Preliminary plans to use all shielded-TWP for copper distribution was overridden by concern for compatibility with all available PABXs: several manufacturers stated that shielding "is no good for them at very high bit rates" because of high induced capacitance.

The major backbone of the wiring system will be optical fiber, comprising interbuilding trunks and computer-to-wiring-closet interconnection.

4.4.2 U.S. Department of Agriculture Upgrade

The U.S. Department of Agriculture (USDA) contracted, at the end of FY 85, for a turnkey Agriculture LAN, which will be one of the largest LANs installed to date[21]. Schedules call for a 3-year implementation period of a system design incorporating a media growth transmission capacity equal to three times initial capacity, to accommodate projected needs of a 10-year expansion period, which may result in network requirements for 8000 terminals serving 20,000 people. Highlights of the USDA LAN requirements include:

- Interconnection within and among the four buildings of the USDA Washington, D.C., complex: the South Building, Administration Building, Auditors Building, and Cotton (Agriculture) Annex Building, a complex that houses 23 significant ADP/T centers.

- Support of four principal communications categories: data, voice, video, and telemetry;

  Data applications requirements include:

  1) 36 FDX (full duplex) dedicated, point-to-point links to support synchronous rates to 64 kb/s,

  2) 12 FDX dedicated, point-to-point links to support synchronous rates to 1.544 Mb/s,

  3) 100 FDX, circuit-switched, point-to-point links to support synchronous and/or asynchronous rates to 19.2 kb/s, and

  4) 2000 FDX, packet-switched links to support asynchronous rates to 19.2 kb/s.

  Voice applications requirements include:

  1) 12 FDX, dedicated, point-to-point links operating at the DS-1 rate, to be available throughout the D.C. complex, and

  2) DS-3 multiplexing.

  Video applications requirements include:

  1) Video origination and broadcast capability for all offices within the complex, utilizing five 6-MHz broadcast channels and two 6-MHz origination channels, all compatible with standard NTSC (North American standard for broadcast color television color video).

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[21] Content of this section has been excerpted from U.S. Department of Agriculture LAN procurement documents provided by Herb Mendelsohn of USDA (private communication).

Telemetry applications requirements include:

1) 1000 FDX, dedicated, point-to-point links to support rates of 300 b/s, and

2) 20 FDX, dedicated, point-to-point links to support rates of 19.2 kb/s.

- Gateways to connect the USDA LAN to the following target networks:

1) A planned replacement telephone system (to incorporate both X.25 and asynchronous TTY gateways),

2) DEPNET (existing USDA-wide packet-switched DEPartment NETwork provided by GTE Telenet),

3) Existing IEEE 802 CSMA/CD networks, and

4) Existing Wang networks.

- Support of various communication protocols for compatibility with specified existing terminal equipment.

- Network control center capabilities to include:

1) Periodic testing for system status and verification,

2) Fault detection, reporting, isolation, and restoration,

3) Maintenance logging,

4) System usage monitoring,

5) Collection and processing of accounting data,

6) Traffic analysis, and

7) Management of all data base information.

- Multilevel security requirements, including special protection for closed user groups.

A contract award was made to Information Systems & Networks Corp. (ISN). Their network approach, according to their technical proposal, is based on

"Ungermann-Bass baseline system design."[22] Highlights of the system design, to meet the above requirements, include:

- Dual broadband cable system approach that supports the entire spectrum of connectivity required for data, voice, video, and telemetry data transfer, and provides for future bandwidth expansion requirements. (Stated to provide twice the bandwidth of a single-cable system at a small incremental price increase.)

- Capability to extend the network to a 1-mile (1.6-km) distance. Initial requirements are for a maximum of 2500 ft (750 m).

- Provision of full channel spectrum, without guard bands, from 5 MHz to 450 MHz.

- Permits trunk transmission at 5 Mb/s with multiplexing efficiency to support 2000 users (stated as calculated network throughput), with adequate capacity for the estimated future quadrupling of requirements.

- Use of modular, single-frequency Network Interface Units for all network interfaces.

- Network equipment that uses the CSMA/CD access method (based on suitability for video transmission); USDA requirements for also supporting token bus access will be met by use of a logical token ring based on the IEEE 802.3 token bus media access control (MAC).

- A Network Control Center, incorporating all required functions, with total network control from a single point, using a 32-bit micro computer incorporating the Motorola MC68010 processor.

In their technical proposal, ISN recommended that optical fiber cable be included in all underground trunking provided for the USDA LAN, "in anticipation of its eventual usefulness when the technology matures." This is not being done, because (a) of inadequate remaining space in the 4-inch (102-mm) interbuilding ducts after the coax installation, and (b) for the short runs involved, the USDA did not consider the approach cost-effective (private communication, Herb Mendelsohn, USDA). The initial ISN investigations indicated that while optical fiber cable price is dropping significantly, the

[22] In their RFP, the contractor discusses the Ungermann-Bass Net/One™ LAN; Ungermann-Bass offers several mutually compatible versions of the Net/One, including an optical fiber implementation (DataPro, 1985). From the ISN data, they appear to be basing their system on the Net/One Broadband version.

current cost of connectors is prohibitive for large LANs requiring many outlets.

Also, the lack of efficient optical taps became a critical element in the USDA decision not to use fiber for horizontal distribution; their LAN design requires taps every 50 ft (15 m). Use of fiber for the primary backbone, with copper for horizontal distribution, was considered but decided against for several reasons: requisite electronics for transition from fiber to TWP were too expensive and too large to fit into existing wiring closets, and this approach would not have fulfilled all system requirements, since TWP would not have handled total video and high-speed data needs. Hybrid use of fiber and coax (for the horizontal distribution) was also considered, but devices for fiber-to-coax transition did not exist.

Thus, no viable systems alternative to broadband, end-to-end CATV/coax technology was found. The USDA received no proposals for overall optical fiber implementation of the proposed network, i.e., for distribution to the user work-station area (private communication, Herb Mendelsohn, USDA).

5. BUILDING DISTRIBUTION SYSTEMS

The post-divestiture competitive environment, coupled with the rapid evolution of new communication terminal equipment as well as PABX and LAN systems, has made on-premises "wiring" crucially important. From the user's vantage point, building distribution costs are no longer concealed in communications lease costs, and existing plant is often found to be inadequate for and/or incompatible with new equipment. This is so not only for high-speed data, LAN-type transmission requirements, but also for state-of-the-art PABXs.

An example of such obsolescence is the Library of Congress on-premises upgrade discussed in Section 4.4.1 of this report. Although the LC decided to remove all existing wiring in the two older buildings in their D.C. complex, they hoped to utilize existing TWP plant (at least for voice and low-speed data) in Madison, the "new" building, with the knowledge that the wiring belonged to the local operating company. Accordingly, arrangements were made with Northern Telecom to test the wiring system with their Meridian voice/data PABX (private communication, presentation by Manny Bahrami, LC, to the FOTG, February 4, 1986).

Results were discouraging; the horizontal wiring proved to be 24 AWG (which the Meridian requires), but vertical distribution was 26 AWG, which is too small to handle the switch trunks. On testing the 24-AWG plant with a data circuit, installers found it impossible to get any transmission at all through randomly selected pairs; testing of characteristic impedance showed a Z_O ranging between 600 and 800 ohms, with some pairs as high as 1200 ohms. (The Meridian requires a maximum Z_O of 100 ohms.) Northern Telecom cleaned up some lines, resplicing the wire, and the Z_O fell to ≈100 ohms, permitting the switch to function normally over these circuits. Based on this experience, the LC has decided to rewire Madison using the AT&T Premises Distribution System, a long-range plan to follow the rewiring of the two older buildings in conjunction with their renovation.

Problems similar to this have become so chronic that not only have users banded together in experience/problem-sharing activities such as the FOTG, but industry has also found it necessary to take action. The EIA TR-41.8 ad hoc Working Group on Building Wiring for Commercial Enterprises was formed by terminal equipment manufacturers in November 1985 as the result of the growing number of experiences similar to those of the Library of Congress above. These manufacturers have found that their state-of-the-art equipment all too often will not meet performance specifications when operating with embedded wiring plant. The goal of the ad hoc Working Group is to prepare an on-premises wiring standard that will serve as a vendor-independent user installation guide for distribution systems capable of handling all perceived requirements for the foreseeable future.

In recognition of the multitude of problems associated with building-wiring obsolescence, several large U.S. firms have announced proprietary building-distribution systems within the past 2 years. It is important to note that these distribution systems constitute building-<u>wiring</u> architectures, and are not necessarily associated with specific <u>communication</u> systems such as LANs. Indeed, all vendors offering wiring-distribution systems stress, to some degree, vendor-independence (e.g., transparency to terminal equipment and data networks). Some systems, however, (such as IBM's) are tailored to specific requirements of proprietary LANs (although not necessarily limited to their use). Some vendors are engaged in both manufacturing wire and cable, including optical fiber cable, and installing it (e.g., AT&T-IS and Siecor FiberLAN).

Others only manufacture cable (e.g., AMP); whereas for some (e.g., IBM), the primary motivation for cabling systems specification and sales appears to be the assurance of optimum compatibility with their LAN and terminal product lines.

Most of the major contenders are represented on the EIA ad hoc TR-41.8 Working Group and, not unexpectedly, are negotiating for approval of key elements of their proprietary distribution systems. As of August 1986, there has been considerable progress in agreement on overall building wiring architecture, but contention still exists over types of transmission media proposed for horizontal distribution. Candidates include several TWP gages of at least two Z_O's, several optical fiber core/cladding diameters, and coax. December 1986 is the target date for completion of the draft EIA wiring standard; participants are confident that it will be a useful design document.

The following sections give highlights of some of the available building distribution systems. These summaries are deliberately brief; vendor documentation on most of the systems is very detailed, and in-depth analysis is not within the scope of this report. The interested reader is directed to the referenced sources for further information. Selection of vendors is somewhat arbitrary, including those who have given technical presentations to the FOTG, and is certainly not all inclusive. As indicated by the USDA on-premises upgrade (discussed in Section 4.4.2 of this report), independent firms are capable of designing major installations and winning contracts for them.

5.1 AMP, Inc., Undercarpet Cabling System

The firm, AMP, has previously been known primarily as a connector manufacturer. In early 1985, it was announced that their top management had become committed also to networking, and involved in the OSI Physical Layer of networking, "the backbone of any networking system."[23] While the manufacturer has indicated intentions of marketing LAN systems, the initial systems contribution to on-premises communications has been development of the AMP Undercarpet Cabling System, which uses flat, under-the-carpet cable for intrabuilding distribution of all utilities (communications and power).

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[23] This section is excerpted from transcripts of a technical presentation given by AMP to the FOTG on April 17, 1985. Additional information is obtainable from: Marketing Director, AMP Special Industries, Southeastern, PA 19399.

The flat communication cable is manufactured in a variety of types, including TWP, coax, and optical fiber. A unique feature of the flat optical fiber cable is the AMP "turn fitting," which permits a 45° or 90° turn around room corners without requiring a difference in fiber length or creating fiber microbends. Their optical fiber product line (which includes flat and conventional cable), designated the AMP OPTIMATE Fiber Optic Interconnection System, includes everything required for on-premises interconnection except outdoor cable. Thus, they can provide interconnection to outside trunks supplied by the telephone company (or other interconnect supplier), with the capability for all internal distribution, including that to individual work station areas, by means of the flat undercarpet optical fiber cable.

Primary AMP goals in designing an office building distribution system using the flat cable are to make it more cost effective and more flexible in the changing and moving of people, typically within modern "open landscaping," partition-divided areas. Under-the-carpet installation achieves these goals by eliminating all exposed conduits and permitting work station moves without creating a proliferation of "extension" cables.

While AMP does not perform installation of their cabling systems, the firm does work closely with installers, providing training backed by an in-house laboratory test program.

5.2 AT&T-IS Premises Distribution System

The AT&T-Information Systems' Premises Distribution System (PDS) is considered by AT&T to be a common distribution architecture tying together their voice, data, and office products as well as those of other vendors.[24] The AT&T PDS services include site reconnaissance, distribution planning, custom engineering, product procurement, project management, installation, administration, and maintenance.

In developing PDS, AT&T has taken the perspective that a vendor cannot afford continuously to offer new products that require different distribution

[24] This section is paraphrased from private communications from W.C. Hubner, Jr., AT&T-IS, and from various PDS technical/promotional literature. Because much of this literature is in progress of revision, the reader is directed to the nearest AT&T Information Systems Account Team for current PDS technical information.

systems. For AT&T, PDS represents internal consistency in this sense; but they realize that customers also want flexibility with respect to vendors, and AT&T is therefore working with other vendors to include a wider variety of voice and data applications. Their PDS support includes the AT&T STARLAN 1-Mb/s CSMA/CD local area network, the AT&T 8.64-Mb/s baseband Information Systems Network (ISN), which offers protocol conversion for IBM 3270 BSC and SDLC terminals, and AT&T System 85 and System 75 digital PABXs.

Technical highlights of the "most recommended" (by AT&T) PDS options are summarized below, including AT&T rationale for transmission media recommendations.

- Topology: modified star, with station outlets connected to satellite closets that are then connected to main administration points (common equipment and/or computer rooms), with modifications for very large or small installations. Claimed advantages are those historically associated with physical star topologies: simplified changes and rearrangements with the centralized approach; simplified expansion because stations are added from the node out (only the stations directly served by a link are affected by failure of that link); easy, central access to status and trouble information; and natural concentration points formed by intermediate nodes to utilize, for example, higher bandwidth media such as fiber optics.

- Common Distribution Architecture Concept (Subsystem Model): particularly suited for the modified star topology. The model can also be applied to other topologies:

  - Work location wiring subsystem: connects user equipment to the wall outlet, typically using a simple mounting cord with modular plugs. Various active and passive adapters are also available, e.g., for EIA-232-C, IBM 3270 Type A, and Wang OIS/VS devices, the latter incorporating baluns (devices for balanced/unbalanced conversion).

  - Horizontal subsystem: connects wall outlets to satellite closets; unshielded TWP cable is typically used, each link serving one station. Two 4-pair cables are recommended for flexibility, for example, to access easily two applications such as a PABX and a LAN simultaneously. Recommended maximum path length is 250 ft (76 m), even though all current PDS applications can be supported over greater distances. The two cables are terminated in a wall outlet with two 8-pin modular jacks, which act as a universal interface to PDS. (Various versions of the 8-pin modular jack are currently being considered for standardization as ISDN basic and primary interfaces.) "Shared jack" arrangements are available, to allow two applications, e.g., for an analog telephone and an IBM 3270 terminal to share one 8-pin jack and one 4-pair cable run.

- Backbone (riser) subsystem: connects satellite closets to main administration points, each link serving many stations, using both unshielded multipair TWP and optical fiber cable. This higher bandwidth requirement can be satisfied by either using many cable runs in parallel or using a higher capacity medium and performing multiplexing or concentration in the satellite closet.

- Campus subsystem: an extension of the backbone subsystem to interconnect buildings in a campus or office-park environment, again using both unshielded multipair TWP and optical fiber cables. May include protection and grounding facilities.

- Equipment cabling subsystem: connects equipment in main equipment room or in satellite closets to the distribution system via administration hardware. Can utilize simple patchcords or special harnesses or adapters.

- Administration subsystem: ties the other subsystems together and permits routing and tracking of individual connections. Includes both copper and fiber cross-connects, interconnects, and wall outlets.

- Transmission media: PDS is based on use of unshielded TWP copper cables and fiber optics:

  - Unshielded TWP cable in sizes of 22, 24, and 26 AWG are all used, the most popular being the 24-AWG version called "D-type Inside Wire" (DIW). Used extensively in PDS, DIW cable supports data applications at 1, 1.5, 2.4, and 4.3 Mb/s, and can often replace other media such as coax or twinax.

    During development of PDS, AT&T considered and compared various copper transmission media, including coax and shielded TWP. Unshielded TWP was chosen as the optimum copper medium in the analysis of performance/cost tradeoffs. Shielded TWP cable, which is more expensive and presents installation difficulties, is considered effective for horizontal distribution only if employed in an environment where <u>all</u> building wiring is shielded. Coax is no longer recommended by AT&T-IS for new building-wiring installations, and is included in PDS specifications only to handle retrofits of older buildings where coax is already in place. Their goal in such cases is "to show customers how to convert to TWP and fiber" (private communication, Hank Dorris, AT&T-IS, presentation to the FTSC, April 10, 1986).

  - Fiber optics is the other medium extensively used in PDS, offering well-known advantages. PDS recommends 62.5/125-μm fiber, which is available in many cable sizes and different sheath characteristics for various environments. One cable example is a backbone ribbon design, of approximately 0.5-in. (1.3-cm) diameter, containing up to 144 fibers.

The AT&T anticipates that the optical fiber backbone will increasingly replace the copper system in the next several years, and that, with this evolution, the satellite closet will house more electronics to perform concentration, multiplexing, and routing functions. They also expect that as fiber technology evolves, it will find increased usage in the horizontal subsystem, where currently it is typically used only for very high frequency devices such as full-motion video. As of early 1986, AT&T-IS reports their use of fiber for customer horizontal distribution to be <10% of total installations (private communication, W.C. Hubner, Jr., AT&T-IS, presentation to the EIA TR-41.8 ad hoc Working Group). (See Section 4.4.1 of this report on the Library of Congress application of PDS, using optical fiber and TWP cable for horizontal runs to work station areas.)

5.3 IBM Cabling System

The IBM Cabling System,[25] publicly announced in May 1984, provides a uniform, structured approach to the interconnection of data processing equipment within a building or campus of buildings. Original specifications for the Cabling System are directed toward data transmission, apparently intended primarily for application to IBM LAN products. However, an October 1985 IBM announcement added support for unshielded TWP cable (designated Type 2), which is suitable for PABX use, and whose specification is compatible with much installed on-premises telephone wiring.

The first IBM LAN product designed for operation over their Cabling System was introduced on October 1985: the IBM Token Ring Network, a LAN that operates over the Cabling System at speeds to 4 Mb/s. The IBM Token Ring Network conforms to IEEE 802.5 as well as ECMA (European Computer Manufacturers Association) 89 for token-ring baseband LANs. The LAN constitutes an "open" architecture for the potential accommodation of both IBM and non-IBM terminal equipment. As of January 1986, however, only IBM PCs could be attached to the Cabling System, by means of the Token Ring Network. (This application should not be confused with the [IBM] PC Network, which is manufactured by Sytek,

[25] Datapro Section C11-491-901, January 1986, gives a summary of the IBM Cabling System capabilities; information is contained in planning and installation guides available from: IBM Corp., Information Development, Dept. E01, PO Box 12195, Research Triangle Park, NC 27709.

which does not operate over the Cabling System, but rather over broadband coax.) IBM has stated that, in the future, most of their communication products will be able to be attached to the Cabling System via the Token Ring Network, as an alternative to coax and other cabling now used. (As with the AT&T PDS, IBM does not recommend coax for building distribution in their Cabling System but, like AT&T, provides a variety of devices to attach coax and twinaxial devices to the Cabling System.) A summary of highlights of the IBM Cabling System follows:

- Topology: physical star, logical token ring. Star wiring connects work stations to a centralized wiring closet, providing historical advantages of the star configuration. (See discussion in Section 5.2 above.) The logical ring token-passing flow control is handled by a central control device at the wiring closet.

- Transmission media: the Cabling System is based on use of shielded TWP and optical fiber cables for data transmission, with a recently introduced unshielded TWP cable for telephony; of the cable types below, the Token Ring Network supports all but Type 5, the optical fiber version:[26]

  - Type 1, Type 1 Plenum, and Type 1 outdoor (data applications): two twisted pairs of 22-AWG solid conductors, in shielded cable with appropriate sheaths.

  - Type 2 and Type 2 Plenum (data and telephone applications): two shielded twisted pairs of 22-AWG solid conductors for data, plus four unshielded 22-AWG pairs for telephony, within a common cable jacket, with appropriate sheaths.

  - Type 3 Specified (low-speed data and telephone applications): unshielded 22/24-AWG, solid copper TWP, minimum two twists per foot; 4-pair cable is recommended. Not manufactured or sold by IBM.

  - Type 4: No data are available in the current specifications.

  - Type 5 (optical fiber): cable containing two 100/140-μm fibers; recommended indoor for non-plenum applications, outdoor for aerial applications or in dry, waterproof, underground conduits.

  - Type 6 (data applications): two twisted pairs of 26-AWG stranded conductors; for use in making patch cables; available for non-plenum applications only.

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[26] Update: According to Photonics Spectra's Press Time Bulletin (May 1986, p.8), IBM has announced product availability for optical fiber implementation of their token ring LAN. This includes cable (using 100/140-μm fiber), connectors, E/O converters, and repeaters.

- Other components: the IBM Cabling System provides a full range of other devices for TWP cable interconnection between user work station area and external network interface, including: connectors, face-plates, surface mounts, distribution panels, surge suppressors, patch cables, and test equipment. The anticipated announcement on optical fiber implementation may be expected to add similar fiber-compatible components.

IBM specifies a nominal characteristic impedance of 150 ohms (3 to 20 MHz) for their "data grade," shielded twisted-wire pairs. The goal is to reduce attenuation (compared to that experienced by the more-often used 100-ohm TWP), and thereby to increase run lengths for their Token Ring Network. Shielding is specified to minimize EMI within a range of unknown environments.

6. SUMMARY AND CONCLUSIONS

This report has presented background for establishing an interagency task group to develop guidelines for Federal agencies wishing to consider optical fiber media in on-premises communication systems. Tutorial introductions to LANs, PABXs, and optical fiber transmission media are presented. Current sources for LANs and PABXs are given in an attempt to show technology readiness for on-premises digital communications upgrades. Emphasis is placed on National standards activities that promise support for the interoperability requirements of Federal agencies. The group has recommended pFS 1070 as a means of limiting the choices of optical fiber sizes for applications within the Federal government. Amendments to this proposed Federal standard are under consideration to limit the choice to one fiber size.

Work of the FOTG will continue, with the goal of pursuing--if not optimum solutions to the myriad problems of on-premises upgrades--at least a useful set of guidelines for their analysis. This report is intended as an interim documentation of current progress toward this achievement.

7. REFERENCES

Acampora, A.S., and M.G. Hluchyj (1984), A new local area network architecture using a centralized bus, IEEE Commun. Mag. 22, No. 8, August.

AMP (1982), Designers Guide to Fiber Optics (AMP, Inc., Harrisburg, PA 17105).

AT&T (1985a), Product Announcement: AT&T Premises Distribution System (PDS), May 7 (AT&T Customer Info. Ctr., P.O. Box 19901, Indianapolis, IN 46219).

AT&T (1985b), A guide to premises distribution (Technical Publications, AT&T Information Systems, Middletown, NJ).

AT&T-IS (1983), Consultant Report 2, Dimens on AIS^{TM}/System 85, April (AT&T Information Systems, Morristown, NJ 07960).

Bergman, B.L. (1984), Survey of fiber optics local area networks, 1984-85 Handbook and Buyers Guide, Vol. VI (Information Gatekeepers, Inc., Boston, MA).

Bergman, L.A., and S.T. Eng (1984), A synchronous fiber optic ring local area network for multi-gigabit/s mixed traffic communication (Stallings, ed.), Tutorial, Local Network Technology (IEEE Computer Society Press, Los Angeles, CA).

Black, U.D. (1983), Data Communications, Networks and Distributed Processing (Reston Publ. Co., Inc., a Prentice Hall company, Reston, VA.).

Bonaventura, G., and U. Rossi (1984), Standardization within CCITT of optical fibres for telecommunication systems, CSELT Technical Reports XII, No. 6, December.

Bruhnke, H.W., and C.L. Richards (1985), New York Teleport begins digital network, Lightwave 2, No. 10, October.

Bruu, L. (1986), PBXs, Centrex slug it out; KTS left on the mat, MIS Week 7,2 No. 22, June 2.

Buckler, M.J. (1984), Fiber design for the subscriber network, Optical Communication, ECOC '84: Tenth European Conference on Optical Communication (Stuttgart, FRG, 3-6 September, 1984; U.S. distributor: Elserier Science Publ. Co., New York, NY).

Burr, W.E., and R.J. Carpenter (1984), Wideband local nets enter the computer arena, Electronics 57, No. 9, pp. 145-150, May 3.

Bushelle, R.J (1986), Opportunity: the window is open for FTS 2000, Government Executive 18, No. 1, January.

Byrne, T. (1985), Satellite vs. fiber: the competition heats up, Lightwave 2, No. 5, May, p. 27.

CCITT (1985a), Recommendation X.200, Reference model of open systems interconnection for CCITT applications, CCITT Red Book, Fascicle VIII.5, ITU, Geneva, Switzerland.

CCITT (1985b), Recommendation G.651, Characteristics of 50/125 µm multimode graded index optical fibre cables, CCITT Red Book, Fascicle III.2., ITU, Geneva, Switzerland.

CCITT (1985c), Recommendation G.652, Characteristics of a single mode optical fibre cable, CCITT Red Book, Fascicle III.2, ITU, Geneva, Switzerland.

Cerni, D.M. (1984), Standards in Process: Foundations and profiles of ISDN and OSI studies, NTIA Report 84-170, December. (Available from National Technical Information Service, Springfield, VA 22161, Order No. PB 85-165041.)

Cheong, V.E., and R.A. Hirschheim (1983), Local Area Networks, Issues, Products, and Developments (John Wiley and Sons Ltd.).

Corman, B. (1985), Group plans national fiber optic network, Telephone Engineer & Management 89, No. 14, July 15, p.1.

Cypser, R.J. (1978), Communications Architecture for Distributed Systems (Addison-Wesley Publishing Company, Inc.).

Data Decisions (1984), LANs - a solution to resource sharing & a PBX adjunctor alternative, Communications Systems, 400715, February, pp. 1-9.

Datapro (1985), All about large-scale local area networks, C11-010-101, September.

Derfler, F.J. (1985), The other side of LANS, selling against LANS with the PBX, Teleconnect 3, No.6, June, pp. 126-129.

Dhawan, A. (1984), One way to end the brouhaha over choosing an optimal LAN, Data Commun. 13, No. 3, March.

EIA (1981), EIA Standard RS-232-C, Interface between data terminal equipment and data communication equipment* employing serial binary data interchange. [*This term has since been changed to "data circuit-terminating equipment".] (Available from Electronics Industries Association, Engineering Dept., 2001 Eye St. NW, Washington, DC 20006).

EIA (1983), Bulletin 15, EIA Engineering Bulletin for provision of premises wiring for one- and two-line voice telephone systems, January (Electronics Industries Association, 2001 Eye St., N.W., Washington, DC 20006).

FED-STD-1037A (1986), Approval Draft of Federal Standard 1037A, Glossary of Telecommunication Terms, October 25. (Final document to be published by GSA Federal Supply Service in 1986.)

Feldman, R. (1986), Consultant blasts PBX hype: basics count most, MIS Week 6, No. 22, May 29, p. 29.

FILAN (1984), A development by Martin Marietta Denver [CO.] Aerospace, under sponsorship of Rome Air Development Center (Contract No. F 30602-81-C-0016).

Finley, M.R., Jr. (1983), Design procedure for fiber optical local area networks, FOC/LAN 83, October. (Information Gatekeepers, Inc., Boston, MA.)

Finley, M.R,. Jr. (1984), Optical Fibers in Local Area Networks, IEEE Commun. Mag. 22, No. 8, August.

Flint, D.C. (1983), The Data Ring Main, An Introduction to Local Area Networks (Wiley Heyden Ltd.).

FOC/LAN (1984), Proceedings of the Eighth International Fiber Optic Communication and Local Area Networks Exposition in the U.S.A., Las Vegas, Nevada. (Information Gatekeepers, Inc., Boston, Mass.)

Fogg, A.F. (1985), Undersea link completes 22-mile net in New York, Lightwave 2, No. 10, October.

Galuszka, P. (1985), Unfazed by projections, carriers kindle the course of lightwave, Data Commun. 14, No. 4, April.

Ghose, R.N. (1984), EMP Environment and System Hardness Design (Don White Consultants, Inc., Gainsville, VA 22065).

Gibson, R. W. (1984), A primer for evaluating and purchasing today's local networks, The Executive Guide to Data Communications (McGraw-Hill Publications, New York, N. Y.).

Glen, D.V. (1985), Local network assessment, NTIA Report 85-174, April (National Technical Information Service, Springfield, VA 22161, Order No. PB 85-217883).

Gordon, E. (1985), Emitter and Detector Technology Forecast, Proceedings--Fiber Optics to the Year 2000 Seminar, Sponsored by ElectroniCast Corporation, June 17 and 18.

Gowar, J. (1984) Optical Communication Systems (Prentice-Hall, Englewood Cliffs, NJ 07632).

Guidelines (1986), Quarterly newsletter (Telecommunications Products Div., Corning Glass Works, MP-BH-5, Corning, NY 14830).

Hanson, D.C. (1981), Fiber optics in local area network applications, Adv. in Electronics and Electron Physics 57 (Academic Press, New York, N.Y.).

Hanson, D.C. (1982), Application of fiber optics to local area networks, Telecommun. 16, No. 12, December.

Horwitt, E. (1984), Looking for the promised LAN, Business Computer Systems, June.

H-P (1983), Fiber Optics Handbook, (Hewlett-Packard GmbH, Boeblingen Instruments Division, Federal Republic of Germany).

Hull, J.A. (1985), High data rate fiber optic LANs, Telephone Engineer and Management 89, No. 12, June 15, pp. 74 ff.

Hull, J.A., and A.G. Hanson (1984), Optical fiber communications link design in compliance with systems performance standards, NTIA Report 84-154 (National Technical Information Service, Springfield, VA 22161, Order No. PB- 111037.)

Hull, J.A., A.G. Hanson, and L.R. Bloom (1983), Alternative transmission media for third-generation interface standards, NTIA Report 83-121, May (National Technical Information Service, Springfield, VA 22161, Order No. PB 83-238345.)

Hussain, A. (1983), Review and trends in fiber optic local area networking, FOC/LAN 83, October (Information Gatekeepers, Inc., Boston, MA).

IBM (1985a), IBM Cabling System Planning and Installation Guide, Sixth Edition, October. (Available from local IBM representatives.)

IBM (1985b), Using the IBM Cabling System with Communication Products, First Edition, October. (Available from local IBM representatives.)

Irwin, M.R. (1982), Local networks in the U.S.--technology versus regulation, Telecommun. 16, No. 3, March, pp. 17-21.

ISO (1983), Information processing systems--Open systems interconnection--Basic Reference Model, IS 7498.

ITS Staff (1983), A primer on integrated services digital network (ISDN): implications for future global communications, NTIA Report 83-138, September (National Technical Information Service, Springfield, VA 22161, Order No. PB 84-152586).

Joshi, S., and V. Iyer (1984), New standards for local networks push upper limits for lightwave data, Data Commun. 13, No. 8., July.

Kao, C.K. (1982), Optical Fiber Systems: Technology, Design, and Applications (McGraw-Hill, New York, NY).

Kao, C.K., and G.A. Hockham (1966), Dielectric-fibre surface waveguides for optical frequencies, Proc. IEE, July.

Keiser, B.E., and E. Strange (1985), Digital Telephony and Network Integration (Van Nostrand Reinhold Co., New York, N.Y.).

Kessler (1986), Route map: Fiberoptic long-haul systems planned and in place, Kessler Marketing Intelligence, Newport, RI, 02840.

Lacy, E.A. (1982), Fiber Optics (Prentice-Hall, Englewood Cliffs, N.J. 07632).

Langford, G.J. (1983), Local area network user needs, Proc. of Localnet '83, Local Networks (Online Publications Ltd., Pinner, U.K.).

Lee, S.E., P.I.P. Boulton, and H.A. Ikeman (1984), A glass-fiber rooted-tree local area network, Proceedings of the Eighth International Fiber Optics and Local Area Networks Exposition in the U.S.A., Las Vegas, Nevada (Information Gatekeepers, Inc., Boston, Mass.).

Mier, E.E. (1986), Question: How open is IBM's much-touted token ring? Data Commun. 15, No. 1, January.

Modern Office Technology (1985), How the competition is planning to steal your customers, May.

Myers, W. (1985), Toward a local network standard, Tutorial Local Network Technology, Second Ed. (IEEE Computer Society Press, Los Angeles, CA.).

Nelson-Rowe, L. (1985), IBM finally gets to the promised LAN but token ring debut greeted by mixed reviews, Commun. Week, October 21.

Palais, J.C. (1985), Fiber optic system design, 1986 Handbook and Buyers Guide VII (Information Gatekeepers, Inc., Boston, MA.).

Patrick, M.W. (1985), The heat is on for phone switches that do a lot of fast shuffling, Data Commun. 14, No. 3, March, pp. 227-232.

Rosenthal, L.S. (1985), Guidance on planning and implementing computer system reliability, NBS Special Publication 500-121, January.

Rosenthal, R. [ed.] (1985), Workshop on analytic and simulation modeling of IEEE 802.4 token bus local area networks, NBS Special Publication 500-127, June (National Technical Information Service, Springfield, VA 22161).

Ryan, J. (1985), Fiber's push into the loop is following diverse routes, Lightwave 2, No. 8, August, p.1.

Stallings, W. (1985), Tutorial--Local Network Technology, 2nd Ed. (IEEE Computer Society Press, IEEE Catalog No. EH 0234-5, IEEE Computer Society Number 657).

Stuck, B.W., and E. Arthurs (1985), A Computer and Communications Network Performance Analysis Primer (Prentice Hall, Englewood Cliffs, NJ 07632).

Sustar, L. (1985), PBXs are for 7 years: cables are forever, Teleconnect 3, No. 2, February.

Tanenbaum, A.S. (1981), Computer Networks (Prentice Hall, Inc., Englewood Cliffs, NJ 07632).

Telephone Engineer & Management (1986), SW Bell installs fiber optic LAN, 90, No. 8, April 15, p. 115.

Tschammer, V., and H. Klessman (1985), Local area network issues, EFOC/LAN '85 Proceedings (Information Gatekeepers, Inc., Boston, Mass.)

8. BIBLIOGRAPHY

Baxter, L.A., P.R. Berkowitz, C.A. Buzzard, J.J. Horenkamp, and F.E. Wyatt (1985), System 75 communication and control architecture, AT&T Tech. J. 64, No. 1 Part 2, January, pp. 153-175.

Buying Guide (1986), 1986 Buying Guide, Technical Handbook and Industry Directory (Lasers and Applications, Torrance, CA 90505, December 1985).

Coover, E.R., and M.J. Kane (1985), Notes from mid-revolution: searching for the perfect PBX, Data Commun. 14, No. 8, August, pp. 141-150.

Dabnor, J. (1985), Do you need a PBX, or a LAN? both? New trends make coexistence cozy, Commun. Age 2, No. 5, May, pp. 37-38.

Darden, W.E. (1985), PBX capacity planning: what is it?, Teleconnect 3, No. 7, July, pp. 57-58.

Datapro (1984a), All about PABX systems, TC07-001K, April, pp. 101-179 (Datapro Research Corporation, Delran, NJ).

Datapro (1984b), AT&T-IS Dimension System 85, TC07-070MQ, pp. 101-112.

Datapro (1984c), Intecom IBX Series 80, TC07-492DM, December, pp. 101-109.

Datapro (1984d), Rolm CBX II, TC07-775M, May, pp. 101-110.

Datapro (1985), Northern Telecom keeps its promise, Datalink Newsletter, C99-501-041, 10, No. 4, April, pp.1-3.

Edelman, L. (1985), Boom year for PBX sales fires competitive frenzy, MIS Week 6, No. 19, May 8, pp. 48-49, 61.

Ferrall, W. (1985), Shorter cables expected to dim the allure of ultralow-loss splicing, Lightwave 2, No. 10, October.

Friesen, G. (1985), Which is the best PBX and why? Teleconnect 3, No. 3, March, pp. 58-65.

Friesen, G., and H. Newton (1984) Competitive Edge (BCR Enterprises, Hinsdale, IL).

Goeller, L. F. (1985), 10 trends to watch in PBXs, Teleconnect 3, No. 3, March, pp. 74, 76, 80.

Goeller, L. F., and J. A. Goldstone (1985), The BCR Manual of PBXs (BCR enterprises, Hinsdale, IL.).

GTE Communication System Corporation (1985), GTE Omni SII/SIII digital private automatic branch exchange system for Version Release (SVR) 8.2.1.X, Issue 1, January (GTE, Northlake, Illinois).

Hegge, W. (1985), Choosing a data communications network, Teleconnect 3, No. 3, March, pp. 66-68, 134-135.

Howard, P. (1985), How to make the right fiber optic choice, Telephone Engineer & Management 89, No. 12, June 15.

Johnson, H.W. (1984), An inside look at the new Rolm CBX II architecture, Business Commun. Rev. 14, No. 1, January-February, pp.9-19.

Killorin, E.H., and P.J. Musich (1986), A master strategy for local networking, Telecommunications Products Plus Technology, March.

Lonie, B. (1984), Power and noise mess up PBXs, Teleconnect 2, No. 9, March, pp. 154-155.

Lonie B., and L.F. Goeller (1985), Teleconnect goes technical, but doesn't get far, Teleconnect 3, No. 7, pp. 111-122.

Lu, Kang-sen, J.D. Price, and T.L. Smith (1985), System 75: maintenance architecture, AT&T Tech. J. 64, No. 1 Part 2, January, pp. 229-250.

Marcus, M.J. (1985), The regulatory point of view: ISDN in the United States, Telephony 208, No.10, March 11, pp. 32-34.

McInerney, F. (1984), PBX market analysis, Teleconnect 2, No. 9, September, pp. 90-92, 116-118.

Medina, S., and J.F. Helms (1985), Designing intelligence into buildings, Data Commun. 14, No. 9, September.

Mier, E.E. (1985a), Long overdue, T1 takes off, but where is it heading?, Data Commun. 14, No. 7, July, pp. 120-140.

Mier, E.E. (1985b), PBX trends and technology update: following the leaders, Data Commun. 14, No. 9, September, pp. 82-96.

Moore, S. (1985), PBX: a big ticket buy, On Communications 2, No. 2, February, pp. 51-55.

Mullinax, B. (1986), Designer's handbook: Fiber optics in the subscriber loop, Photonics Spectra 20, No. 1, January.

Newton, H. (1984), The answer man: the common questions of the consultant liaisons, Teleconnect 2, No. 9, pp. 135-138, 143-147, 151.

Newton, H. (1985), Voice data PBXs, switching data through a PBX, Teleconnect 3, No. 3, March, pp. 61-66.

Palais, J.C. (1984), Fiber Optic Communication (Prentice-Hall, Englewood Cliffs, NJ 07632).

Photonics Spectra (1985), AMP buys into Lytel and FOCS, Press time bulletin, 19, No. 10, October, p. 8.

Pyykkonen, M. (1985), Fiber optics in local networking, Telecommun. 19, No. 12, December.

Rolm (1984), CBX product notes, Product Note #229A (Rolm Corporation, Santa Clara, CA.).

Ryan, J. (1985), Telcos plan for ISDN: AT&T looks farther ahead, Lightwave 2, No. 4, April, pp. 1, 12, 50.

Sara, K. (1985a), Numbers don't tell all, Teleconnect 3, No. 9, September, pp. 94-98.

Sara, K. (1985b), PBX-based OA now driving our industry, Teleconnect 3, No. 9, September, pp. 103-107.

Schlanger, G. (1980), Planning for the application of CCITT No. 7 in the CCIS network, National Telecommun. Conf., Houston, Texas, Vol. 1, pp. 2.5.1-2.5.4.

Serlin, O. (1984), Fault tolerant systems in commercial applications, Computer 17, No. 8, August, pp. 19-30.

Shumate, J. (1985), A bold call for singlemode to every home--now, Lightwave 2, No. 18, August, p.1.

Siewiorek, D. (1984), Architecture of fault-tolerant computers, Computer 17, No. 8, August, pp. 9-17.

Siewiorek, D., and R. Swartz (1982), The Theory and Practice of Reliable Systems Design (Digital Press, Bedford, Massachusetts).

Telecommunications Reports (1985a), FCC unanimously adopts rulemaking notice looking toward end of structural separation rules for AT&T provision of CPE 51, No.5, pp.1-4.

Telecommunications Reports (1985b), BOCs call for broader proceeding aimed at lifting structural rules from their CPE activities, 51, No. 15, pp. 8-10, 38-40.

Wallace, J.J., and W.W. Barnes (1984), Designing for ultra-high reliability: the Unix RTR Operating System, Computer 17, No. 8, August, pp. 31-39.

White, C.E. (1985), Expanding horizons, Telecommun., March, 19, No.3, p.88u.

Wirl, C. (1985), What's the best way to wire a new building for data? Data Commun. 14, No. 9, September, pp. 154-171.

Zipper, S. (1985), Telecom suppliers count on emerging standard to open market for digital voice/data interfacing, Electron. News 31, No. 1542, March 25, pp. 1, 50, 55.

Zita, K. (1984), A primer on PBX architecture, Teleconnect 2, No. 3, March, pp. 77-79.

Zorpette, G. (1985), Computers that are never down, IEEE Spectrum 22, No. 4, April, pp. 46-54.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The Federal Telecommunications Standards Committee, chaired by the Office of the Manager, National Communications System, has established a Fiber Optics Task Group, one purpose of which is to develop guidelines for Federal agencies planning to use fiber optics in on-premises communications upgrades. This report describes the key technical elements under consideration in the Task Group. These technical elements include local area networks (LANs), digital private automatic branch exchanges (PABXs), building-wiring distribution architecture, and the application of optical fiber waveguides in the implementation of these on-premises systems. Each of these technical elements is undergoing rapid technological change.

This report develops some fundamental principles necessary to do tradeoff analyses required to make decisions regarding cost versus early technological obsolescence. Some examples of commercially available technology representing the present state of the art are included. Brief summaries of technology readiness, as presented by several key industry representatives to the Fiber Optics Task Group, are provided.

16. Key Words *(Alphabetical order, separated by semicolons)*

building-wiring distribution systems; digital PABXs; fiber optics on-premises upgrades; office automation; optical fiber LANs; OSI Reference Model; PBXs

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