NTIA Report 90-270

Telecommunications Networks: Services, Architectures, and Implementations

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December 1990

PREFACE

Certain commercial equipment, instruments, services, protocols, and materials are identified in this report to adequately specify the engineering issues. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material, equipment, or service identified is necessarily the best available for the purpose.

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LIST OF ACRONYMS

ACSE	Application Control Service Element
ACTS	Advanced Communications Technology Satellite
ASCII	American Standard Code for Information Interchange
A/D	Analog to Digital
AO&M	Administration, Operation & Management
ATM	Asynchronous Transfer Mode
AT&T	American Telephone & Telegraph
AUTOVON	Automatic Voice Network
B-ISDN	Broadband Integrated Services Digital Network
BOC	Bell Operating Company
BRI	Basic Rate Interface
CATV	Cable Television
CCC	Clear Channel Capability
CCITT	International Telegraph and Telephone Consultative Committee
CCS	Hundred Call Seconds
CO	Central Office
COS	Corporation for Open Systems
CPE	Customer Premises Equipment
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
DACS	Digital Access Control System
DBMS	Data Base Management System
DCE	Data Communication Equipment
DCE	Data Circuit-Terminating Equipment
DNHR	Dynamic Non-Hierarchical Routing
DoJ	Department of Justice
DS	Digital Service
DS	Digital Signal
DTE	Data Terminal Equipment
EFT	Electronic Funds Transfer
EIA	Electronic Industries Association
ET	End Terminal
EM	Electronic Message
ESP	Enhanced Service Provider
ESS	Electronic Switching System
FCC	Federal Communications Commission
FDDI	Fiber Distributed Data Interfaces
FDM	Frequency Division Multiplex
FM	Frequency Modulation
FSK	Frequency Shift Keying
FTAM	File Transfer Access Management
FTS	Federal Telephone System
GC	Ground Control
IC	Integrated Circuit
ISDN	Integrated Services Digital Network
ISO	International Standards Organization
LAN	Local Area Network
LAP-B	Link Access Protocol - Type B
LATA	Local Access Transport Area
LC	Logical Link
LEC	Local Exchange Carrier

LIST OF ACRONYMS (cont.)

LED	Light Emitting Diode
LFC	Local Functional Capability
LLC	Logical Link Control
LOS	Line of Sight
LT	Local Terminal
MAN	Metropolitan Area Network
MFJ	Modified Final Judgment
MHS	Message Handling System
NM	Network Management
NT	Network Termination
NTIA	National Telecommunications and Information Administration
OC	Optical Carrier
ONA	Open Network Architecture
OSI	Open System Interconnection
PABX	Private Automatic Branch Exchange
PANS	Peculiar and Novel Services
PCM	Pulse Code Modulation
PDN	Public Data Network
PLN	Private Line Network
POP	Point of Presence
POTS	Plain Old Telephone Service
PRI	Primary Rate Interface
PRM	Protocol Reference Model
RBOC	Regional Bell Operating Company
RC	Reflective Coefficient
RTS	Remote Terminal Service
RZ	Return-to-Zero
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
STM	Synchronous Transfer Mode
TA	Terminal Adapter
TDM	Time Division Multiplex
TE	Terminal Equipment
USN	United States Navy
VF	Voice Frequency
VPLN	Virtual Private Line Network
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network

TELECOMMUNICATIONS NETWORKS: SERVICES, ARCHITECTURES, AND IMPLEMENTATIONS

R. F. Linfield*

Telecommunications networks are shown to exhibit three attributes that distinguish them from each other, namely, the service offered, the functional architecture necessary to provide this service, and the hardware and software that implements this architecture. For each service there are many possible architectures and for each architecture there are many possible implementations. This report provides a basic understanding of the services, architectures and technologies that are the foundation of advanced telecommunications networks.

Key words: broadband ISDN; layer architecture; narrowband ISDN; network management; physical architectures; protocols; services, telecommunications networks

1. INTRODUCTION

The purpose here is to examine network architectures from a functional standpoint and to show how various implementations of these architectures have evolved and are continuing to evolve as new architectures and new technologies are introduced. This architectural background provides a framework for the subsequent reports concerning network management architectures.

Thirty years ago the digitization of the nationwide network began with the introduction of T-carrier systems and related TDM technology. Twenty years ago the pervasive service of telecommunications was almost exclusively voice telephone. Ten years ago the computer revolution was just beginning and digital data transmission was in common use. Today computer applications are widespread and digitization of the network is extensive but the majority of the traffic is still voice telephone. High-speed digital technology and associated digital transmission techniques rely heavily on integrated circuit chips and network elements such as optical fibers, satellite systems, information systems, and intelligent work stations. These are the precursors to intelligent networks with open system interconnections on a global basis for voice, data, facsimile, video, and other more futuristic services.

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Ultimately, users will have complete terminal portability and transparency on a worldwide network infrastructure of public, private, fixed, and mobile networks to access this information world. This transformation to the worldwide telecommunications infrastructure is described in NTIA (1988).

Understanding the complex nature of telecommunications today is a difficult task. This report describes some of the advanced services offered by modern telecommunications networks, including information processing applications and information transport services. To provide any given service, a number of functional architectures can be envisioned and for each architecture many implementations are feasible. Each step in this process is examined from service provisioning, to architectural concepts, and to hardware and software implementations. We have purposely neglected the subject of how to effectively manage the network to ensure efficiency, quality, and reliability of its performance. This is the so-called field of network management (NM) which is an important part of any network's architecture. In fact, many service providers perceive network management as including everything except the hardware and software used for information transfer. Future reports will be concerned with network management architectures particularly as they impact the interoperation of satellite and terrestrial networks.

1.1 Basic Definitions

Several telecommunication network terms are defined to aid the reader. In all but a few cases these definitions are taken from proposed Federal Standard 1037B (1991), a glossary of telecommunication terms.

<u>Asynchronous Transfer Mode (ATM)</u> - A data-transfer mode in which a multiplexing technique for fast packet switching in CCITT broadband ISDN is used. This technique inserts information in small, fixed-size cells (32-120 octets) that are multiplexed and switched in a slotted operation, based upon header content, over a virtual circuit established immediately upon a request for service.

<u>Asynchronous Transmission</u> - Data transmission in which the instant that each character, or block of characters, starts is arbitrary; once started, the time of occurrence of each signal representing a bit within the character, or block, has the same relationship to significant instants of a fixed time frame.

<u>Broadband ISDN (B-ISDN)</u> - A CCITT proposed Integrated Services Digital Network offering broadband capabilities including many of

the following features or services: a) from 150 to 600 Mbps interfaces, b) using ATM (asynchronous transfer mode) to carry all services over a single, integrated, high-speed packet-switched net, c) LAN interconnection, d) the ability to connect LANs at different locations, e) access to a remote, shared disc server, f) voice/video/data teleconferencing from one's desk, g) transport for programming services (e.g., cable TV), h) single-user controlled access to remote video source, i) voice/video telephone calls, and j) access to shop-at-home and other information services.

Boundary - An abstract separation between functional groupings of protocols. May or may not be a physical interface as well.

Communications System - A collection of individual communication networks, transmission systems, relay stations, tributary stations, and terminal equipment capable of interconnection and interoperation to form an integral whole.

Connectionless Mode Transmission - In packet data transmission, a mode of operation in which each packet is encoded with a header containing a destination address sufficient to permit the independent delivery of the packet without the aid of additional instructions. Note: A connectionless packet is frequently called a datagram. A connectionless service is inherently unreliable in the sense that the service provider usually cannot provide assurance against the loss, error insertion, misdelivery, duplication, or out-of-sequence delivery of a connectionless packet. However, it may be possible to protect against these anomalies by providing a reliable transmission service at a higher protocol layer.

Connection-Oriented Mode Transmission - In data transmission, an association in which the information transfer stage is preceded by a call establishment phase and followed by a call termination phase. In the information transfer phase, one or more packets are transmitted. The header of each information packet contains a sequence number and an identifier field that associates the packet with the previously established logical circuit. Connection-oriented services are generally able to detect lost, errored, duplicated, or out-of-sequence packets.

End System and End User - The ultimate source or destination for information transferred over a network.

Implementation - Software and hardware that performs the logical functions defined by the network architecture.

Integrated Services Digital Network (ISDN) - An integrated digital network in which the same time-division switches and digital transmission paths are used to establish connections for different services. Note: Such services include telephone, data, electronic mail, and facsimile.

Intelligent Network (IN) - A network that allows functionality to be distributed flexibly at a variety of nodes on and off the network and allows the architecture to be modified to control the services.

Interface - A concept involving the definition of the interconnection between two equipment items or systems. The definition includes the type, quantity, and function of the interconnecting circuits and the type, form, and content of signals to be interchanged via those circuits.

Layered Architecture - Functional group of protocols that adheres to a logical structure of network operations.

Network - 1. An interconnection of three or more communicating entities and (usually) one or more nodes. 2. A combination of passive or active electronic components that serves a given purpose.

Network Topology - The connecting structure, consisting of paths, switches, and concentrators that provides the communications interconnection among nodes of a network. Note: Two networks have the same topology if the connecting configuration is the same, although the networks differ in physical interconnections, distance between nodes, transmission rates, and signal types.

Open System - A system whose characteristics comply with specified standards and that therefore can be connected to other systems that comply with these same standards.

Open Systems Interconnection (OSI) - A logical structure for network operations standardized within the ISO; a seven-layer network architecture being used for the definition of network protocol standards to enable any OSI-complaint computer or device to communicate with any other OSI-compliant computer or device for a meaningful exchange of information.

Open Systems Interconnection (OSI) Architecture - Network architecture that adheres to that particular set of ISO standards that relates to Open Systems Architecture.

Overhead Bit - Any bit other than a user information bit.

Overhead Information - Digital information transferred across the functional interface separating a user and a telecommunication system (or between functional entities within a telecommunication system) for the purpose of directing or controlling the transfer of user information and/or the detection and correction of errors. Overhead information originated by the user is not considered as system overhead information. Overhead information generated within the system and not delivered to the user is considered as system overhead information.

Protocol - A set of unique rules specifying a sequence of actions necessary to perform a communications function.

T-Carrier - Generic designator for any of several digitally multiplexed telecommunications transmission systems.

Telecommunication - Any transmission, emission, or reception of signs, signals, writing, images and sounds or intelligence of any nature by wire, radio, optical, or other electromagnetic systems.

Telecommunication Architecture - Within a telecommunication system, the overall plan governing the capabilities of functional elements and their interaction, including configuration, integration, standardization, life-cycle management, and definition of protocol specifications, among these elements.

Telecommunication Service - A specified set of user-information transfer capabilities provided to a group of users by a telecommunication system. The telecommunication service user is responsible for the information content of the message. The telecommunication service provider has the responsibility for the acceptance, transmission, and delivery of the message.

Synchronous Digital Hierarchy (SDH) - A newly adopted standard for multiplexing and interfacing signals for transmission over optical networks. Evolved from Synchronous Optical Network (SONET) developed in the United States.

Synchronous Transfer Mode (STM) - A proposed transport level, a time-division multiplex-and-switching technique to be used across the user's network interface for ISDN.

System - Any organized assembly of resources and procedures united and regulated by interaction or interdependence to accomplish a set of specific functions.

User - A person, organization, or other entity (including a computer or computer system), that employs the services provided by a telecommunication system, or by an information processing system, for transfer of information to others. Note: A user functions as a source or final destination of user information, or both.

User Information - Information transferred across the functional interface between a source user and a telecommunication system for the purpose of ultimate delivery to a destination user. Note: In data telecommunication systems, "user information" includes user overhead information.

1.2 Report Organization

In the sections that follow, we present the basic architectural concepts for telecommunication networks. Service offerings are covered in Section 2, functional and layered architectures in Section 3, and physical implementations in Section 4. The forces that are expected to shape future network architectures are examined in Section 5, along with some evolutionary predictions. References are listed in Section 6.

Our objective is to show how the complexity of networks increases as one progresses from service definitions, through many possible functional architectures, to a multiplicity of implementations using various mixes of hardware and software. This is illustrated in Figure 1. For each end-user service there are many possible architectures and for each architecture, many possible implementations. This complicates the network management tasks that must be responsible for all possible hardware and software implementations.

The network architecture identifies the major system building blocks and specifies how they must interact. Architectures are developed for the long-term and provide a unified consistent means for evolution of the network as needs change and technology advances. The major building blocks that incorporate network management are not included here but will be the subject of subsequent reports.

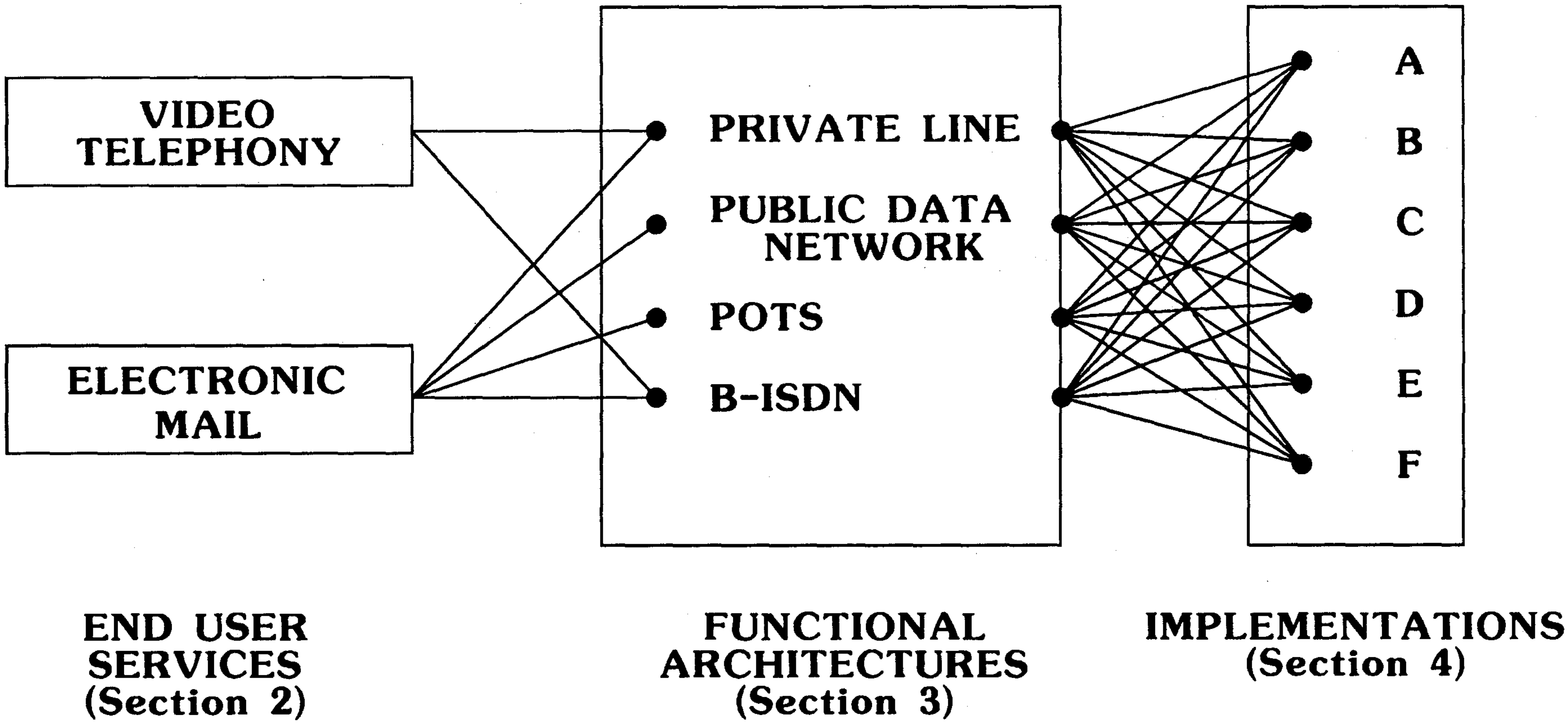


Figure 1. The expanding telecommunications environment.

2. TELECOMMUNICATION SERVICES

Today's telecommunication networks are undergoing constant change. There are new services offered and old services improved. New technologies are being developed and new networks appear on the horizon. Provision of modern telecommunication network services involves a complex series of interactions between network facilities whose underlying technologies are constantly changing and service demands that are constantly increasing. The functions needed to meet these service demands define the architecture. Their functional interrelationship is the subject of this report. We begin with a classification and description of services that are either currently available or will be soon. This is followed by a listing of specific service offerings and the transmission rates required for all services.

2.1 Service Classifications

User services may be classified in various ways. For example, a service is sometimes specified in terms of the attributes of the switching, transmission, and terminal parts of the network (e.g., packet switched data service). Services could be classified in terms of their applications (e.g., fixed, mobile, broadcast, data, etc.). Another basis for defining service classes is to group services so that each group has similar performance characteristics as perceived by the end user. This approach simplifies the development of user parameters and the assignment of values for specified service performance. This type of service classification is illustrated in Figure 2. Five major levels of division are shown. Beginning at the top the levels are:

1. The nature of the information signal perceived by the end user. At this level, the signals are either continuous (analog) or discrete (digital).

2. The type of source or human/machine usage of the information. For analog services, there may be audible, visual, or other sensory sources. For digital services, the sources may be a human operator, device media or computer applications program.

3. Networks are used for three general types of interaction: human access to a machine (such as a computer) and vice versa, machine interaction with one another, and interaction among humans.

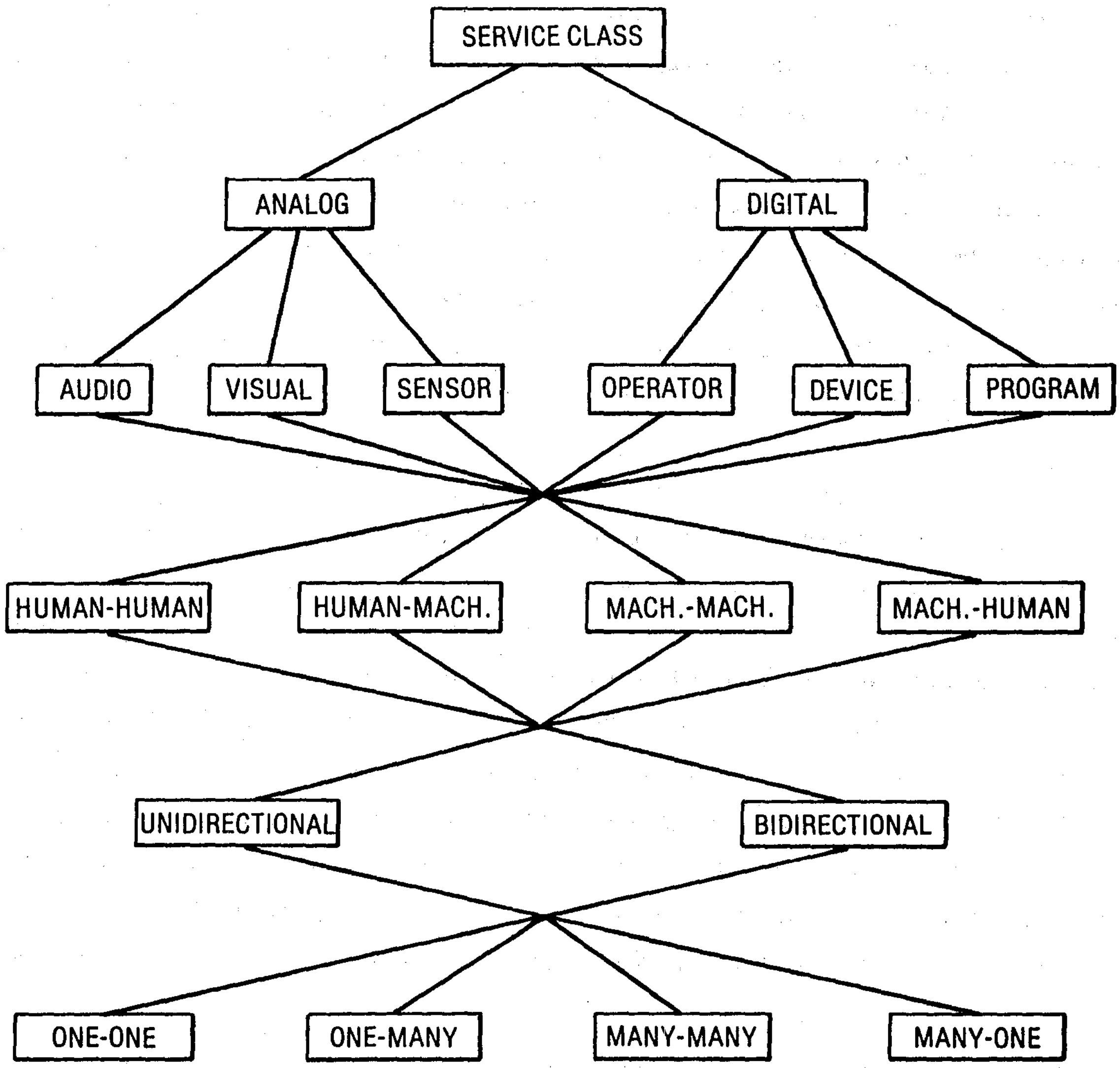


Figure 2. Service classification scheme.

4. The directivity of the access path. The information may be transferred in one direction only (simplex) or in both directions (duplex or half duplex).

5. The number of users, human or machine, that participate in a given dialogue can vary. This involves at least two or more end users on a one-to-one, one-to-many, many-to-one, or many-to-many basis.

It is possible to have various mixtures of these service classes. The actual performance required for each service class depends on application requirements. Some networks are designed to serve users from a single community of interest. Others may serve many communities of interest. The single-user networks are functionally specific and optimized to the user's needs. The common-user networks are less specific. They must be adaptive to many different user's needs. In most cases, the user's view of performance depends on what the user does, or the mission to be performed.

In the United States, the Federal Communications Commission (FCC) defines service offerings for regulatory purposes. A regulatory framework was established by the FCC (1977) under which services were either "basic" or "enhanced." Basic services are regulated. Enhanced services are not regulated. A basic service was defined in 1977 by the FCC as "a pure transmission capability over a communications path that is virtually transparent in terms of customer supplied information." An enhanced service was defined in 1977 as one "offered over common carrier transmission facilities that employees computer processing applications that act on the format, content, code, protocol, or similar aspects of the subscribers information or involves the subscriber with stored information."

Following a third computer inquiry, the FCC allowed the industry to provide enhanced services without structural separation. See FCC (1986). Several possible enhanced service applications that could be provided are listed in Figure 3.

International standards organizations use still other classifications for services. For example, the CCITT (1989) defines three classes as follows:

- Bearer Services - provides for transmission of signals between user-network interfaces.

- Teleservice - provides complete capability including terminals.

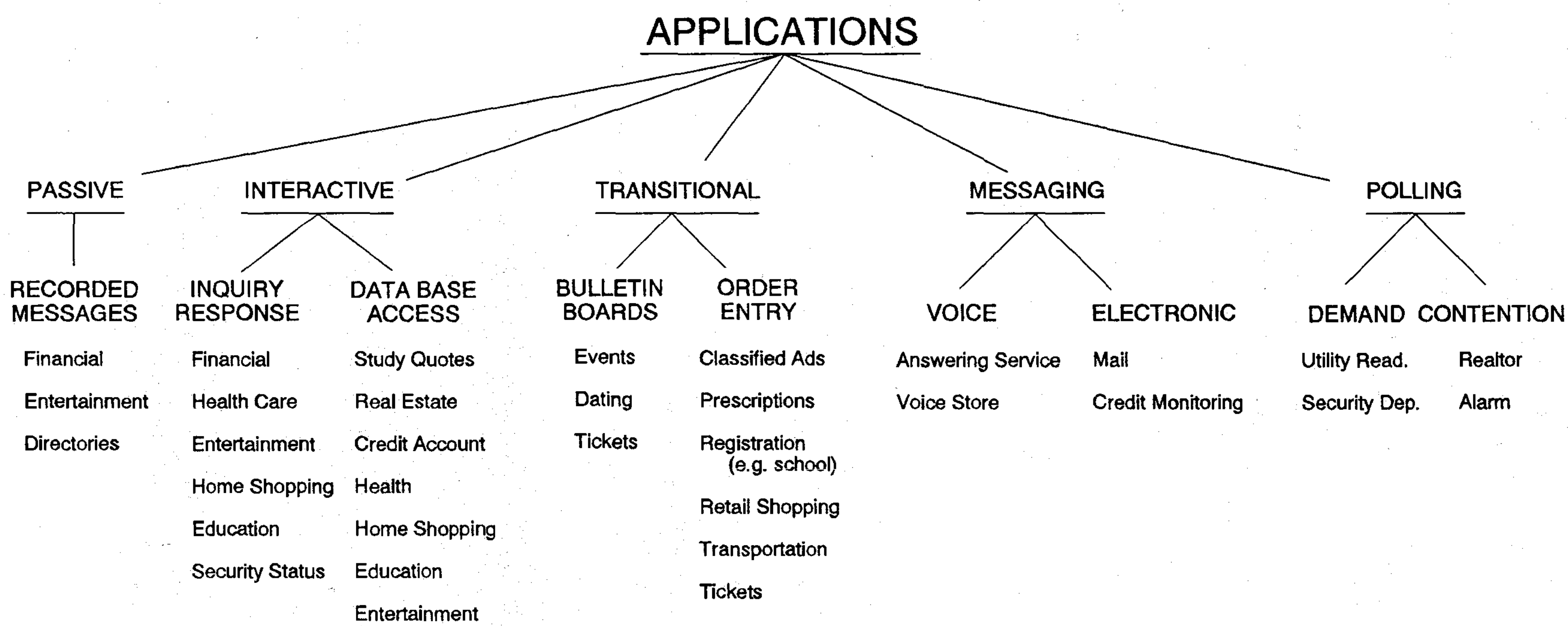


Figure 3. Potential enhanced service applications.

- o <u>Supplementary Services</u> - not a stand alone service but one that modifies a bearer service or teleservice offering.

The International Telephone and Telegraph Consultative Committee (CCITT) provides standards, called recommendations, for an Integrated Services Digital Network (ISDN) in CCITT (1989). The ISDN is expected to evolve from today's telephone network and will ultimately provide voice, data, and possibly low speed video services to the end-user over a single access line. One possible listing for residential and business-type services for an ISDN is given in Table 1. Appendix A lists the service features and functions offered by one modern PABX.

The number and type of services supported by a network usually depends on the available network capacity. The CCITT (1989) classifies Broadband ISDN (B-ISDN) services into two categories: interactive services and distributive services. Interactive services include dialogue, messaging, and retrieval services. Distribution services include services with and without user presentation control. These service classes, their form of communication and specific examples of broadband services are listed in Figure 4. Appendix B expands on this list and includes additional attributes for each service class.

The introduction of broadband networks like B-ISDN is expected to stimulate many new services using a variety of new transport rates. An indication of the rates required for these new broadband services relative to other services is shown in Figure 5.

Approximate bit rates for these and other types of services are also given in Table 2. These are average bit rates. Actual rates will depend on transmission duty cycles. The duration of a session for each service may vary over a wide range. Figure 6 illustrates this range as a function of the transmission rate for various kinds of service.

2.2 T-Carrier Systems

The term T-carrier is the name given to series of digital cable transmission systems developed by the industry beginning in the early 1960's and in common use today. The original technology, known as T-1, replaced 24 wire-pair analog trunks with 2 metallic pairs providing the same transmission capacity. This was accomplished by digitizing 24 analog voice channels with pulse code modulation (PCM) at 64 kb/s and combining them with

Table 1. Possible Service Offerings for an ISDN Architecture

RESIDENCE

1) Normal Dial Pulse Telephone Service
2) Touchtone
3) Custom Calling Services
   - Call Forwarding
   - Call Waiting
   - Speed Calling
   - 3-Way Calling
4) Point of Sale
5) Videotex
   - Home Banking
   - Shopping
   - Information, Reservations
   - Entertainment
6) Energy Management
7) Home Security
8) Meter Reading
9) Advanced Custom Calling Services
   - Call Block (Nuisance Call Reject)
   - Call Return
   - Repeat Dialing
   - Call Trace
   - Selective Call Forwarding
   - Selective Call Waiting
   - Call Monitor
   - Call Tracking
10) Calling Party Number Display
11) Call Completion to Busy Subscriber
12) Voice Announcements
13) Alternate Billing
14) Store and Forward
15) Human Personal Service
16) Hi-Fi Voice
17) Video Billing
18) Video Broadcast
19) Video 2-Way
20) Packet Switched Data Terminal
21) Personal Computer Networking
22) Customer Direct Access
23) ISDN Basic Access

BUSINESS

1) Normal Dial Pulse Telephone
2) Centrex-ESS
   - Message Desk, Attendant Service, Call Queuing
3) City Wide Centrex
4) Small Customer Centrex
5) Local Area Network (LAN)
6) Point of Sale
7) Videotex
8) Energy Management
9) Office Information Service
10) Customer Control and Rearrangement
   - Features
   - Numbers
   - Dial Tone
   - Bit Stream
11) Teleconference
12) Packet Switched Data Terminal
13) Advanced Custom Calling Services
14) Voice Annotated Messaging
15) Calling Party Number and Charges Display
16) Call Completion to Busy Subscriber
17) Alternate Billing Service
18) Hi-Fi Voice
19) ISDN Basic Access
20) ISDN Primary Access
21) High-Speed Digital Fax
22) Private Virtual Network (Software Connected)
23) Simultaneous Digital Voice and Data
24) Video Broadcast
25) Personal Computer Interworking
26) Encryption-Voice and Data

Service Classes	Communication Form	Broadband Services
Dialogue Services	Video Communication	Video-telephony Video-telephone Conference Video-conference Surveillance Video/Audio transmission
	Data Communication	High-speed Data Transmission High-volume File Transfer Computer Aided Services (e.g. CAD/CAM) Real-time Control and Telemetry Services for LAN Interconnection
	Document Communication	High-speed Facsimile Document Communication Service (text, graphics, audio, images, moving pictures)
Messaging Services	Video Communication	Picture Mail
	Document Communication	Document Mail Service (text, graphics, up to moving pictures)
Retrieval Services	Videotex	Broadband Videotex
	Retrieval for Text, Data, Graphics, Audio, Images, Moving Pictures	Audio Retrieval High Resolution Image Retrieval Film Retrieval Document Retrieval
Distribution Services without User Individual Presentation Control	Audio Distribution	Radio Program Broadcasting
	Television	TV Program Broadcasting Enhanced TV, HQTV, 3DTV, HDTV, Pay TV
	Electronic Publishing	Electronic Newspaper
Distribution Services with User Individual Presentation Control	Broadcast Videography	Teletext Cable Text

Figure 4. Possible broadband services.

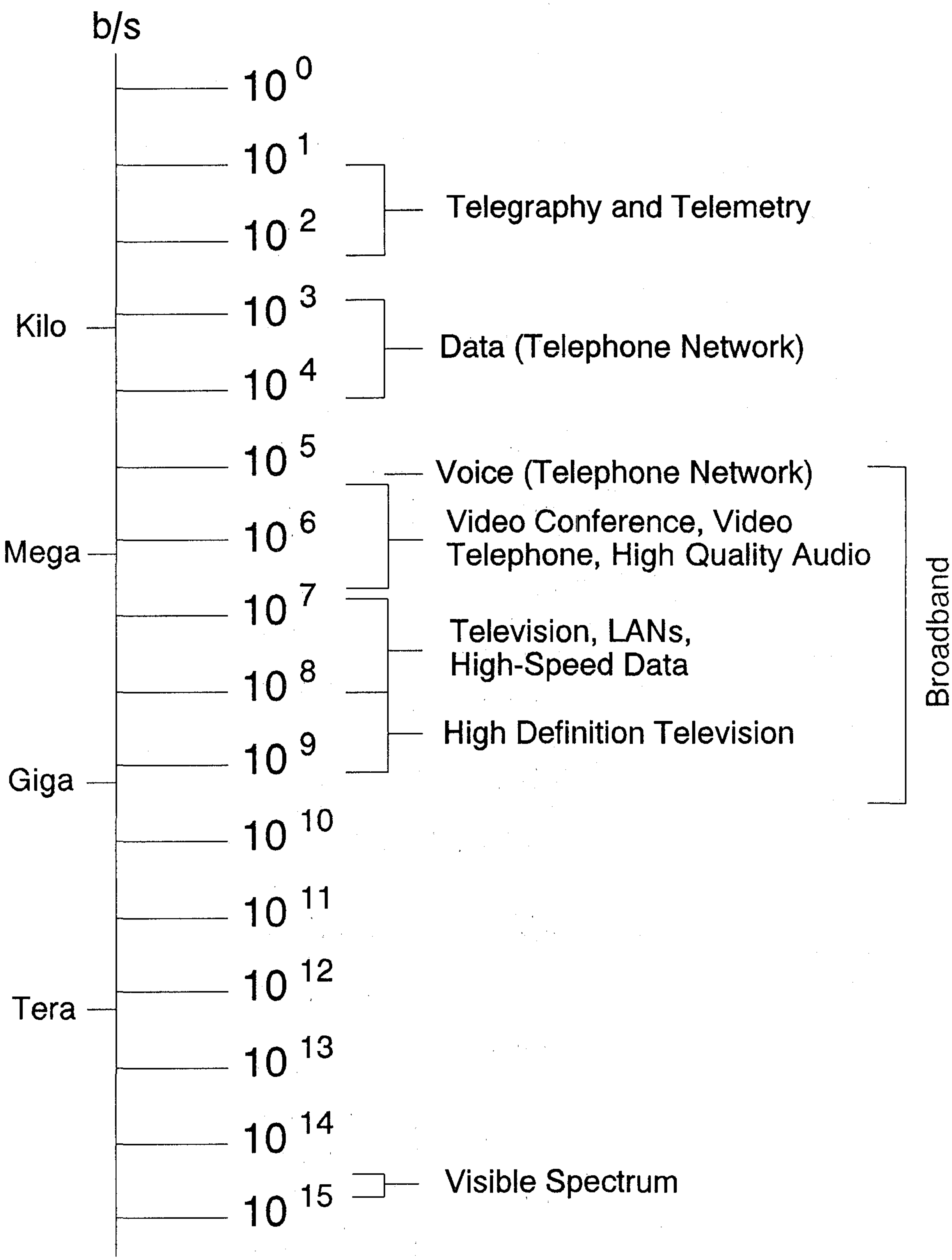


Figure 5. Broadband services rate structure.

Table 2. Approximate Bit Rates for Various Services

Service	Mbit/s
o Telemetry	.0001
o Data/Text	.01
o Low Fidelity, Voice and Data Image	.1
o High Fidelity Sound	1.0
o Videophone	1 to 10
o Data/Image Medium Quality	1 to 10
o Conventional TV	50 to 100
o High Definition TV	150 to 1000
o Data/Image High Quality	10 to 10,000

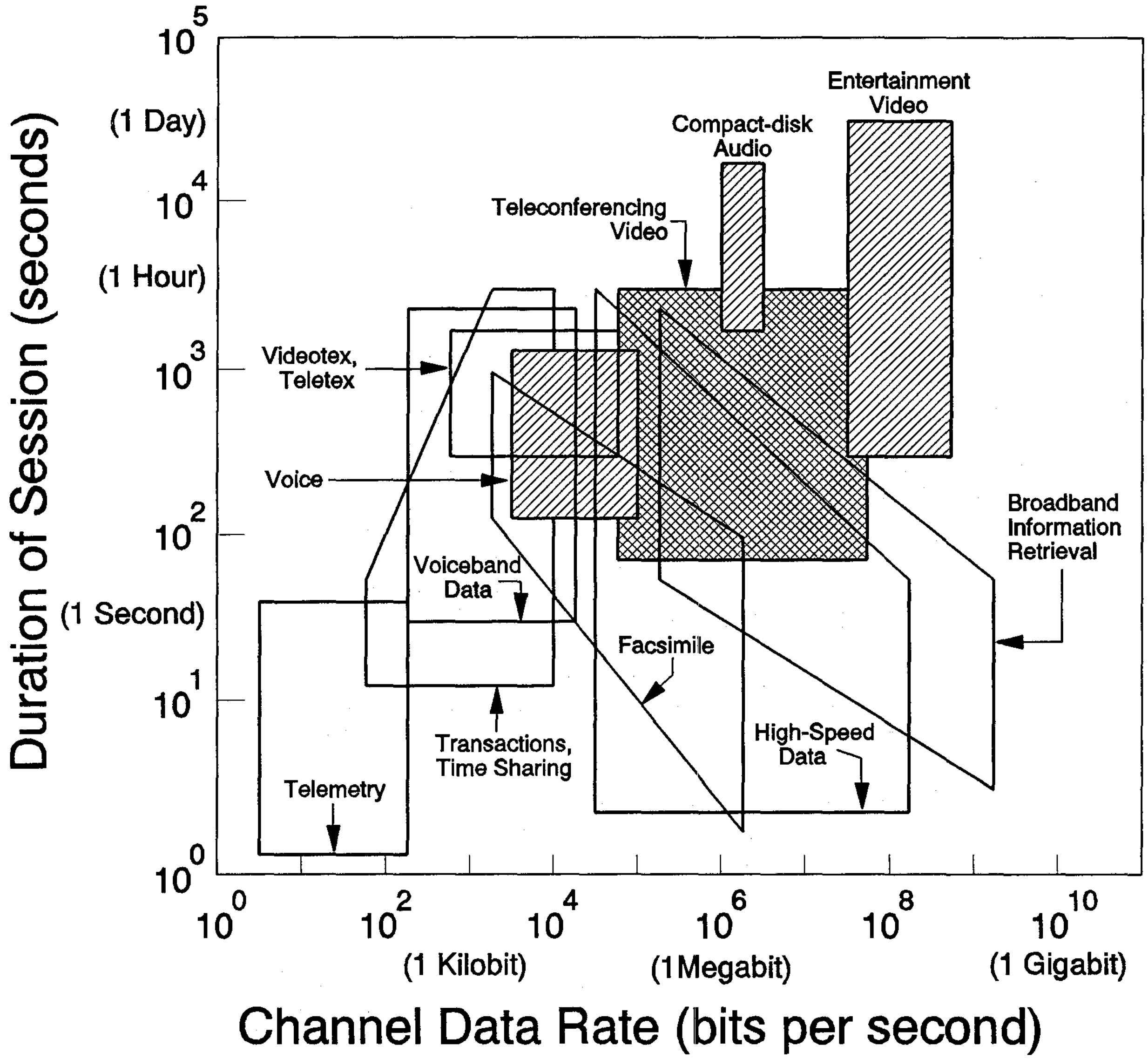


Figure 6. Transmission rate and duration of various services (from Weinstein, 1987).

synchronizing signals into a single 1.544 Mb/s data stream for transmission. The 1.544 Mb/s contains 1.536 Mb/s of usable capacity for voice or data plus 8 kb/s of overhead for framing and synchronization. Since development of the T-carrier, an entire series of T-carrier systems have evolved to transport digital signals at rates ranging up to 274.176 Mb/s using either cable or microwave radio links.

The T-1 carrier is the most commonly used transmission facility. Since T-1 was tariffed in 1982, it has had rapid growth as a basic element of private networks. Equipment for digitizing and multiplexing analog voice signals, known as D-channel banks at switch installations, as well as a whole range of digital interfaces and digital access and cross-connecting systems (DACS) have evolved for use with T-carrier systems.

A channel bank contains analog to digital conversion equipment that converts a 4-kHz analog voice signal into a 64-kb/s digital signal known as a DS-0 signal. This is accomplished using PCM. PCM involves sampling the amplitude of the analog signal at a 8 kHz rate and coding each sample into 8 bits.

The digital channel banks in common use today are designated D-3 or D-4. The D-3 banks digitize 24 voice channels and multiplex them into a 1.544-Mb/s digital signal known as DS-1. This DS-1 signal can then be transmitted over a T-carrier facility known as T-1 or multiplexed to higher levels before transmission. A D-4 channel bank actually contains two 24-channel digital groups or digroups, i.e., 48 full duplex channels. The D-4 banks have also been adapted for use in digital data systems. A D-4 digital data bank can terminate data loops, multiplex subrate data channels, and implement multipoint circuits along with test and maintenance technology.

The North American digital hierarchy for T-carrier transmission systems is tabulated in Table 3 with the multiplex levels depicted in Figure 7 for the pulse code modulation and time division multiplex (PCM-TDM) system in common use today.

2.3 High Speed Transport

With the recent introduction of optical fiber networks, the high-speed transport of digital signals in the 50 Mb/s to 10 Gb/s range became feasible.

In 1988, the CCITT accepted a synchronous digital hierarchy (SDH) as the international standard for high-speed transport over fiber. See Section 3.3.

Table 3. North American Digital Hierarchy

Digital Signal Levels	Transmission Rate	Number of T1 Equivalents	Digital Transmission Facilities
DS-4	274.176 Mb/s	168	T4M
DS-3	44.74 Mb/s	28	T3
DS-2	6.312 Mb/s	4	T2
----	3.152 Mb/s	2	T1C
DS-1	1.544 Mb/s	1	T1
DS-0	.064 Mb/s (64 kb/s)	1/24	---

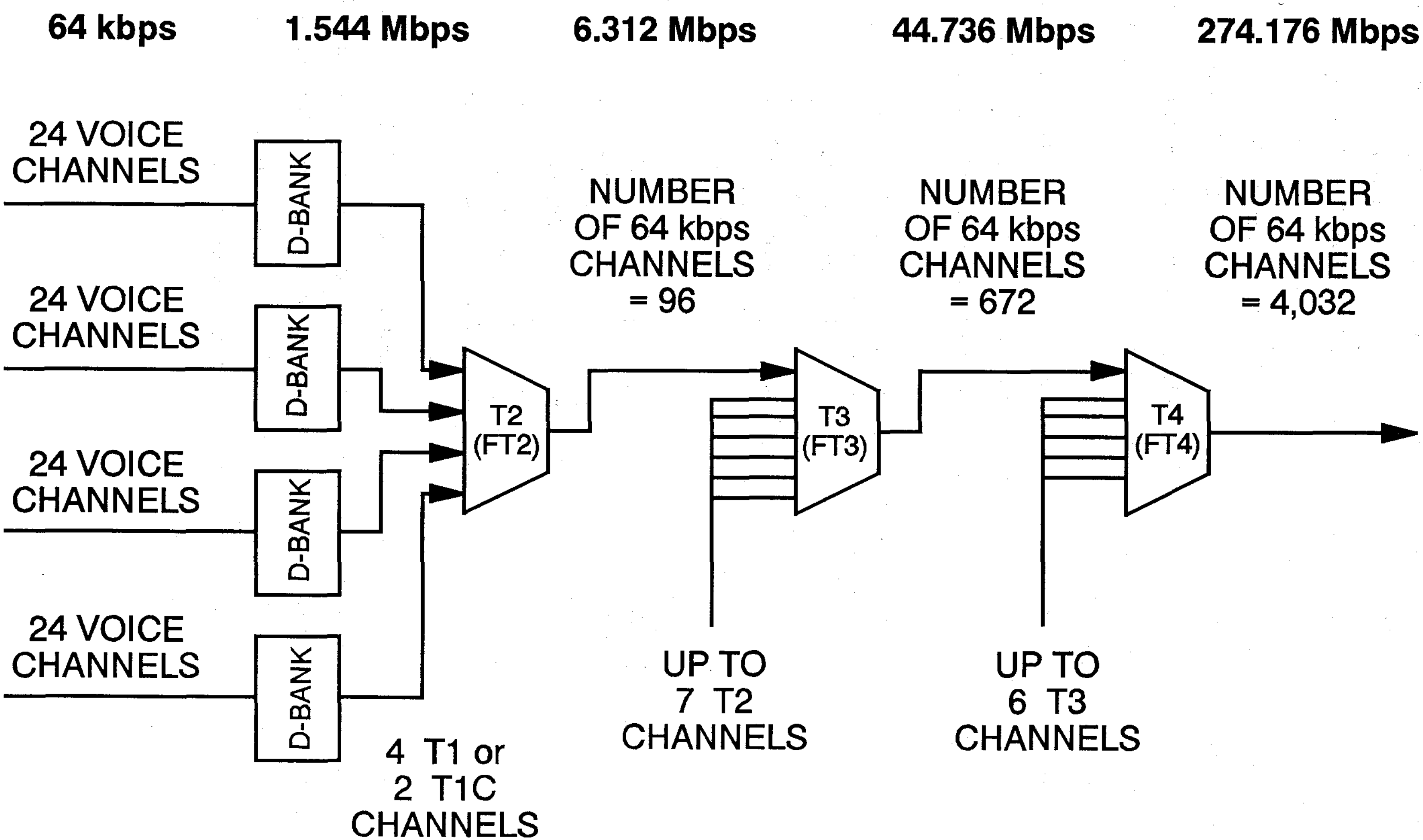


Figure 7. The PCM-TDM hierarchy.

Similar standards have been adopted by the American National Standards Institute (ANSI) in the United States. SDH incorporates phase-locked frequency standards located around the world to synchronize the transmission of bits. This synchronization process eliminates bit stuffing, storing, and frame detection along with other complexities commonly associated with asynchronous and plesiosynchronous digital networks. SDH is expected to lead to simpler multiplexing and demultiplexing hardware and software at reduced cost. Single-chip multiplexers can access any 64 kb/s channel from a 155.52 Mb/s B-ISDN channel.

The basic first optical carrier level (OC-1) for SDH is 51.840 Mb/s. Certain higher levels are the integer multiples 3, 9, 12, 18, 24, 36, and 48 of CO-1 yielding the hierarchy of transmission rates given in Table 4.

Table 4. Selected SDH Signal Levels and Their Rates

Carrier Level	Optical Carrier Rate (Mb/s)	Clear Channel Capability Rate (Mb/s)
OC-1	51.84	49.54
OC-3	155.52	148.61
OC-9	466.56	445.82
OC-12	622.08	594.43
OC-18	933.12	891.65
OC-24	1,244.16	1,188.86
OC-36	1,866.24	1,783.30
OC-48	2,488.32	2,377.73
OC-192	9,953.28	9,510.91

Rates OC-3 and OC-12 have been selected by the CCITT for transmission in both the interexchange long-distance network and the user-network interface. The OC-3 level of 155.520 Mb/s, for example, will be extended to subscribers for video services. Digitized and high definition television (HDTV) can both be carried within the OC-3 channel and integrated circuit technologies can potentially handle this rate at low cost.

3. FUNCTIONAL AND LAYERED ARCHITECTURES

The term network architectures is defined in many different ways. For example:

> "Network architecture is a descriptive phrase for the combinations of hardware and software that comprise a (computer) network." Auerbach Editorial Staff (1976).
>
> "Network architecture may be specified in terms of protocols for communication between pairs of peer-level layers." Green (1980).
>
> "Architecture (or topology) concerns the physical arrangement and connectivity of network elements." Rosner (1982).
>
> "The functional view of a network is called the network architecture. This view is independent of implementation." Konangi and Dhas (1983).
>
> "The architecture of a physical network consists of a structured topology of physical elements and their interconnections." LeMay and McGee (1987).
>
> "Telecommunication architecture within a telecommunication system is the overall plan governing the capabilities of functional elements and their interaction, including configuration, integration, standardization, life cycle management, and definition of protocol specifications, among these elements," see proposed Federal Standard 1037B (1991).

These are a few examples of definitions for architecture found throughout the telecommunications literature. Our purpose here is to clarify the meaning of functional architecture as it pertains to the telecommunications network designer. Therefore our emphasis is on functional architectures in use today, particularly layered architecture. The implementation of the any architecture is sometimes referred to as the physical architecture. Implementation consists of hardware and software and by definition it must adhere to some functional architecture. Layered architectures are discussed below. Implementation of these architectures is described in Section 4.

Layered architectures are often based on an open systems interconnection (OSI) model called the protocol reference model (PRM) explained in Section 3.1. The architecture itself is defined by precise functions or groups of protocols that specify relationships within and between layers. The application of layered models to advanced networks such as ISDN and B-ISDN is described in Sections 3.2 and 3.3. In Section 3.4, we present some other functional architectures that apply to networks in common use today but are not based on the 'open systems' model.

3.1 Layered Architectural Models

The precise definition of functions that a network should perform to provide a service is denoted as its functional architecture. This is distinct from the implementation which specifically defines the hardware facilities and software programs that either implement or execute the functions defined by the architecture.

The functional architecture of telecommunication systems usually involves interactions between two network elements such as two users, two processors, two controllers, two modems, etc. The rules for these interactions between similar elements are called protocols and the functional architecture is often expressed in terms of protocols for the communication between pairs of peer-level network elements - thus the term peer-protocols is often used. See Knightson et al., (1988). The basic elements of a protocol are its syntax, semantics, and timing. These elements are described below.

The exchange of information, whether it is subscriber or overhead information, requires symbols which are clearly defined and preferably standardized. Otherwise it is difficult to interpret and distinguish their meaning. In telecommunications where the information exchange takes place by electromagnetic means, symbols are represented by changing circuit conditions to generate signals or vary signal states. Since these conditional changes are generally limited (by bandwidth, distortion, and noise), many distinct symbols can only be conveyed by introducing group signals using time as one element. The resulting systematic arrangement provides an alphabet or code, i.e., the syntax.

The meanings given the syntax (the concepts associated with the symbols or signals in the mind of an interpreter) is a field known as semantics. The ordering and duration of events invoked by syntax and semantics involves timing. Combinations of syntax, semantics, and timing provide a means for conducting interactions or controlling the behavior between two or more entities. These combinations are known by the generic name - protocols. Note that protocols inherently include format and code (the syntax), speed and duration (timing), and their contents invoke specific actions and responses (semantics). Thus protocols may be considered as the logical abstraction of the entire physical process of communications and, when implemented in software or hardware, they may be included in subscriber information transfer as well as in the control functions which effect that transfer.

Due to the complex nature of modern telecommunication networks it is desirable to organize the functional architecture into layers. Each layer consists of a group of protocols. The function of each layer is to offer services to the higher layer. The implementation method is not important to the higher layer. The resulting hierarchical network structure is usually called a layered architecture or sometimes a protocol architecture. The general layered architecture concept is described in Appendix C. The layers and protocols define the network architecture according to Tannenbaum (1981).

Layered architectures have been developed by standards organizations, common carriers, and computer manufacturers. An example of the later is the Systems Network Architecture (SNA) developed by the International Business Machines (IBM) Corporation. SNA is currently widely used but this may change as the OSI model grows according to Martin (1988).

The seven layer OSI model was developed by the International Standards Organization (ISO). The OSI model is illustrated in Figure 8. Only recently have attempts been made to apply this layered concept to other networks. Narrative descriptions of the value-added services provided by protocols in each layer to the adjacent layer above are defined by proposed Federal Standard 1037B (1991). They are as follows:

> Physical Layer: Layer 1, the lowest of seven hierarchical layers. The Physical Layer performs services requested by the Data Link Layer. The major functions and services performed by the Physical Layer are: (a) Establishment and termination of a connection to a communications medium; (b) Participation in the process whereby the communication resources are effectively shared among multiple users, e.g., contention resolution and flow control; and, (c) Conversion between the representation of digital data in user equipment and the corresponding signals transmitted over a communications channel.
>
> Data Link Layer: Layer 2. This layer responds to service requests from the Network Layer and issues service requests to the Physical Layer. The Data Link Layer provides the functional and procedural means to transfer data between network entities and to detect and possibly correct errors that may occur in the Physical Layer.
>
> Network Layer: Layer 3. This layer responds to service requests from the Transport Layer and issues service requests to the Data

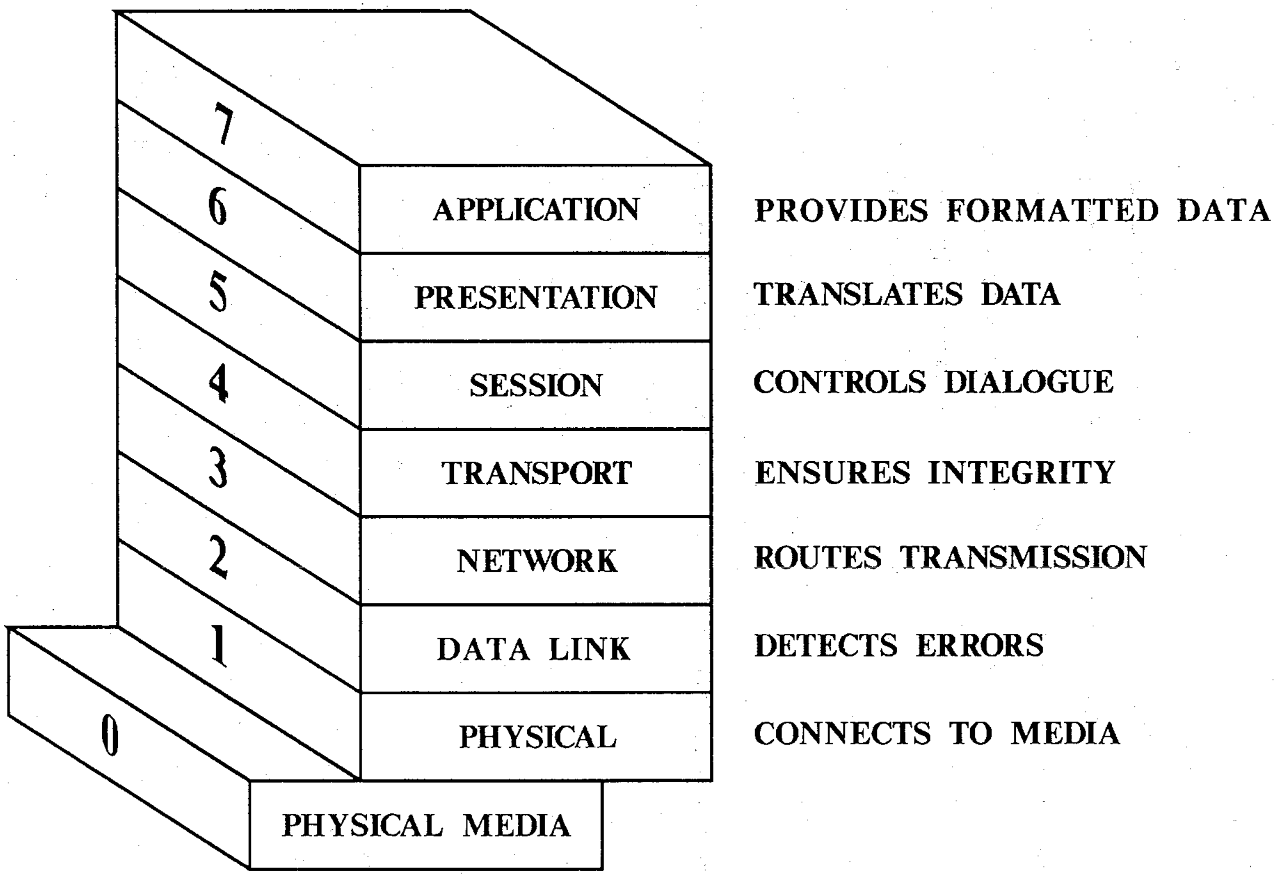


Figure 8. Protocol reference model for data communications.

Link Layer. The Network Layer provides the functional and procedural means of transferring variable length data sequences from a source to a destination, via one or more networks while maintaining the quality of service requested by the Transport Layer. The Network Layer performs network routing, flow control, segmentation/desegmentation, and error control functions.

Transport Layer: Layer 4. This layer responds to service requests from the Session Layer and issues service requests to the Network Layer. The purpose of the Transport Layer is to provide transparent transfer of data between end users, thus relieving the upper layers from any concern with providing reliable and cost-effective data transfer.

Session Layer: Layer 5. This layer responds to service requests from the Presentation Layer and issues service requests to the Transport Layer. The Session Layer provides the mechanism for managing the dialogue between end-user application processes. It provides for either duplex or half-duplex operation and establishes checkpointing, adjournment, termination, and restart procedures.

Presentation Layer: Layer 6. This layer responds to service requests from the Application Layer and issues service requests to the Session Layer. The Presentation Layer relieves the Application Layer of concern regarding syntactical differences in data representation within the end-user systems.

Application Layer: Layer 7. The highest layer. This layer interfaces directly to and performs common application services for the application processes; it also issues requests to the Presentation Layer. The common application services provide semantic conversion between associated application processes.

While the upper layers are embedded in the terminal software, the lower three layers are network-specific layers that support information transfer. Layer 1 assumes the existence of physical communication to other network elements as opposed to the virtual connectivity used by the higher layers. Some authors e.g., Knightson et al., (1988) denote the transmission media itself including network topology as layer 0, since it is logically below layer 1 and is concerned with switch placement, concentrators, and lines, and what capacities to assign to the lines. Section 4 of this report is primarily concerned with the implementation of lower layers 0 through 3.

There is an abstract boundary between adjacent layers that is sometimes called an interface. This boundary separates functions into specific groupings. At each boundary, a service that the lower layer offers to its upper neighbor can be defined. Service providers are not required to physically implement access to these layer boundaries and may even merge layers. The important functional entities that must be transmitted are the protocols between peer-level layers. This protocol information is exchanged between network elements by appending it along with the final message in the sequence of transported bits (see Appendix C). The implementation will conform to international standards when the protocol information that is transmitted between two layers of the local system and the corresponding layers of the communicating end systems is interpreted correctly by both systems.

The protocols within all layers define the networks' functional (or protocol) architecture. The specification of these protocols is needed to implement a service to an end user. Implementation of these protocols in hardware and software can be accomplished in many ways. Neither the details of the implementation nor the boundary services are part of this architecture. One major advantage of this layered architecture concept is that lower layer implementations can be replaced as technologies advance, for instance, when a fiber link replaces a coaxial cable. The only requirement being that the new implementation provide the same set of services to its adjacent upper layer as before.

It is not always necessary to implement every layer or every protocol within a layer. For example, error checking, a function of Layer 2, may not be necessary on links with low error characteristics.

Sometimes users may want access to specific layers in their implementations. For example, access to the Transport Layer would permit a users software program to use services of Layers 1 through 4 to reliably transfer data between different end systems. Although networks may have different implementations, there are certain internationally accepted protocols for network access. This is desirable from the vendor's point of view since it allows their products to be used in many countries. It is also desirable from a user's point of view because it allows him to easily interconnect terminals and hosts from different vendors via a public network.

There are limitations to the OSI model. For example, it may be difficult to apply to certain distributed systems where computing functions are dispersed among many physical computing elements. It does not in its present form, represent important existing and future services such as analog voice communication. It tends to restrict certain functions to end systems.

This can be inconvienent in those instances where said functions could be better performed by the network itself. The model is connection oriented whereas many real applications are connectionless. Finally, the OSI reference model involves perhaps too many interactions between network elements to establish a simple connection. For example, it can be shown that for a network with two intermediate nodes (as in Figure 9) a complete connection from Layer 7 of System A to Layer 7 of System B requires 24 passes through the network.

Figure 9 illustrates the application of this model for connecting a user to a computer program via two intermediate switching nodes. Note that only the lower layers 0 to 3 are involved at a transfer node. Layer 4 is concerned with the end-to-end integrity of the information transferred between systems A and B. Actually a functional architecture based on this model and the subsequent implementations could be different for each link in this configuration. Thus, the protocols from System A to the first node may be entirely different than protocols 1 through 3 between the switching nodes. Even the physical transmission media may differ. Figures 10a and 10b indicate the relationships between the OSI protocol reference model and conventional data terminal equipment (DTE), as well as data communication equipment (DCE). In Figure 10c, we relate this reference model to the functional grouping of the elements in an ISDN. Figure 10d illustrates one implementation of the two communicating systems with a subnet containing the two nodal switches. Later in this report, we will show how the reference model can take on more dimensions to include the network management and control functions.

Based on the OSI reference model, it is possible to define a number of architectures for a given end-service. This is accomplished by selecting appropriate protocols for each of the seven levels. An example of some standard architecture combinations is illustrated in Figure 11. These combinations were selected by the Corporation for Open Systems (COS, 1987). Here an International Standard Organization (ISO) number is assigned for each protocol level for two end-user services, namely file transfer and electronic mail. The networks are defined at the bottom of each column. Such lists of protocols and their relationships are not necessarily sufficient to ensure that different implementations can communicate with each other. In order to do so they must 1) correctly implement the protocols, 2) select compatible

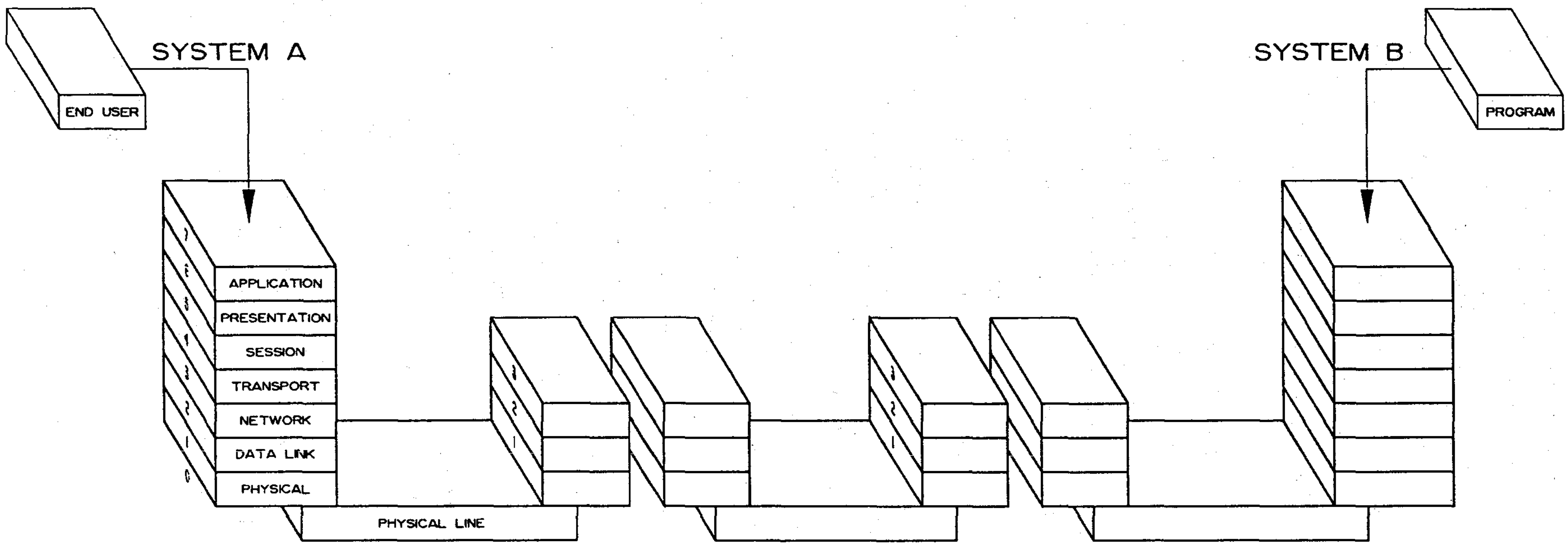
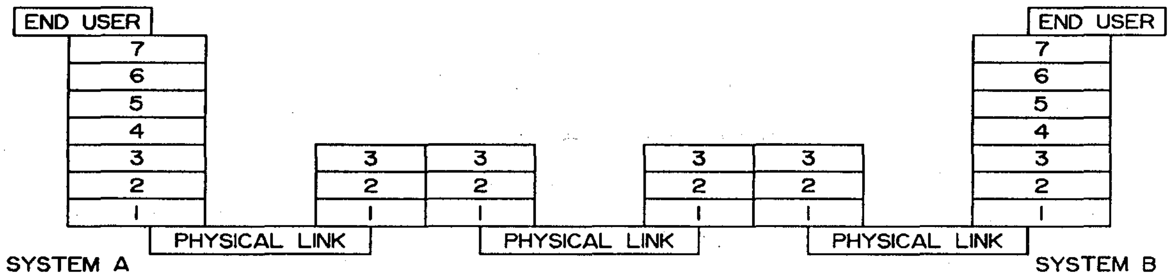
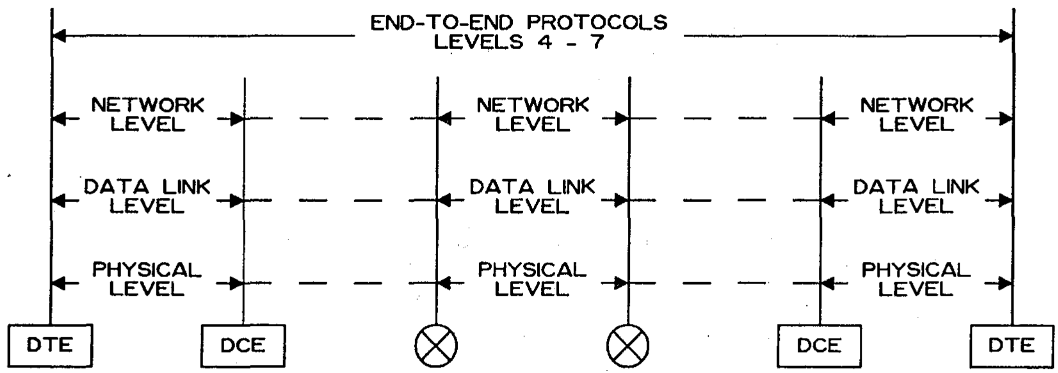


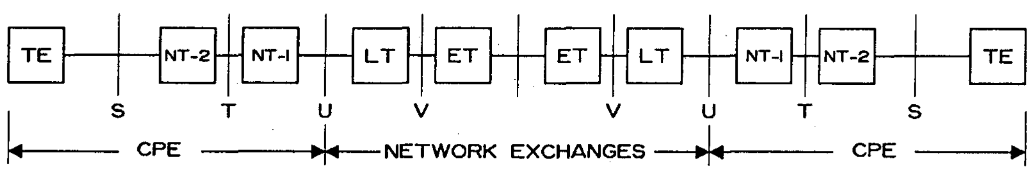
Figure 9. Application of protocol reference model to a network with intermediate nodes.



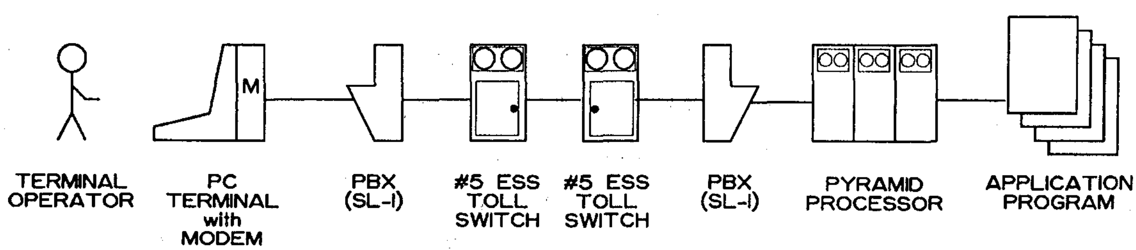
a) OSI Reference Model



b) Functional Groupings



c) Implementation example



d) Functional Grouping for ISDN

Figure 10. Architectural models and an implementation.

protocol options, and 3) have compatible interpretations of the protocol specification.

There are several interesting points that can be noted from Figure 11. Although the file transfer service differs considerably from an electronic mail service, they can only be distinguished at the application level (Layer 7). The protocols at levels 4, 5, and 6 are identical in terms of the actual protocol standard but may differ internally (e.g., as a function of transmission rate). Layers 1, 2, and 3 show differences, not because of the service difference, but because of the network differences. The three LANs are distinguished by different protocols at Layer 1. The other packet and private line networks are distinguished by differences in the Layer 3 protocols.

Network and service distinctions may not always occur at the levels indicated in Figure 11. In addition, the layered architecture may change at different hierarchical levels and even between source and destination terminals. Such differences are often handled with protocol converters (or gateways). For example, a protocol converter would be required where a LAN interfaces with the X.25 packet network.

Standards organizations such as CCITT, ISO, and ANSI are engaged in developing standards for various protocol layers. Figure 11 shows a few of the many functional architectures for file transfer and electronic mail services that can be implemented from these standard protocols. There are of course, other services and other architectures that could be provided. Later, we will show that there may be several possible implementations of each architecture.

3.2 Narrowband ISDN

The OSI model is currently being expanded to include multidimensional models for ISDN and B-ISDN. In the following paragraphs, we describe these ISDN structures and their protocol reference models.

The CCITT (1989) defines ISDN as a "network, in general, evolving from a telephony integrated digital network, that provides end-to-end digital connectivity to support a wide range of services, including voice and nonvoice, to which users have a limited set of standard multipurpose user-network interfaces". Standard interfaces are based on multiples of 64 kb/s channels called bearer or B channels and a control signaling channel of

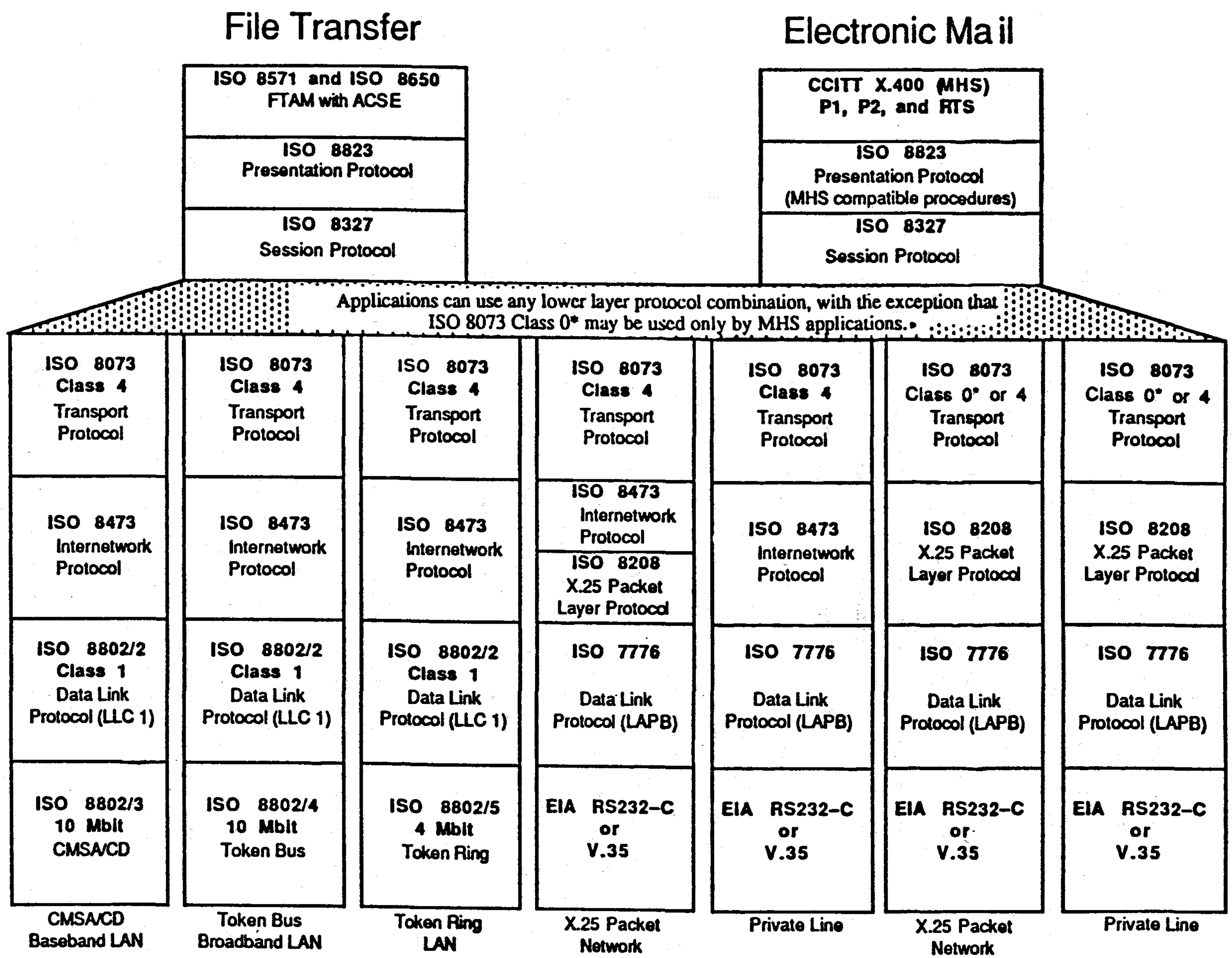


Figure 11. Protocol combinations defining specific network architectures.

64 kb/s or 16 kb/s called the data or D channel. Thus, in North America, the basic rate interface (BRI) is 2B + D (D = 16 kb/s) and the primary rate interface (PRI) is 23B + D (D = 64 kb/s).[1]

The fact that ISDN is evolving from telephony limits these access rates generally to less than 2 Mb/s. This is because much of telephony's embedded plant including the so-called "last mile" to a users premises, was and is twisted wire pair. An ISDN interface that integrates digital voice with data permits both to be transmitted over these wires.

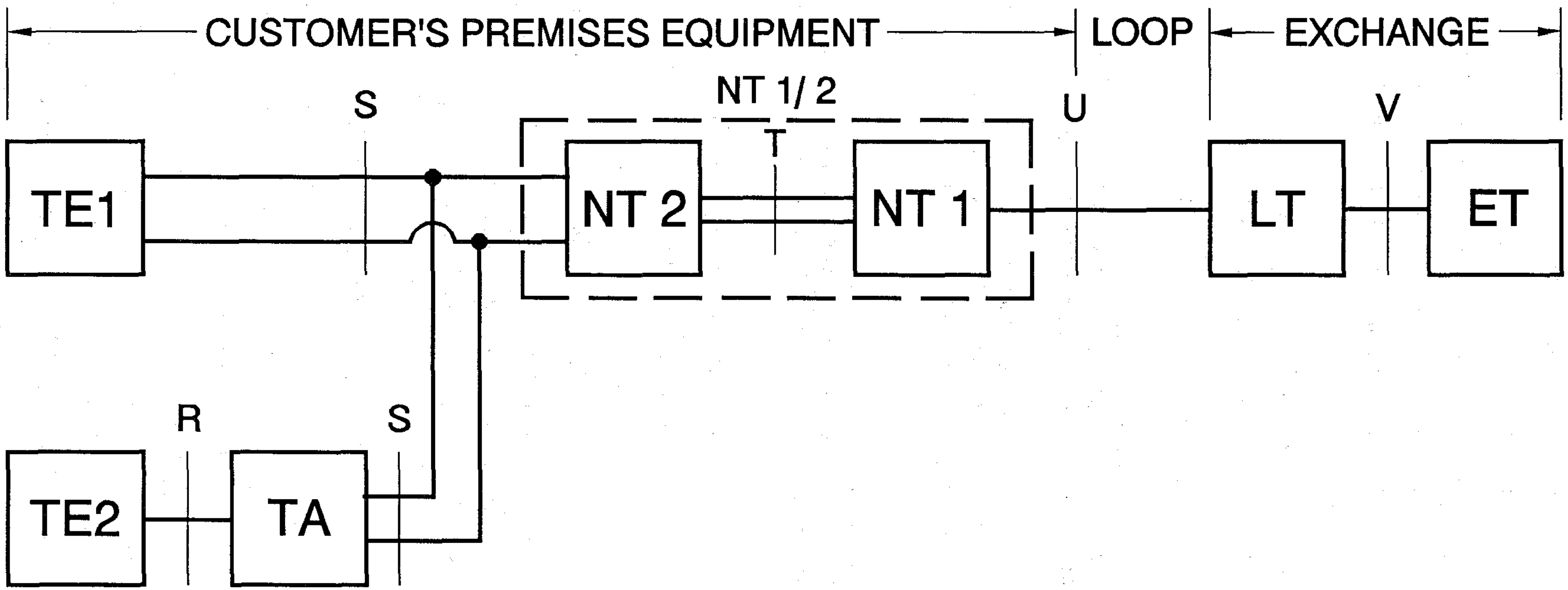
Unlike ISDN, B-ISDN is not aimed at maximizing the use of the existing copper cable plant. B-ISDN uses some of the concepts developed for ISDN but it also contains intelligence to provide additional service features, maintenance, and network management functions. It will have the ability to carry all types of traffic, including ISDN traffic, over a wide range of switching, multiplexing, and transmission rates with network administration, operation, and management (AO&M) data embedded within the channels. ISDN defines end-user interfaces, while B-ISDN includes the interexchange networks interfaces. B-ISDN permits dynamic allocation of the capacity of transport resources whereas ISDN provides fixed channel transmission rates.

The ISDN Recommendations (CCITT, 1989) define functional groupings of user equipment and various reference points between these groupings as indicated in Figure 12. The major functional groups are ISDN terminal equipment (TE1), non-ISDN terminal (TE2), terminal adapters (TA), network termination type 2 (NT2), and network termination type 1 (NT1).

TE includes devices that generate and receive information (e.g., a personal computer). Terminal adapters (TA) convert non-ISDN interfaces to an ISDN interface. Any TE2 can therefore be connected to ISDN through a suitable TA. Reference point R refers to the interface between the TE2 and the TA. Network terminations NT1 and NT2 provide distinct functions, but may be combined in a PABX or LAN. NT2 refers to on-premises switching or other intelligence that is employed by the user for communication. PABXs and LANs may contain NT2 functions. NT2 functions are separated from TA or TE1 functions by reference point S.

NT1 functions connect the users' equipment to the digital subscriber transmission system. Reference point T designates this separation between NT1

[1]In Europe PRI = 30B + D.



ET = Exchange Terminal
LT = Line Terminal
NT = Network Termination
TA = Terminal Adapter
TE1 = ISDN Terminal
TE2 = Non-ISDN Terminal
R, S, T, U, V = ISDN Interfaces

Figure 12. Recommendations for ISDN interfaces.

and NT2 functions. NT1 and NT2 functions may be combined as a single functional group, which is designated as NT1/2.

In the United States, the NT1 function is considered customer premises equipment, whereas in most other countries it is considered part of the network. Reference point U has been designated as the attachment between an NT1 and the digital subscriber line system.

The interfaces between terminals, network terminations, and the central offices (COs) and indicated as R, S, T, and U are defined below.

R - Existing interface specifications (e.g., RS-232).

S - ISDN terminal or terminal adaptation interfaces characterized by 144 kb/s user access rates (2B+D). Up to 8 terminals can be connected on a single passive bus.

T - Normally the same as the S interface for basic access. For primary access in the United States, the T-interface accesses 23B+D service (using 1.544 Mb/s); in Europe access is to 30B+3 service.

U - Primary rate transmission system (e.g., T-1 carrier interface). The basic rate U-interface uses an echo canceling hybrid for full duplex operation over 2-wire loops.

The OSI model is currently being extended to ISDN as illustrated in Figure 13, see CCITT (1989). The separation between control information, user information, and management information is shown using multidimensional user, control, and management planes. The control plane may be divided further into local control (LC) and global control (GC) planes. Each plane may be a full protocol layered process or may only be partially implemented for some services. The management function coordinates the activities of all the planes.

Another way of depicting the functional groupings of an ISDN is shown in Figure 14. Here the lower layer (0-3) functions are provided by the control office or local exchange and higher layer capabilities may be external or internal to the network or both. Lower layer capabilities may be combined or provided on separate networks. The protocol reference model applied to a network with two intermediate nodes is illustrated in Figure 15.

The switching and multiplexing techniques used in ISDN are known as synchronous transfer modes (STM), see Minzer (1989). Systems that use STM for subdividing and allocating the available bandwidth of a transmission channel

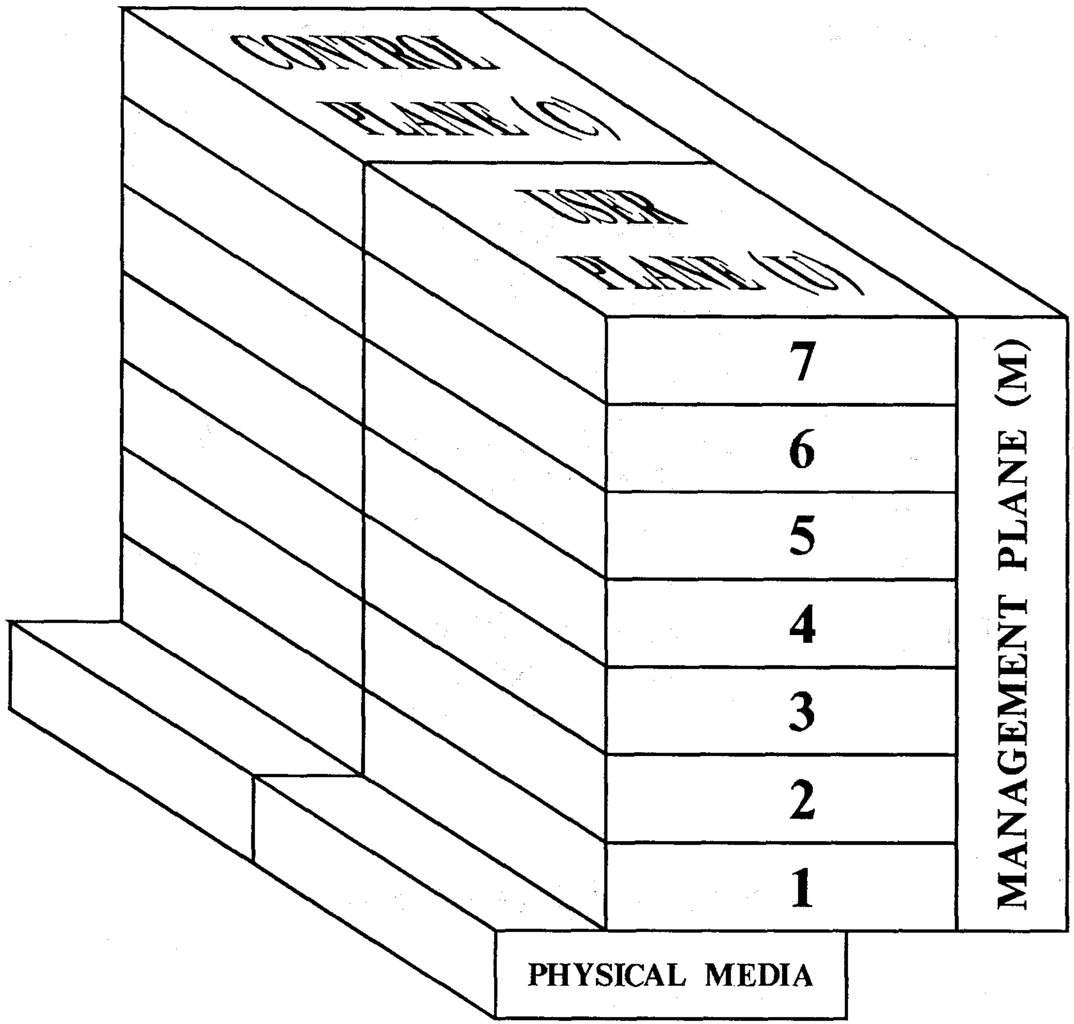


Figure 13. Protocol reference model for ISDN.

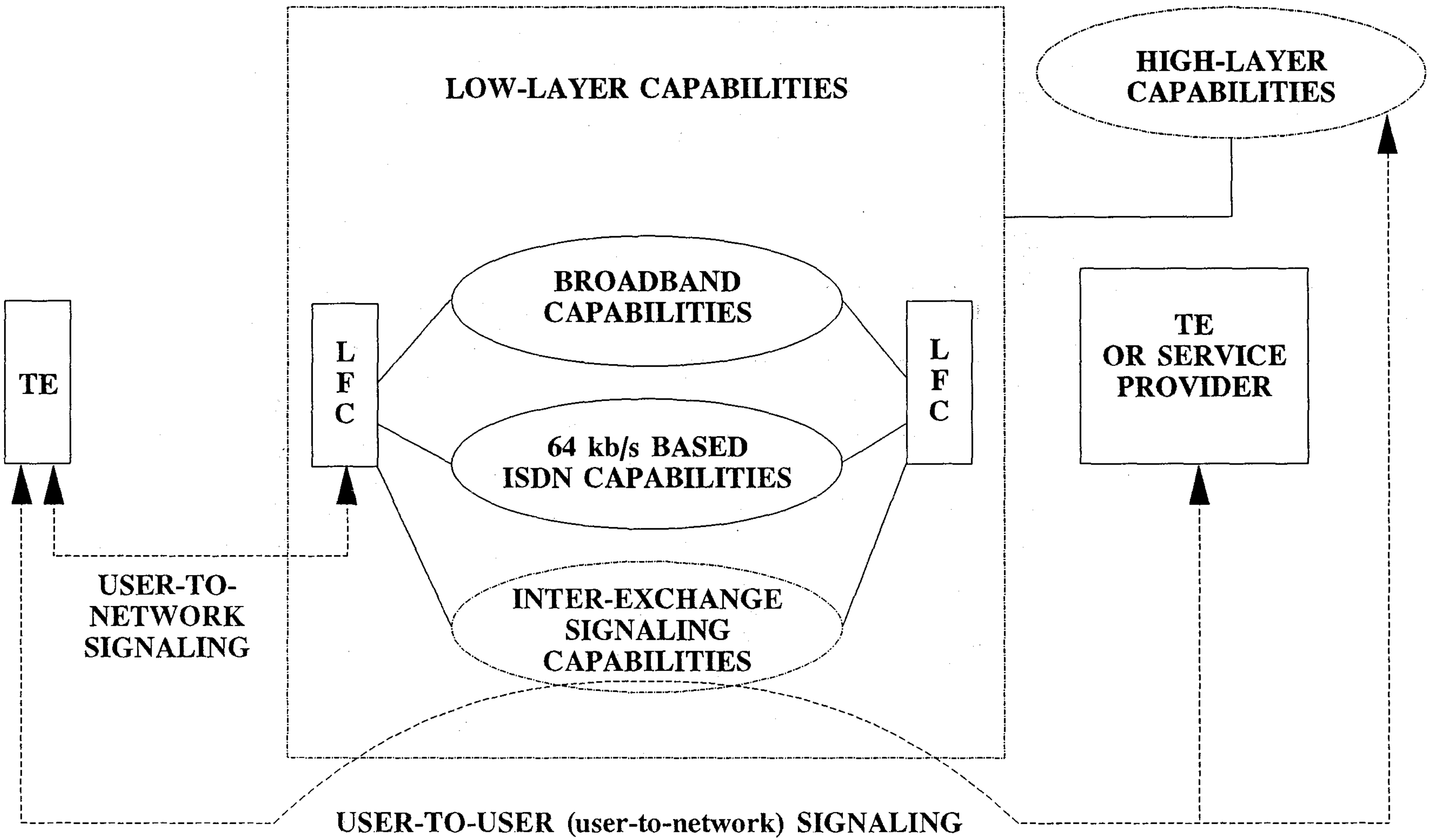


Figure 14. Structural configuration of the basic ISDN model (CCITT, 1989).

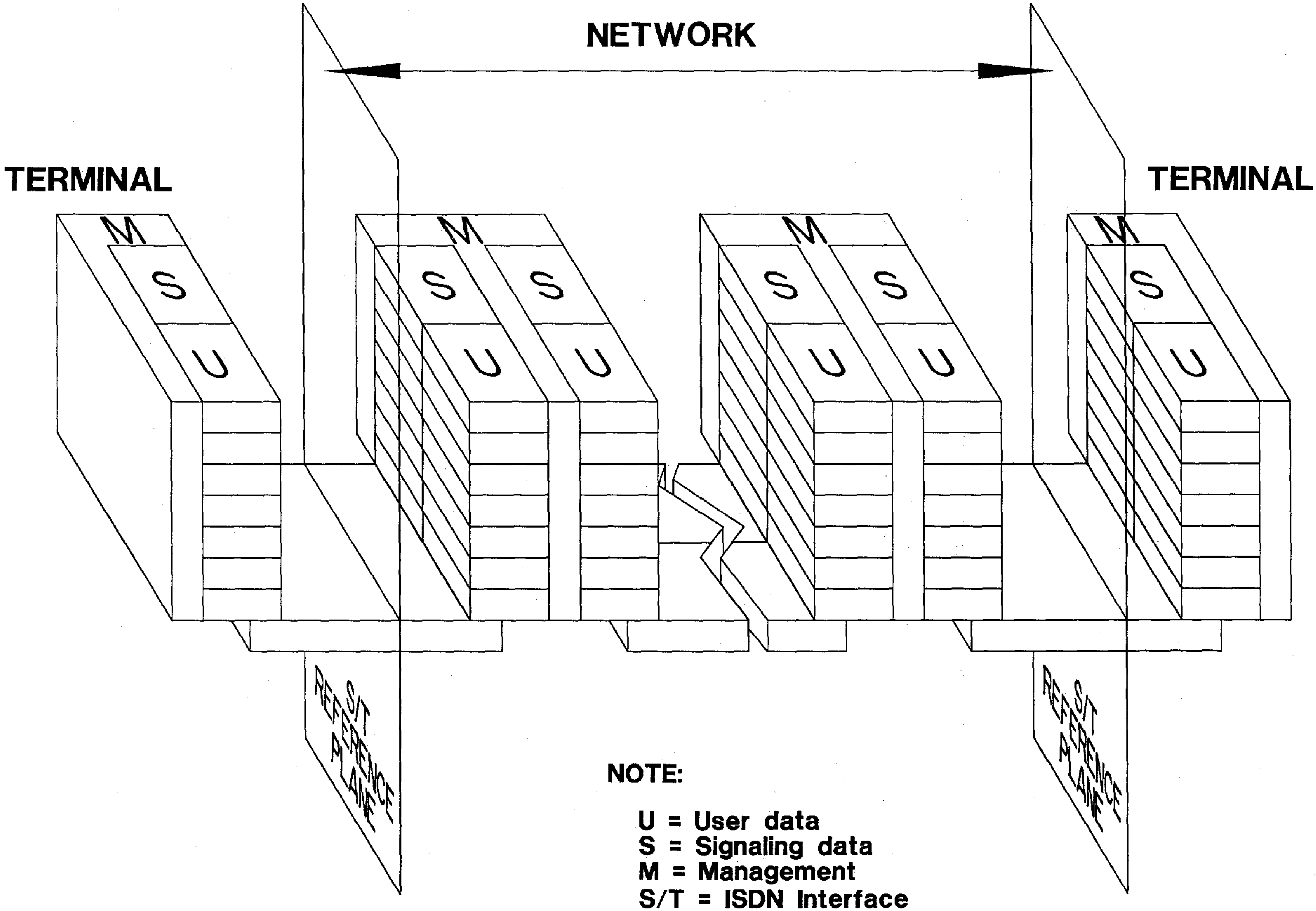


Figure 15. Application of protocol reference model to ISDN network with intermediate nodes.

do so by allocating time slots within the recurring frame structure to a service for the duration of a call. This leads to the digital transmission hierarchies of NB+D channel structures for ISDN interfaces, where B = 64 kb/s and D = 16 kb/s. This is different from the channel structure of B-ISDN that uses an asynchronous transfer mode for switching and multiplexing as described in the following subsection.

3.3 Broadband ISDN

A protocol reference model for B-ISDN is also based on the ISDN PRM using the concept of separate planes for the segregation of user, control, and management functions. For B-ISDN, however, certain enhancements and extensions are required. A description of the planes follows:

> User plane. The user plane, with its layered structure, provides the user information flow transfer, with associated controls (e.g., flow/error control), verifications and retransmission if necessary.

> Control plane. This plane handles the call control and connection control information; it deals with the signaling flow necessary to set up a call/connection, to vary its characteristics and to disconnect or connect the call.

> Management plane. The management plane is divided into two portions,namely Layer Management functions and Plane Management functions. Plane Management functions are related to the system as a whole and provide coordination between all the planes. Layer Management functions are related to resources and parameters residing in its protocol entity. Layer Management handles the Administration, Operation, and Maintenance (AO&M) information flows.

The lower layers of the B-ISDN model differ considerably from the ISDN model because the switching and multiplexing is based on the asynchronous transfer mode (ATM) instead of STM as described by Minzer (1989). The physical layer 1 for B-ISDN contains three major sublayers. They include a physical media independent sublayer, the ATM sublayer, and an adaption sublayer. The model for B-ISDN is depicted in Figure 16.

The CCITT (Study Group XVIII) selected ATM as the international standard for B-ISDN because it can dynamically allocate capacity on demand. ATM is a high-bandwidth, low delay, fast-packet switching, and multiplexing technique. It is envisioned as a basis for supporting both connection-oriented and connectionless services. Unlike the STM used for ISDN, the ATM-based network

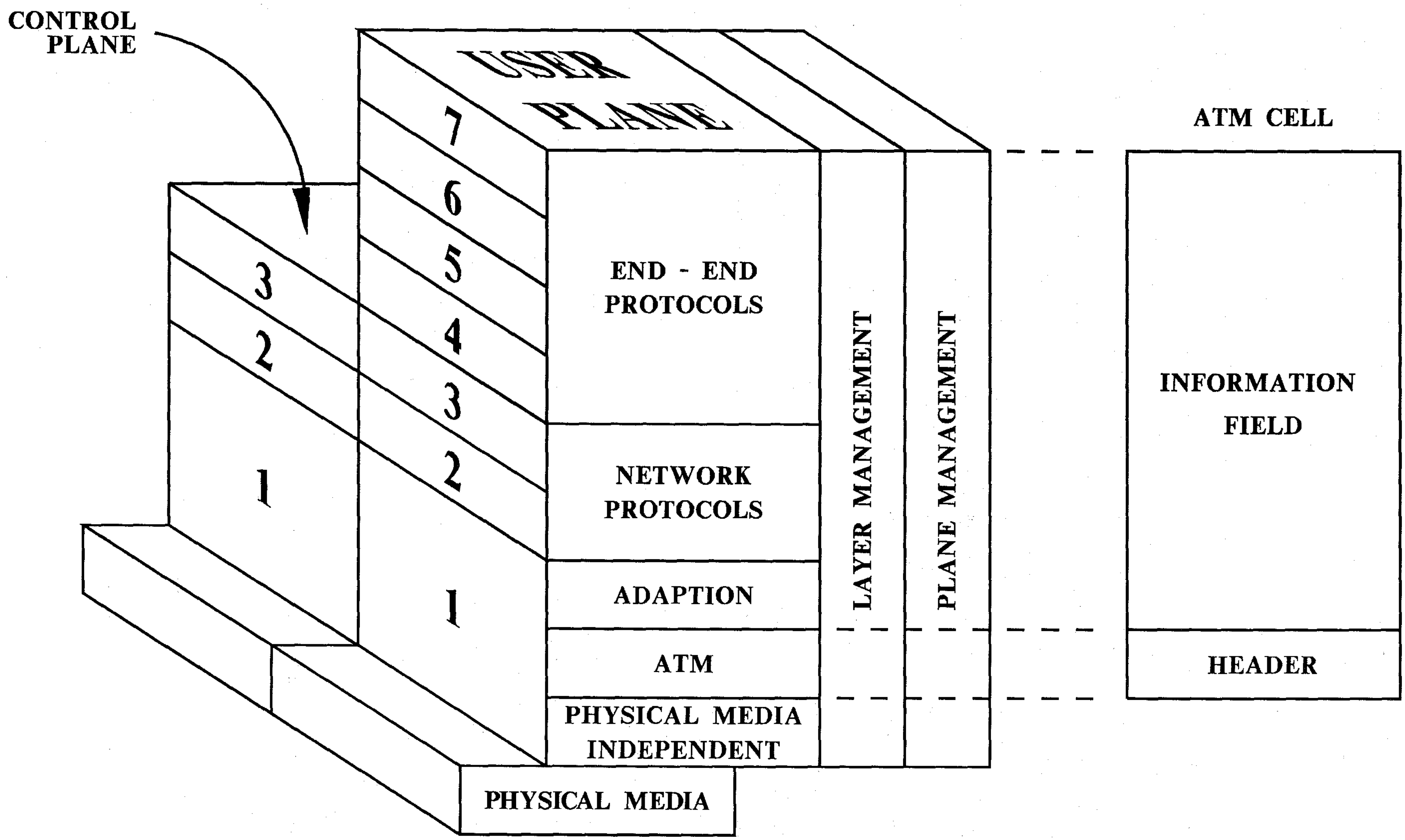


Figure 16. Protocol reference model for B-ISDN.

can perform efficiently for bursty traffic as well as continuous traffic. This is because the usable capacity is segmented into fixed information-bearing units called cells. Each cell contains a header and an information field, and each cell can be allocated to any service on demand. The make up of a cell is shown in Figure 16. Details are given by Minzer (1989).

Individual cells can be allocated to different services on demand because each cell header contains a virtual channel identifier (VCI). Thus the channels are labeled independently of their time slot positions and the service mix and transfer rates are decoupled from the switching fabric.

The primary function of the adaption sublayer is to convert user-specific information units to the ATM cell format.

The CCITT (1989) version of a basic configuration for B-ISDN is shown in Figure 17. The local functional capabilities, interexchange signaling functions, 64 kb/s based transfer functions, and broadband functions may be combined or provided by separate networks for a particular implementation.

For high-speed synchronous transport it is possible to multiplex several ATM streams together using STM technology so that transmission rates far exceeding those used in ATM switching and multiplexing can be achieved. This capability is provided by the Synchronous Digital Hierarchy (SDH), recognized as the international standard for the transport of ATM signals. The SDH evolved from the Synchronous Optical Network (SONET) concept developed in the United States. Primarily designed for high-speed (>150 Mb/s) transmission over fiber optical network, SDH offers a unique transport solution to B-ISDN. In addition to carrying all types of traffic over a wide range of transmission rates, the SDH concept includes a provision for embedding network management and control channels. Thus SDH provides network management of multiple services over a single interface. This newly-adopted standard is described in detail by Ballart and Ching (1989).

Figure 18 illustrates the frame format for SDH. The 155 Mb/s signal is based on a frame format of 9 x 270 bytes that repeats at a rate of 8 kHz. The payload portion of a SDH frame carries a continuous stream of 53-byte ATM cells. Each cell contains a 48-byte information field and a 5-byte header for channel identification, routing control, and other functions as indicated in Figure 18.

Figure 19 illustrates how several ATM channels can be multiplexed on to a single SDH channel.

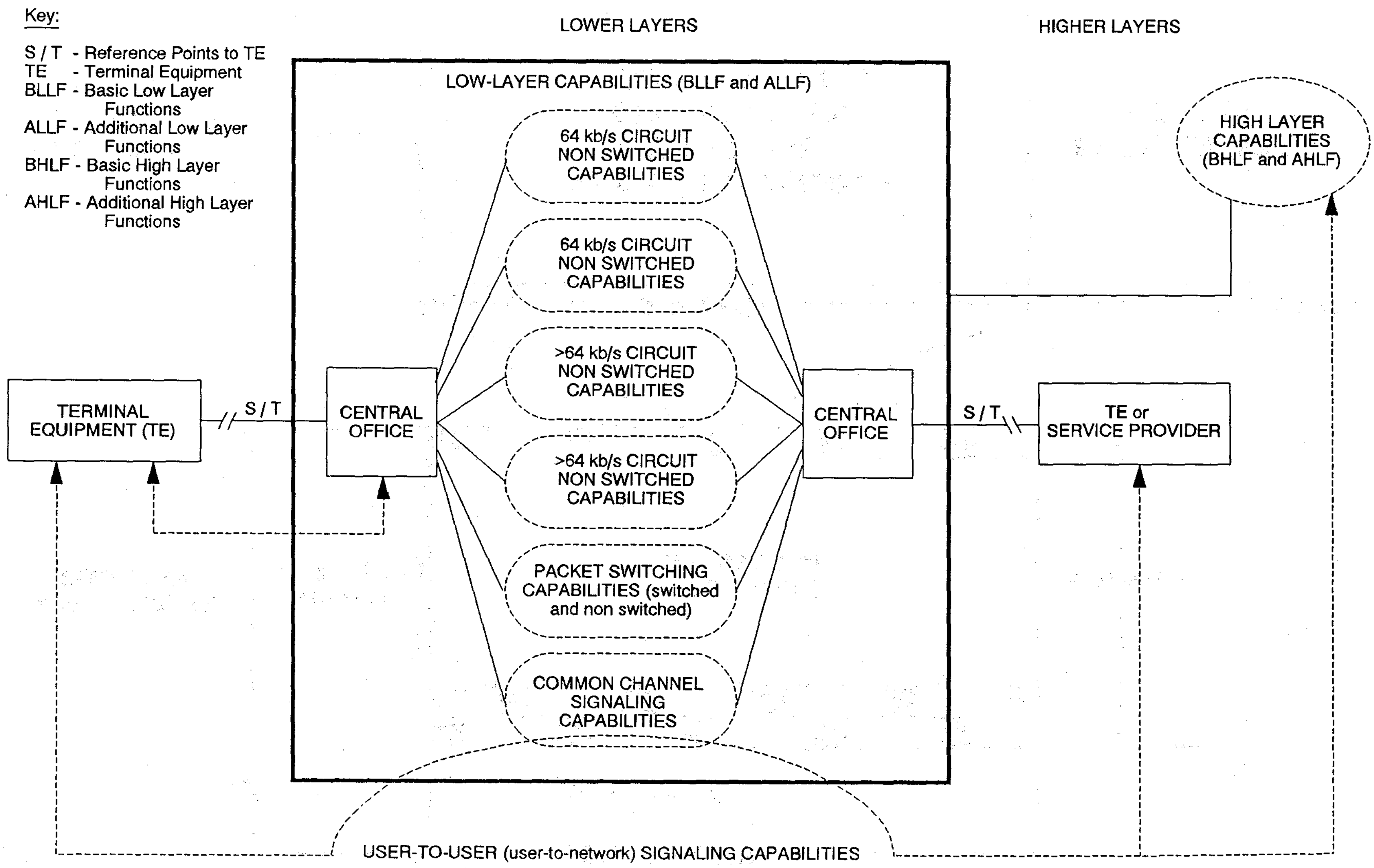


Figure 17. Structural configuration of B-ISDN.

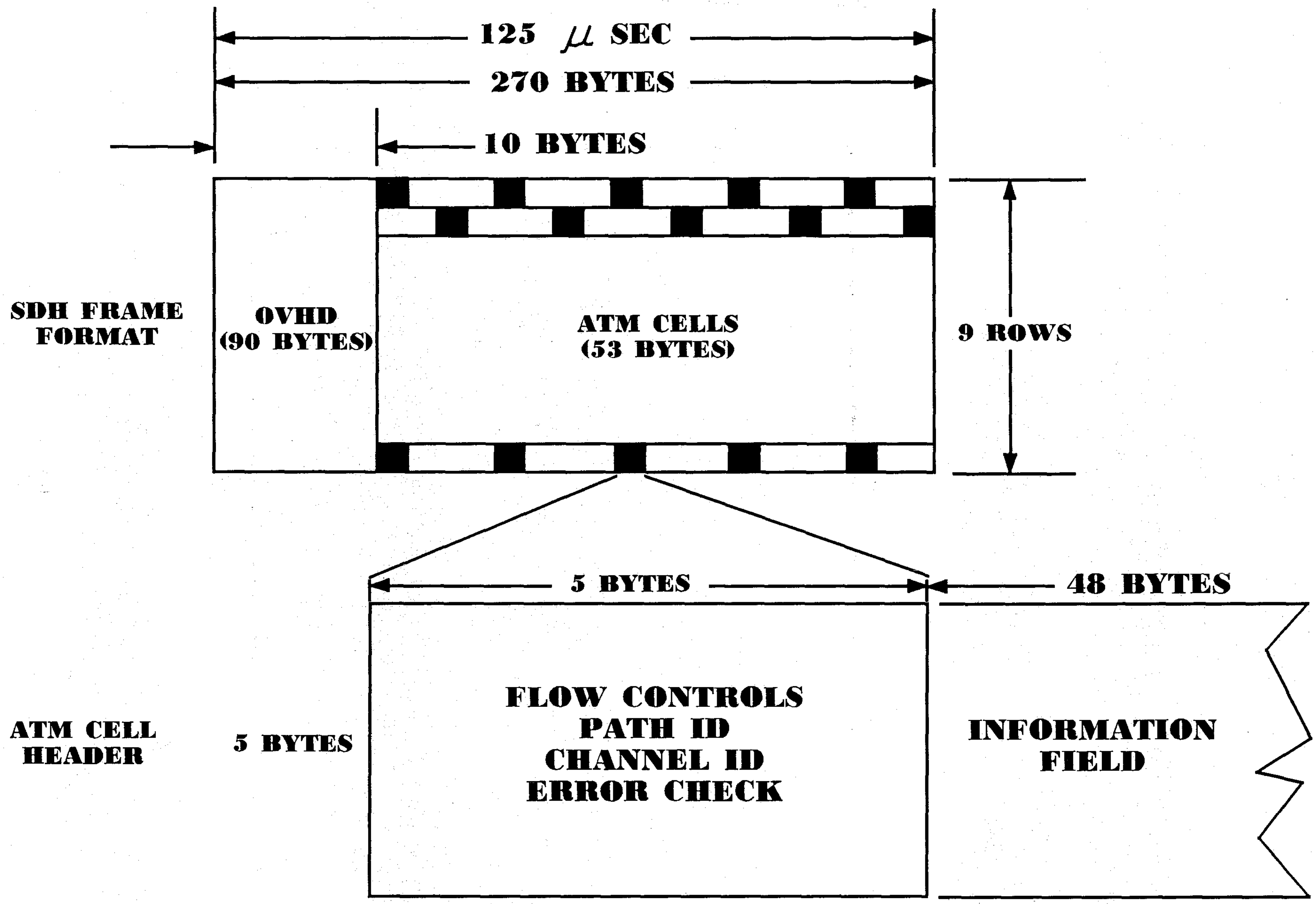


Figure 18. SDH and ATM formats.

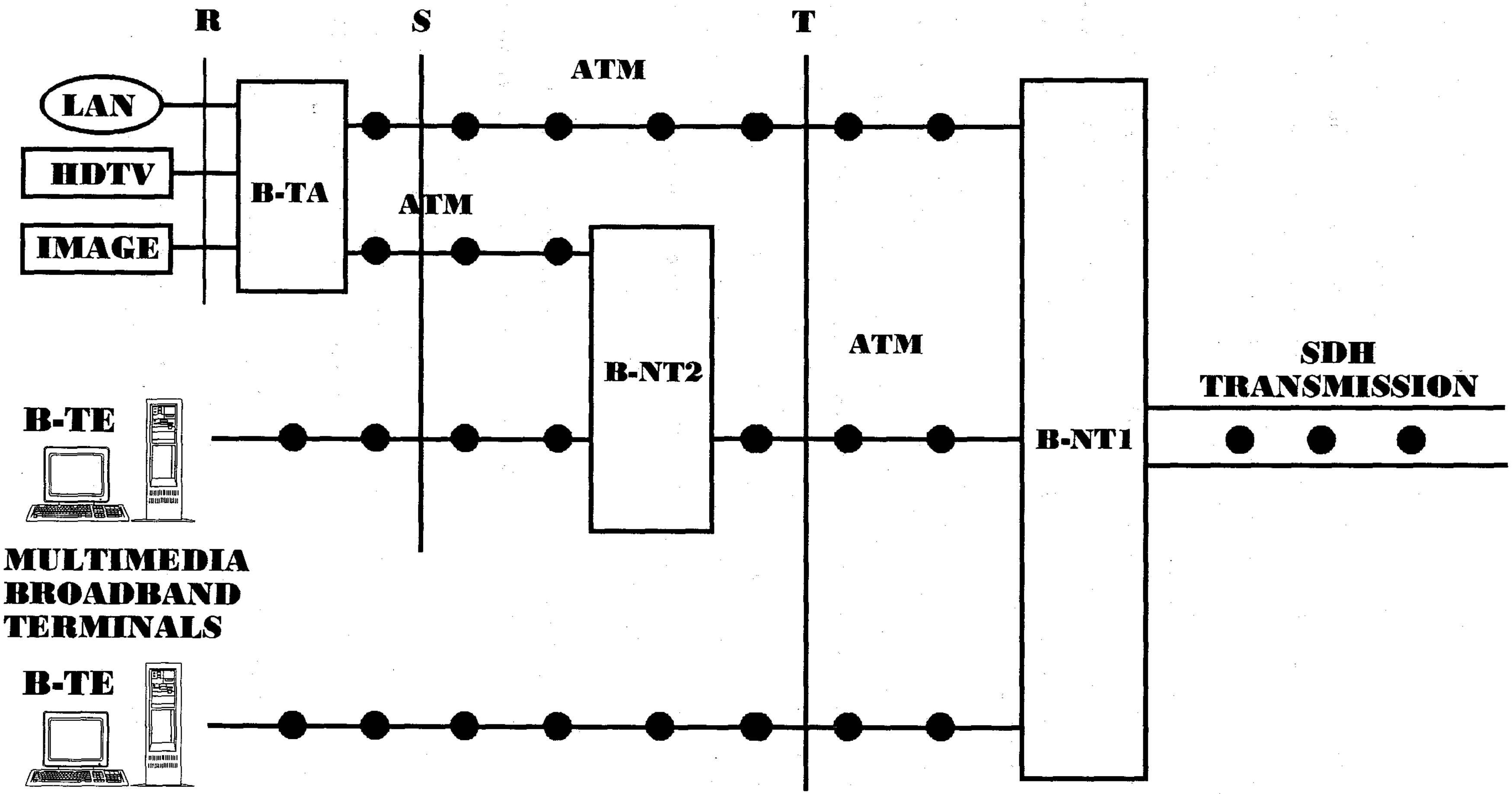


Figure 19. Application of ATM and SDH to B-ISDN nodes.

3.4 Other Functional Models and Architectures

There are other functional models and functional architectures that are not based on any layer protocol model. These models may relate indirectly to the lowest layers of the OSI model but in general do not apply to analog systems. Attempts to apply the PRM to analog telephone networks is difficult due to certain aspects such as signaling, network access, directory services, etc. Some functional models are discussed here to show how they apply to conventional systems that are not based on the OSI model. Non-OSI systems have been around for some time and will undoubtably be more familiar to the reader. Here we reduce such systems to their basic functional elements, first for a system providing plain old telephone service (POTS), and then some more generic functional models.

For telephony the architecture is often defined by three basic functions, interconnection, signaling, and controlling, see Joel (1977). The interconnection provides a path between end users. Signaling provides the means to remotely control the switching that establishes the interconnection. Signaling functions include <u>attending</u> to requests for service, addressing, <u>alerting</u> (or ringing) and <u>supervising</u> call status. These basic telephony functions are interrelated in the network, shown in Figure 20. The controlling function <u>interprets</u> the nature of the request and network status, the signaling <u>selects</u> the path, <u>tests</u> for busy, and establishes the connection.

Although these appear to be somewhat simple functions, their interaction during the progress of a call is relatively complex. The network architecture that is implemented to perform these functions depends on the service provided and on any special features wanted by the user (e.g., call waiting, speed dialing, etc.). The switching system that provides these services and features may also be very complex. Appendix A lists available features from one manufacturer's switch.

The basic functions required for public telephone service are given below in the order in which they generally occur.

> <u>Attending</u> - This is the reception by a central office of a request for service from a station or another office, i.e., dial tone response to call origination.

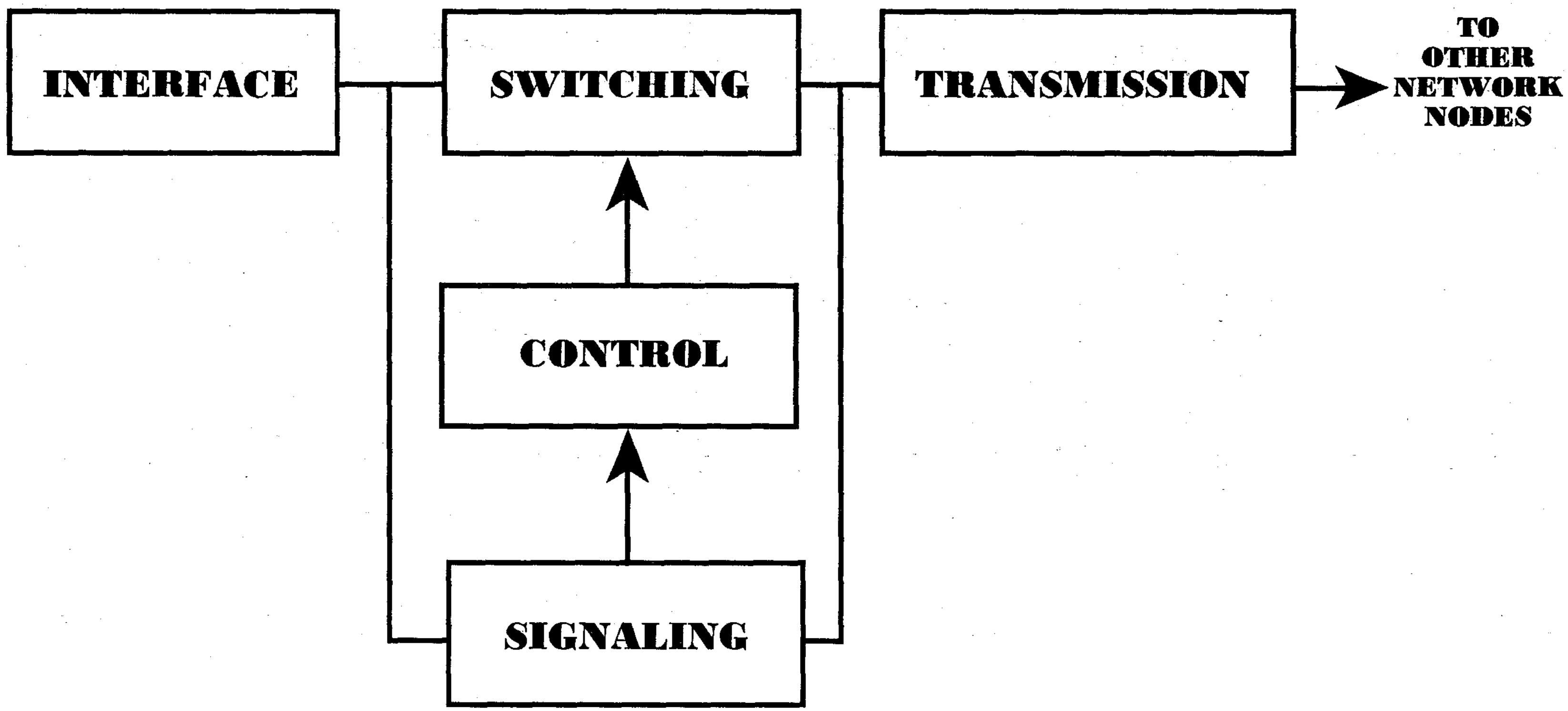


Figure 20. Basic functions of a circuit switched network.

Signal Reception - After the central office responds to the request, it receives dialed digit information, usually numerical, to address the desired called station.

Interpreting - Determination of the action required based on the received signal information.

Path Selecting - Determining an idle link, series of links, or channels through the switching center network.

Route Selecting - Determining the trunk group to which a path is to be established including interoffice calling.

Busy Testing - Determining that a link or trunk is in use or reserved for use on another call. When links or trunks are busy successive testing of trunks or links is known as "hunting."

Path Establishment - Control of the elements of the switching center network to establish a channel for use on the call thereby making the desired interconnection. This function in circuit switching requires some form of memory to retain or remember the connection for the duration of the call. In older systems, the physical position of a mechanical switch constitutes the memory.

Signal Transmission - On interoffice calls transmission of the addresses of the call for which a connection is to be established.

Alerting - Informing the called station or office that a call is being sent to it. On calls to stations this is called "ringing." On interoffice calls it is the transmission of the attending signal.

Supervising - To detect when the connection is no longer needed and to effect its release. Supervision is also required for other purposes, such as call service features.

In addition to these basic transmission, switching, and control functions there are usually additional functions necessary in order to access a network. These include such functions as information and signal conversion, media matching and physical transfer. Specific functions depend on the service and type of source (analog or digital), the signal design (analog, quasi-analog, or digital), and the transmission medium (radio, wire pair, optical, or guided waves).

Major functions to be performed are shown in Figure 21 with specific functions listed in the block diagram across the top of the figure. These are grouped into the major classifications of information conversion, signal conversion, media matching, and physical transfer. Each class is described in the paragraphs below, assuming transfer from source to destination. The

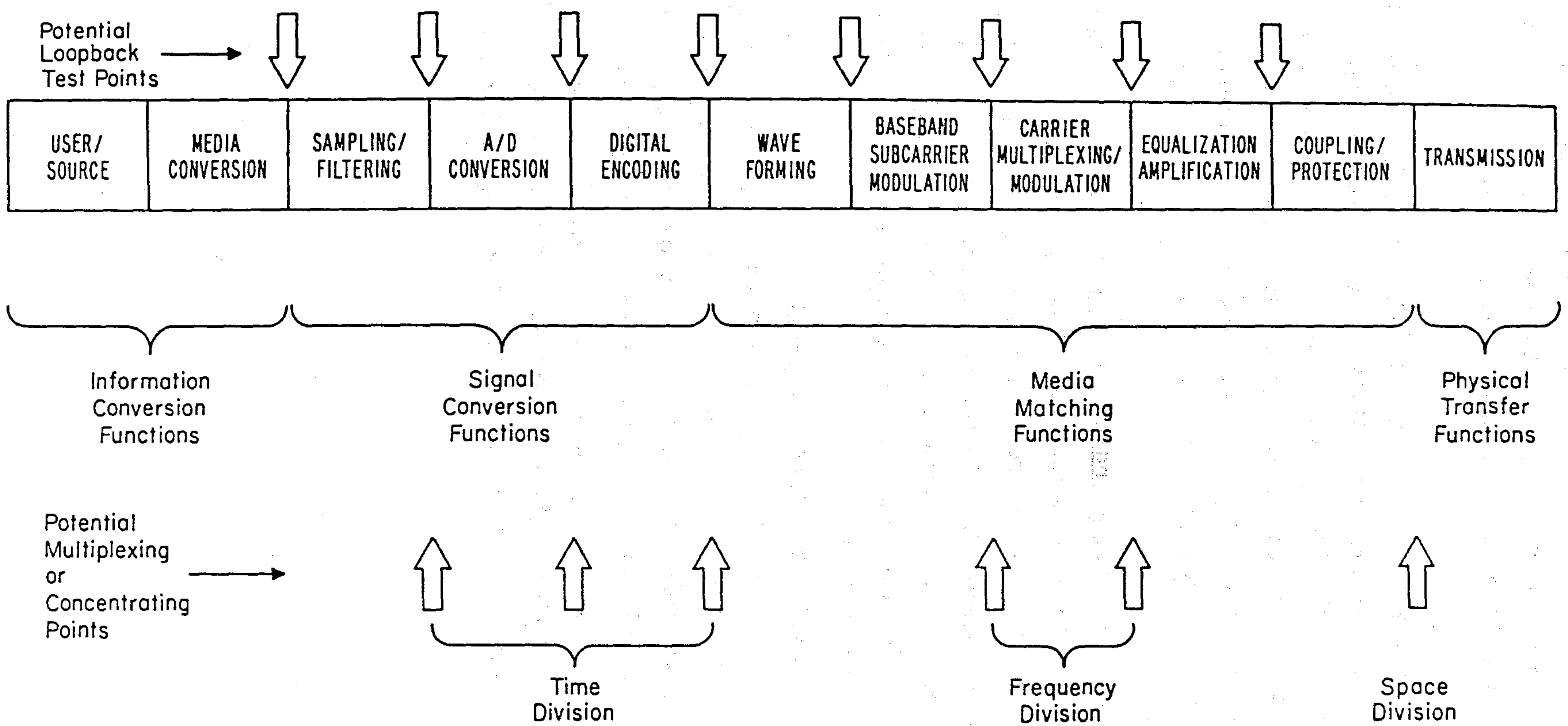


Figure 21. Basic functions for accessing communication systems.

inverse of certain functions must be performed at the destination. This includes, for example, demodulation, detection, decoding, digital-to-analog conversion, and finally media conversion from electrical signals to human usable form.

Information Conversion (corresponding to OSI Levels 4-7). The conversion process transforms information in human usable form (e.g., printed words and numbers, visual display characters, acoustic speech, holes in tape, etc.) to and from electrical form. These information conversion functions usually reside in the terminals and nodes and are not performed by the link. Thus, the starting point for the network is an electrical signal which may be analog or digital.

Signal Processing (corresponding to Levels 2 and 3). These functions involve changing the initial electrical form to another form suitable for transfer. The new form would ensure that the information is not inadvertently or surreptitiously changed. The functions include filtering, A/D conversion, and digital encoding in various combinations. The encoding functions include binary or higher level code conversions, encryption for security, and error control to enhance reliability.

Media Matching (corresponding to Level 1). This ensures successful entry, transmission, and delivery by shaping the signaling waveform and, if necessary, translating these waveforms to other frequencies or modulating carrier frequencies in order to match the transmission media. It includes, for example, signal modulation for carrier system compatibility.

Figure 22 illustrates a number of access systems using various combinations of the functions given at the top of the figure. This includes access to microwave radio, twisted wire pairs, fiber optical transmission, and coaxial cable.

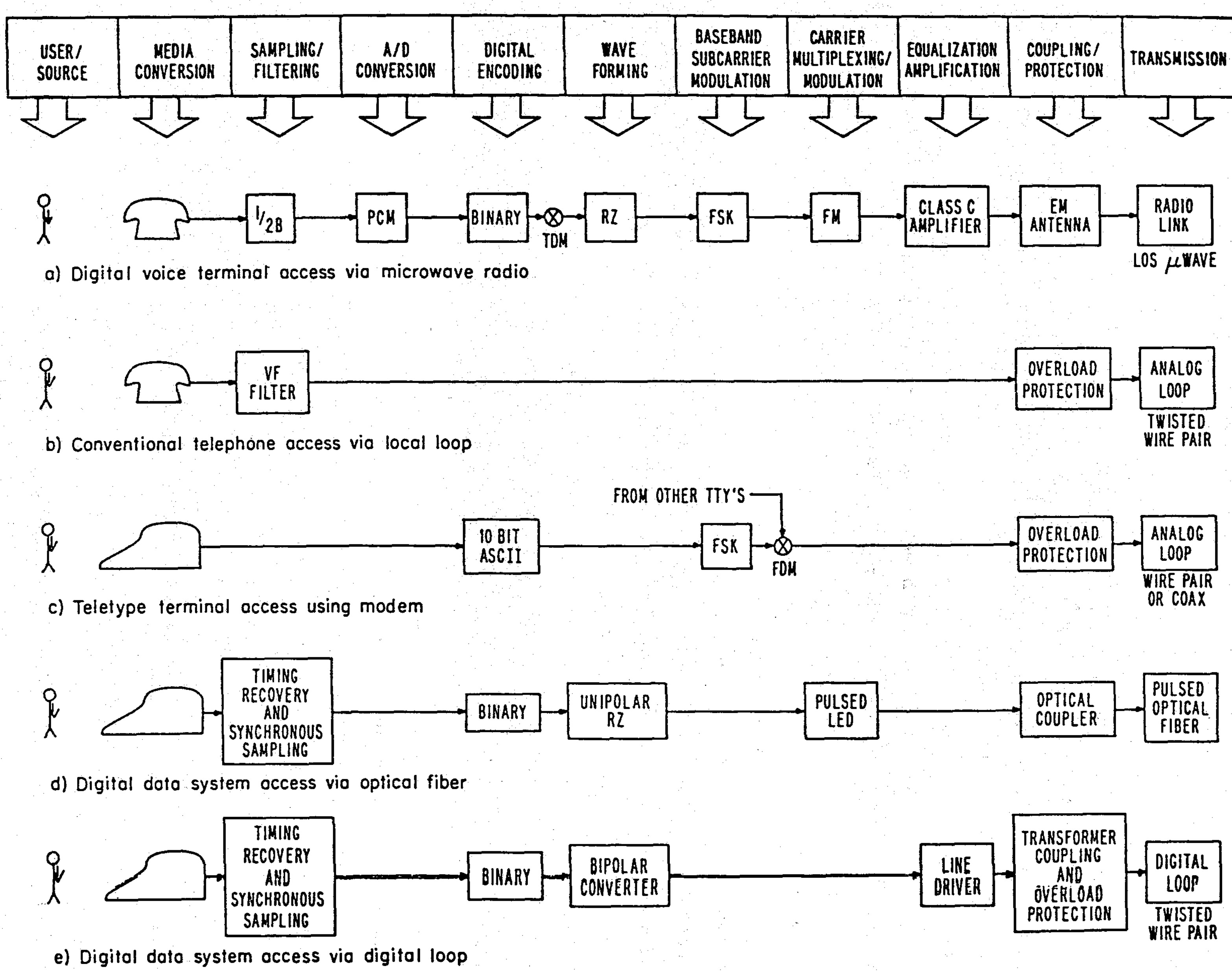


Figure 22. Functional combinations for various communication systems.

4. NETWORK IMPLEMENTATION

We have seen how functional architectures can be designed for OSI using a seven-layer PRM. This PRM provides a framework for standardizing advanced digital network architectures. In this section, we describe how these architectures may be implemented. The emphasis is on the lower layers (0 through 4) and on network topology, see Figure 23. Network topology includes the physical arrangement of the communication facilities, the nodes, links, and terminals, and their connectivity patterns. Layers 1 through 4 are concerned with the actual transport of information, including the signaling and network management functions. The upper layers (5 through 7) view the network as a clear channel. They apply to the end-user services and are of less interest here. They may however be pertinent when certain enhanced services are provided within the network structure itself such as directory service electronic mail or voice messaging. Layer 4 provides end-to-end transparent transport.

For transmission purposes (layers 0 through 3) the architectural functions are imbedded in the hardware and software of the network's nodes and peripheral facilities. The hardware consists of traditional components such as wire pairs, coaxial cable, and fiber for transmission, digital computers for switching, processing, storage, and peripheral equipment for printing and display. Software, in terms of data bases, coding schemes, languages, and protocols, exploits these hardware resources to provide the needed functions. The layered architecture concept decouples the hardware technologies and software technologies so they can evolve independently. The operating system provides the interface between hardware and software and between softwares. In the past telecommunications operating systems used concurrent processing where processing activities were modeled separately and each intelligent element in a network could have its own unique operating system. The trend now, however, is toward fully distributed operating systems where a single master operating system handles complex structures incorporating distributed data bases, distributed processing and distributed communication networks, see Vichers and Vilmansen (1987).

Network implementations today are highly dependent upon integrated circuits, digital computers, and photonic technologies. Network implementations exploit these technologies in many ways. See for example, Mayo (1985), and Vickers and Vilmansen (1987). For a more detailed

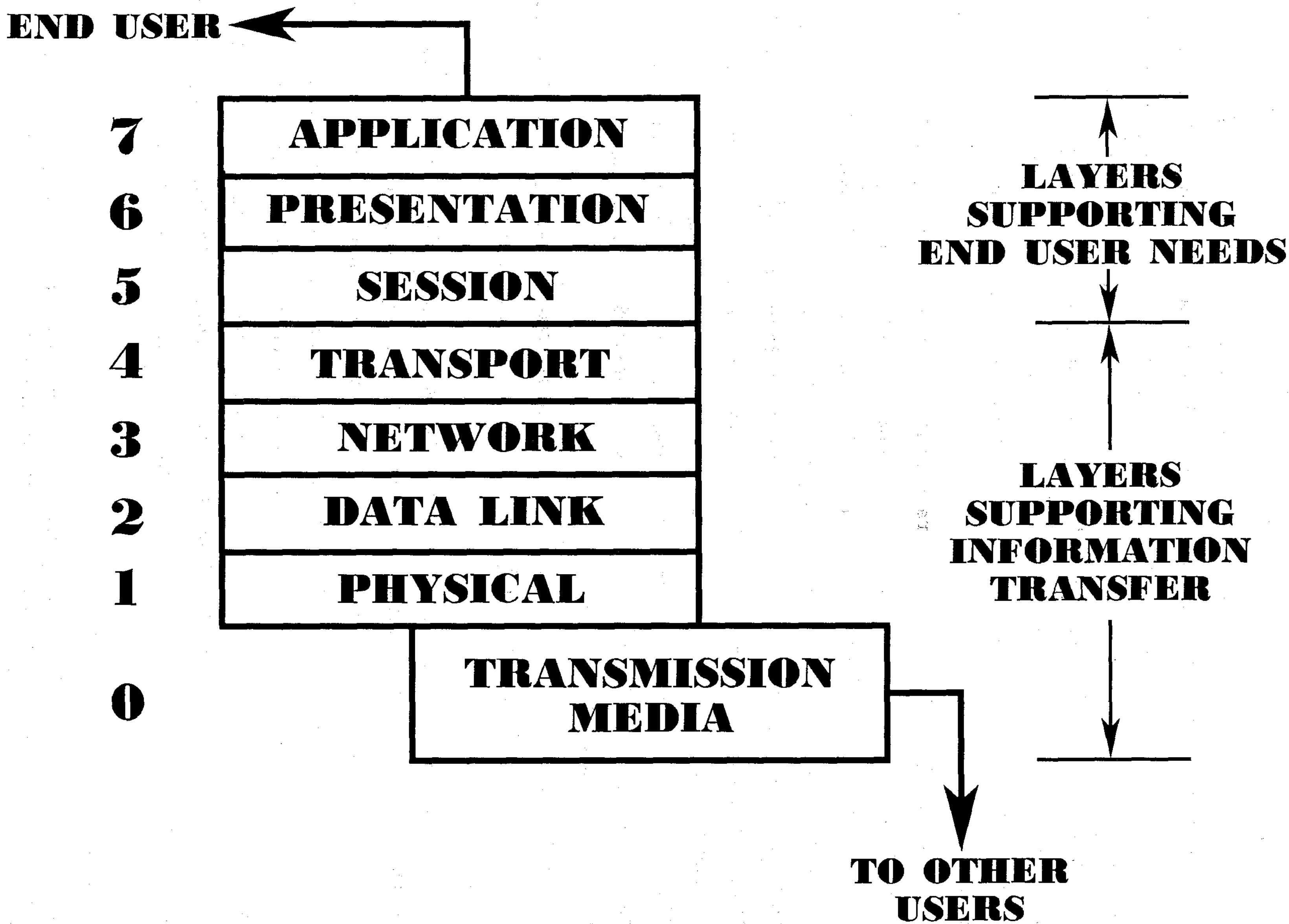


Figure 23. OSI protocol reference model.

description of some existing terrestrial and satellite networks see Nesenbergs (1989).

4.1 Network Topologies

Characterization by means of network topology has evolved from graph theory. Topology, a branch of geometry, is the study of the properties of lines and surfaces that are independent of their size and shape. For telecommunication networks, these properties include the connection pattern of the nodes and links as depicted in Figure 24. These basic topologies can be combined in various ways to form hierarchical and non-hierarchical networks of various kinds as described below.

Hierarchical Networks. Hierarchical structures have often been used in the engineering design of numerous telecommunication networks. At each level of the hierarchy, different node and link functions may be specified to meet the overall network design objectives. An example of one hierarchical structure which has been used to access an office complex to the long haul network is shown in Figure 25. In this figure a star connection is employed to connect office terminals to the PABX. A bus topology connects several PABXs to the base central office. Several central offices are connected together using a mesh network. Different terminals and switch types may be used at each level in the hierarchy.

A hierarchical ring structure is illustrated in Figure 26. This is a topology with applications in local area networks (LANs) and metropolitan area networks (MANs).

Nonhierarchical Networks. The multilevel hierarchical public switched network in the United States is gradually being replaced by a network structure having two parts: a hierarchical part and a dynamic, nonhierarchical routing (DNHR) part. The basic structure is shown in Figure 27. The nonhierarchical nodes contain computer controlled switches and common channel signaling.[2] All switches perform similar functions. Ultimately the public switched network in the United States is expected to contain approximately 120 switching nodes. The routing in the network is

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[2]Common channel signaling is a means of remotely controlling the switches using a packet-switched network that is separate from the information carrying circuit-switched network.

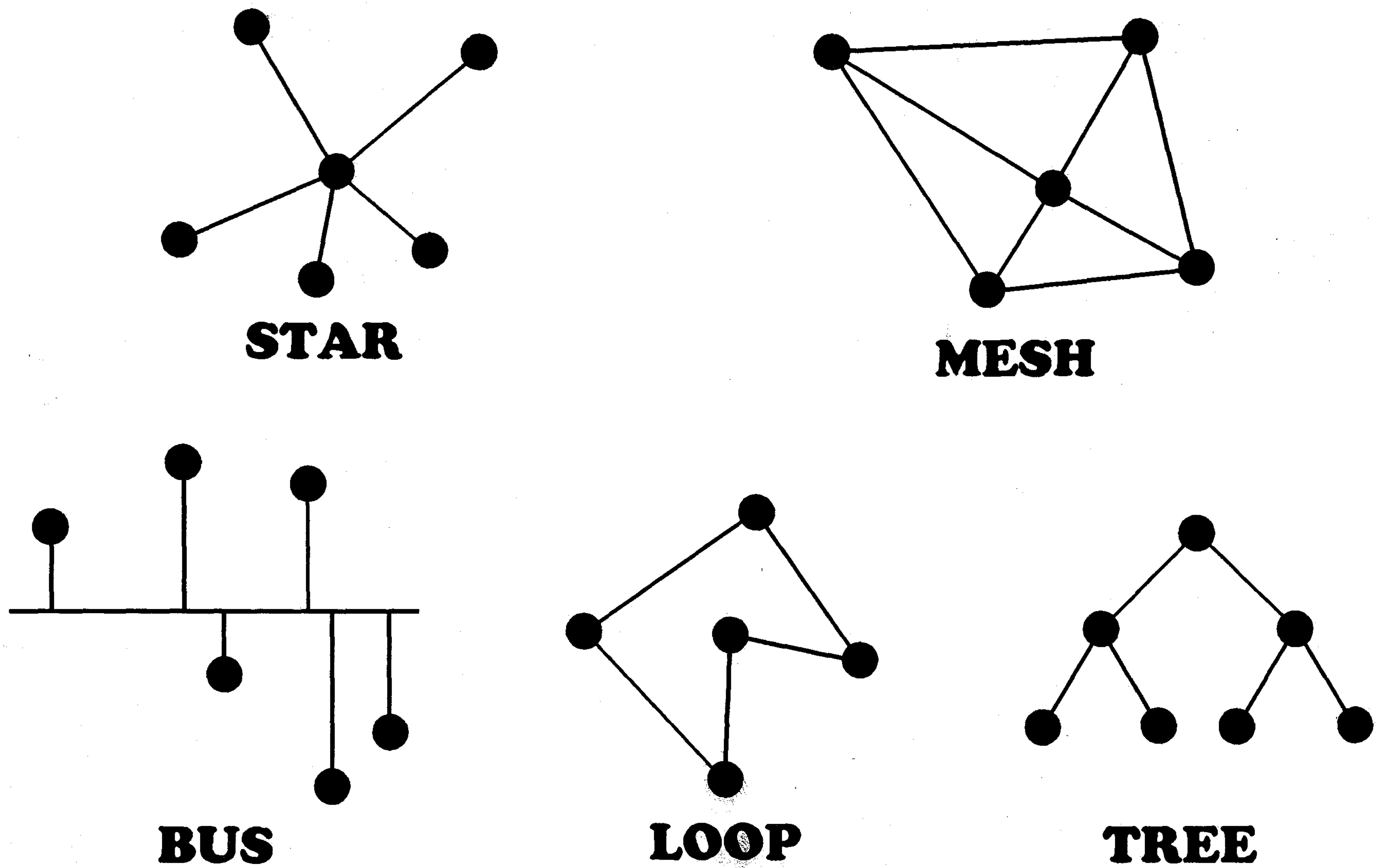


Figure 24. Network topologies.

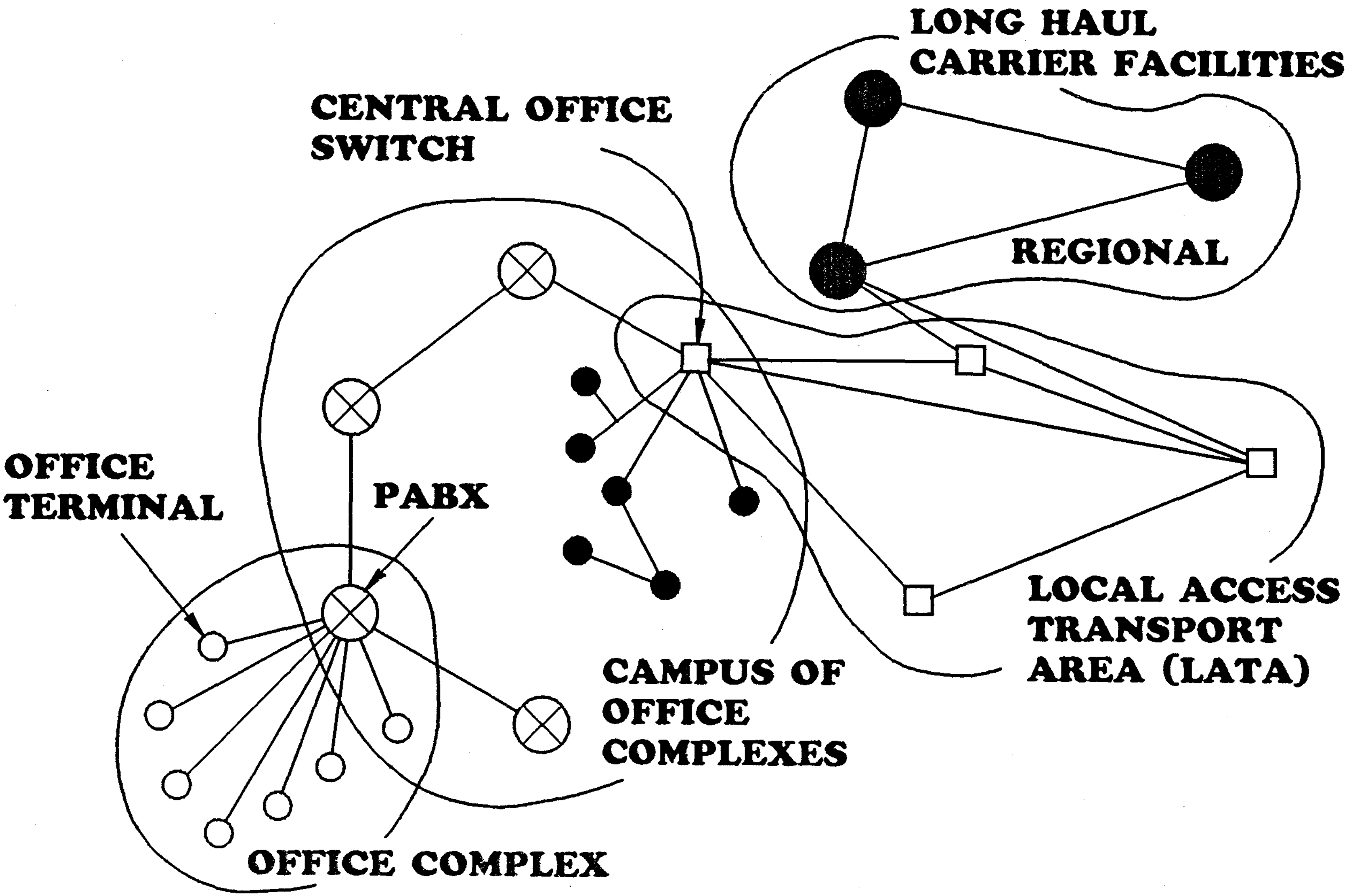


Figure 25. Hierarchical configuration for local, regional, and national access.

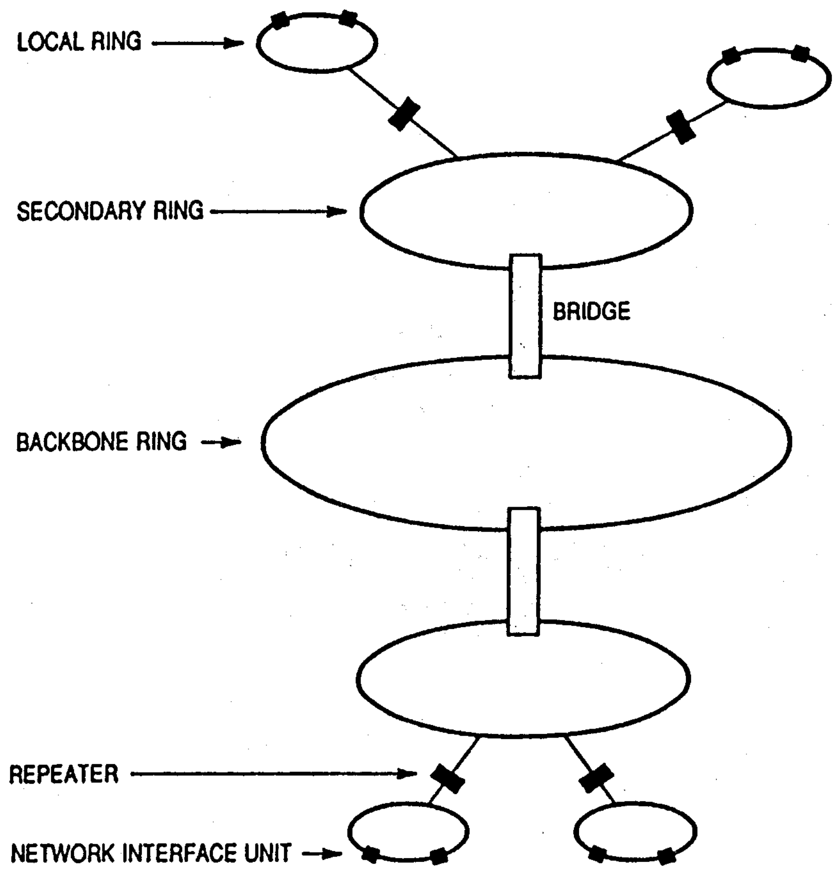


Figure 26. Hierarchical ring network.

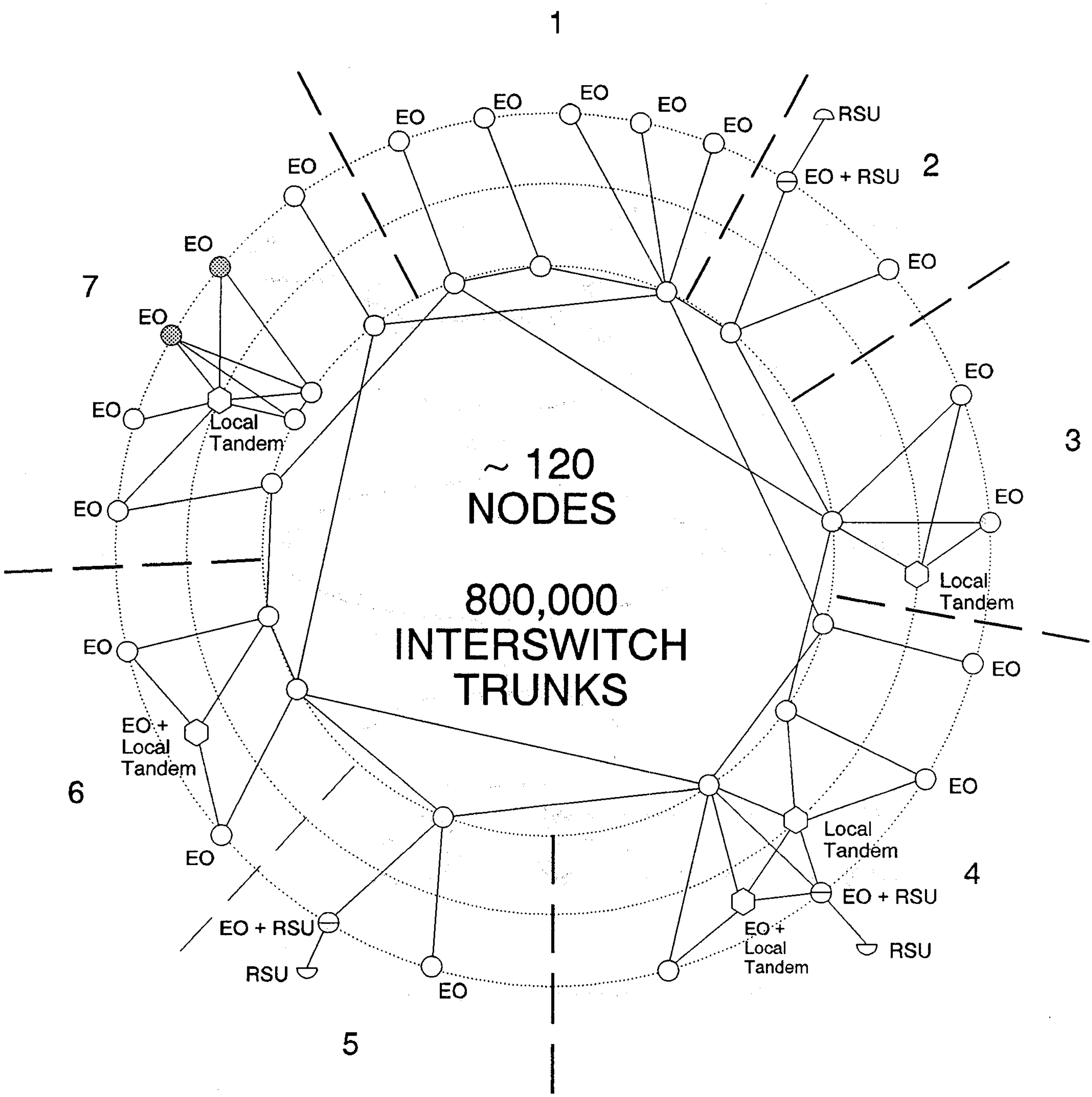


Figure 27. Intra- and interexchange network structure after divestiture.

considered dynamic because routing can change at any time as directed by the signaling transfer points (SPTs). Overall network efficiency is maintained as calling patterns change by rerouting calls through uncongested portions of the network.

4.2 Structural Levels in a Network

There are many ways to implement networks: switched and nonswitched, analog trunks, digital trunks, voice and data, narrowband and wideband, packet switched and circuit switched, leased and government owned, etc. We have found it useful to separate networks into two domains--public and private. The public and private domains may also be divided into four levels; the users level, local level, access level, and backbone level, as illustrated in Figure 28. Within each level various physical network elements may reside and the interconnections between levels may indicate both switched and nonswitched circuits. Examples of the network elements that currently might reside at each level are listed in Figure 28. One viewpoint for the future is shown in Figure 29. A simplified diagram of a public and private network based on this structured configuration is shown in Figure 30.

This method of multilevel network presentations differs from the conventional method of diagram networks and provides a more complete insight into a network's functional and physical architecture. It is possible to depict many additional details (e.g., interface location and method), interactive between public and private domains (e.g., interconnect points and media types), show responsibility boundaries (e.g., customer premises versus carrier), and define functional and physical architectural levels. The four structural levels used in Figures 28, 29, and 30 are described below.

> The users level includes the interfaces between users and terminal. Here are found the voice, data, and video terminals. In some cases one might also find application programs, data base management systems, multimedia workstations, and host computers.
>
> The local level is where traffic concentration, multiplexing, switching, and local distribution functions occur. At this level, one finds PBXs, LANs, and even the central office switch of the local telephone company.
>
> The access level includes elements from a broader geographical area. Traffic is collected from, and distributed to, other nodes at this level. Gateways to other networks such as FTS 2000 and PLNs via digital patch and access systems, multifunction switches,

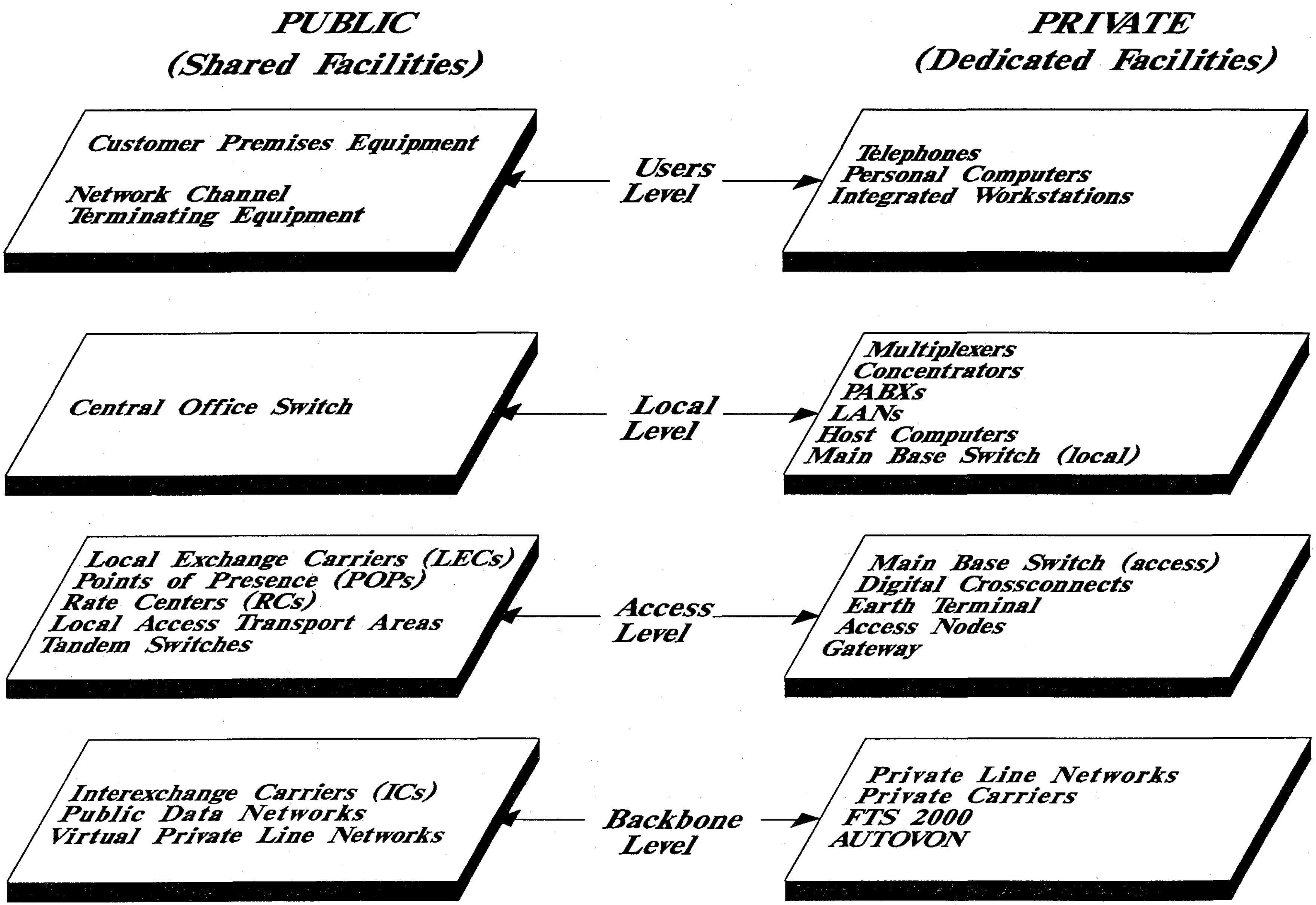


Figure 28. Multilevel structure of the network (current view).

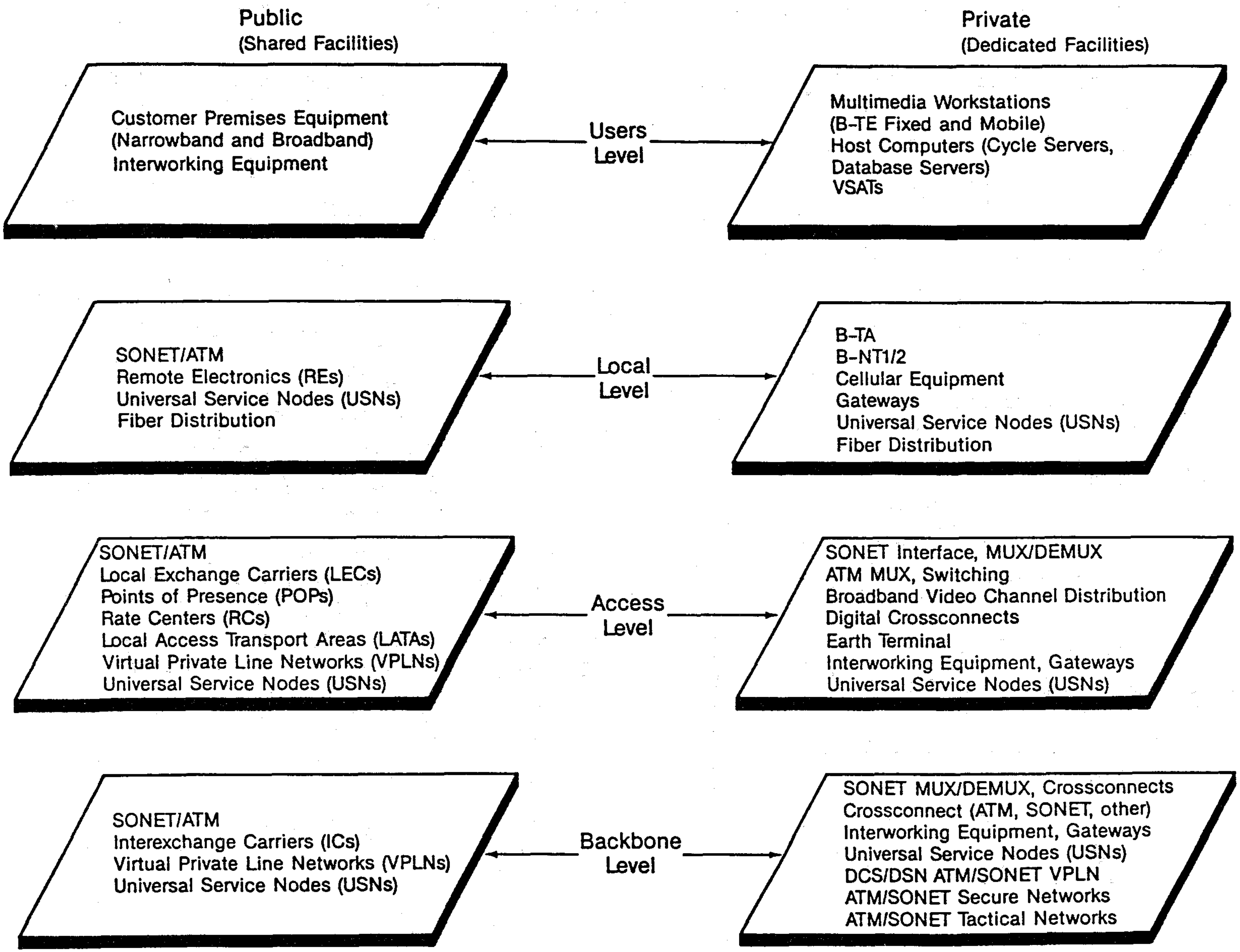


Figure 29. Multilevel structure of the network (future view).

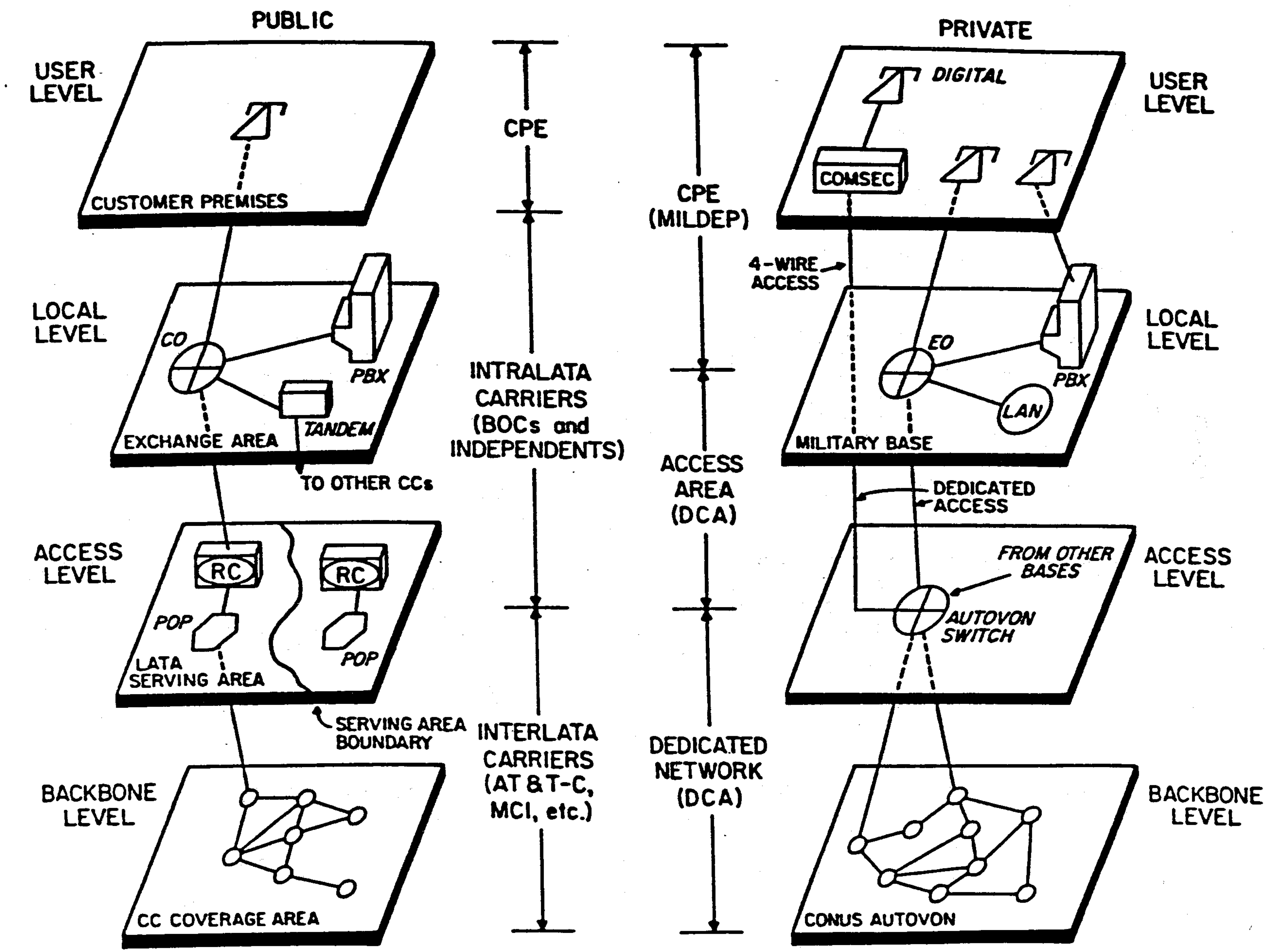


Figure 30. Structural configuration for public and private networks.

and stand-alone switches are at this level. On the public side, the access level consists of the LATA. The size of LATAs may vary considerably depending on the number of subscribers (e.g., two LATAs cover the entire state of Colorado). Each LATA may be subdivided into zones for intra-LATA billing purposes. Switch locations designated points of presence (POP) are for billing purposes.

Long-haul transport is accomplished at the backbone level. Here the inter-LATA carriers and private line networks are viewed on a national, or even global, basis. Several backbone networks may be dedicated. These include a Public Data Network (PDN) (e.g., Telenet and Tymnet) and Virtual Private Line Network (VPLN) in the public domain; the FTS 2000 Network and private line networks (PLNs) in the private domain.

We have found this multilevel, two-domain structural approach to be a useful way to present both functional and physical views of network architectures to aid in understanding the overall structure. Special symbols on these diagrams may be used to indicate features such as 2-wire and 4-wire connections, location of protocol converters, and interface boundaries. This approach permits a simple way to indicate areas of network management responsibility. The demarcation of responsibility between customer premises equipment and the intra-LATA local exchange carrier in the public sector may not be the same as in the private sector as shown in Figure 30. In the private sector, customer premises equipment may include not only the terminal equipment, but also some switching and accessing facilities.

In our structured approach, public networks are considered to be those networks where switching and transmission facilities are shared by the general public. The facilities of private networks are dedicated to a specific group of users. Private networks may be leased, privately owned, or Government owned and operated. Both public and private networks may be switched or nonswitched. An example of a nonswitched network in the public domain might be electronic funds transfer (EFT) from remote banking facilities. Airline reservations systems are examples of private, switched networks since their facilities are solely for use by the airlines industry.

In describing complex networks, it is important to distinguish between virtual and transparent facilities. A transparent facility actually exists but appears not to exist. A virtual facility appears to exist but in fact does not.

VPLNs as opposed to dedicated private line networks (DPLNs) fall in the public domain. Therefore, a VPLN only appears to be dedicated, but its facilities are shared since the VPLN is embedded (by software) in public facilities.

A key to the question whether a public network or private network best meets ones needs is dependent on a number of factors including:

- amount and type of traffic
- cost of providing the service and capital investment
- network ubiquity
- diagnostic and maintenance responsibility
- special needs (e.g., security and reliability).

Figure 31 is an example of how this multilevel concept might be used as a tool to depict a private ISDN network accessing the public switched telephone network via a digital access cross-connect system (DACS). This type of access might be used at Government facilities that would normally use the private Federal Telephone System (FTS) for business calls, but would still need access to the local and long distance networks for other calls.

4.3 Classification of Network Implementations

Tables 5, 6, and 7 demonstrate the classification of various network implementations. These three tables provide a number of blank rows for specifying different attributes for each hierarchical level (local, access, backbone) of any network. The attributes include basic concepts (topology, control, etc.) in Table 5, switching in Table 6, and transmission in Table 7. Other choices may be added with additional columns as future networks evolve.

Figures 32, 33, 34, and 35 indicate some but not necessarily all of the choices available for switch control, switch technology, signaling, and routing, respectively. As the technology evolves, other classifications can be added.

To illustrate the number and complexity of options one is faced with in selecting just a switch, we have included, as Appendix A, a feature availability matrix for the Meridan SL-1 PBX available from the Northern Telecom Corporation in the mid 1980's. The features and functions listed in Appendix A are divided into what the manufacturer calls basic PBX features and

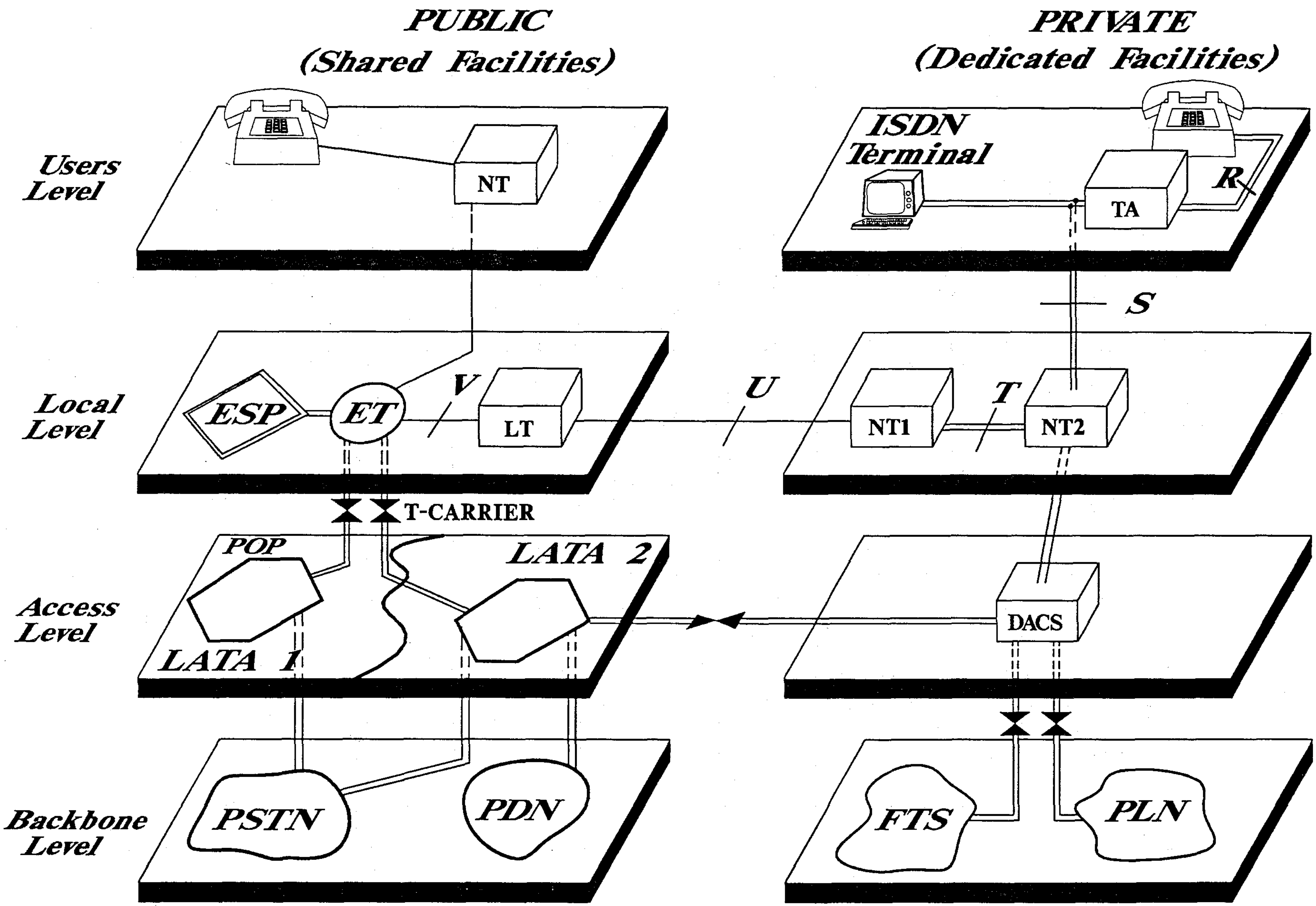


Figure 31. Accessing public ISDN from a private network domain.

Table 5. Classifications Based on Network Concepts

NETWORK ATTRIBUTES / TYPE & LEVEL	USERS		TOPOLOGY						LINKS				CONTROL			CALL ACCEPTANCE			ROUTING		
									SWITCHED		DEDICATED										
	COMMON	SPECIAL	LINE	TREE	STAR	LOOP	GRID	HYBRID	PT. TO PT.	MULTIPOINT	PT. TO PT.	MULTIPOINT	CENTRALIZED	DECENTRALIZED	DISTRIBUTED	BLOCKABLE	ALWAYS ACCEP.	ACCEPT. BUT THROTTLED	FIXED	ADAPTIVE	SATURATION

Table 6. Classifications Based on Switching Concepts

SWITCHING CONCEPTS / TYPE & LEVEL	CIRCUIT SWITCHED											STORE AND FORWARD SWITCHED										NONSWITCHED		
	CROSS POINTS		ANALOG					DIGITAL				MESSAGE SERVICE		PACKETIZED SERVICES			LINK CONTROL		ERROR CONTROL			ACCESS		
			MATRIX			SIGNALING		MATRIX		SIGNALING														
	METALLIC	NONMETALLIC	FREQ. DIVIDED	TIME DIVIDED	SPACE DIVIDED	PER CHANNEL	COMMON CHANNEL	TIME DIVIDED	SPACE DIVIDED	BORROWED BITS	ALLOCATED BITS	MANUAL	AUTOMATIC	VIRTUAL	DATAGRAM	TERMINAL EMULATED	BITS ORIENTED	CHAR. ORIENTED	NONE	ARQ	FEC	POLLED	RESERVED	RANDOM ACCESS

Table 7. Classifications Based on Transmission Concepts

TRANSMISSION CONCEPTS / TYPE & LEVEL	SERVICE				SIGNAL										MODE						
	FIXED		MOBILE		AMPL.		TIME		CHANNEL-IZATION		FORMAT				OPERATING			PARALLEL		SERIAL	
	PT. TO PT.	MULTIPOINT	PT. TO PT.	MULTIPOINT	CONTINUOUS	DISCRETE	CONTINUOUS	SAMPLED	SINGLE	MULTIPLE	CODED	UNCODED	MODULATED	UNMODULATED	SIMPLEX	HALF DUPLEX	FULL DUPLEX	SYNC	ASYNC	SYNC	ASYNC

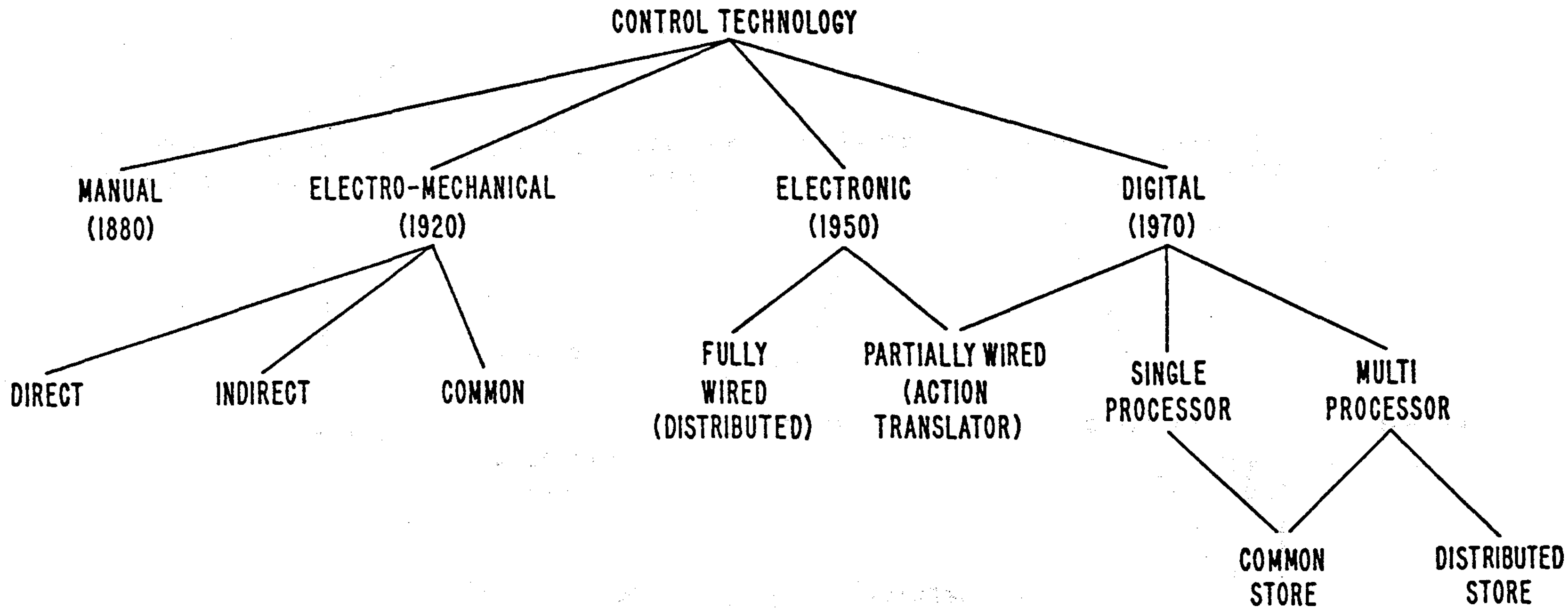


Figure 32. Control technologies used in circuit switched networks.

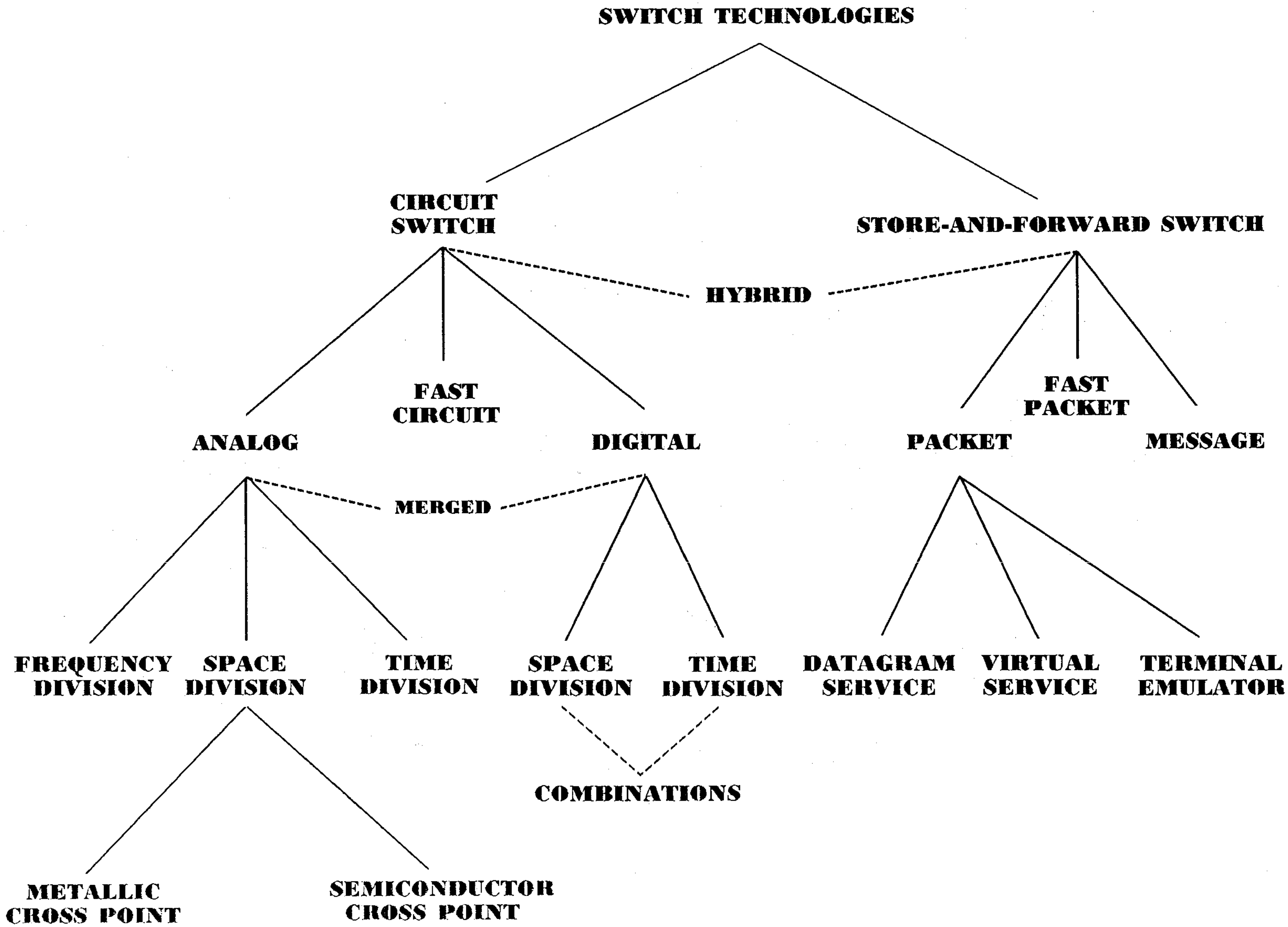


Figure 33. Switch technologies.

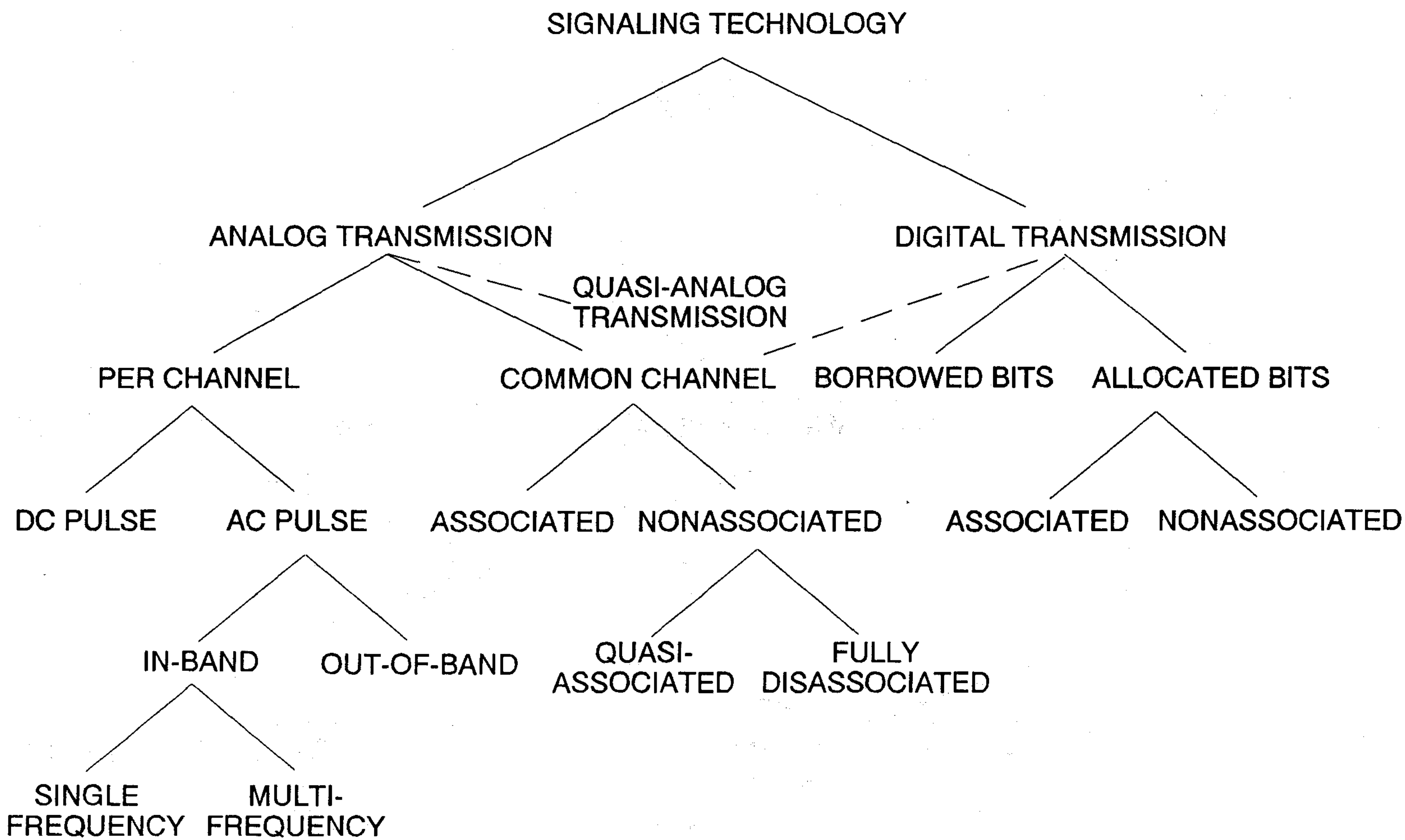


Figure 34. Signaling technologies used in a circuit switched network.

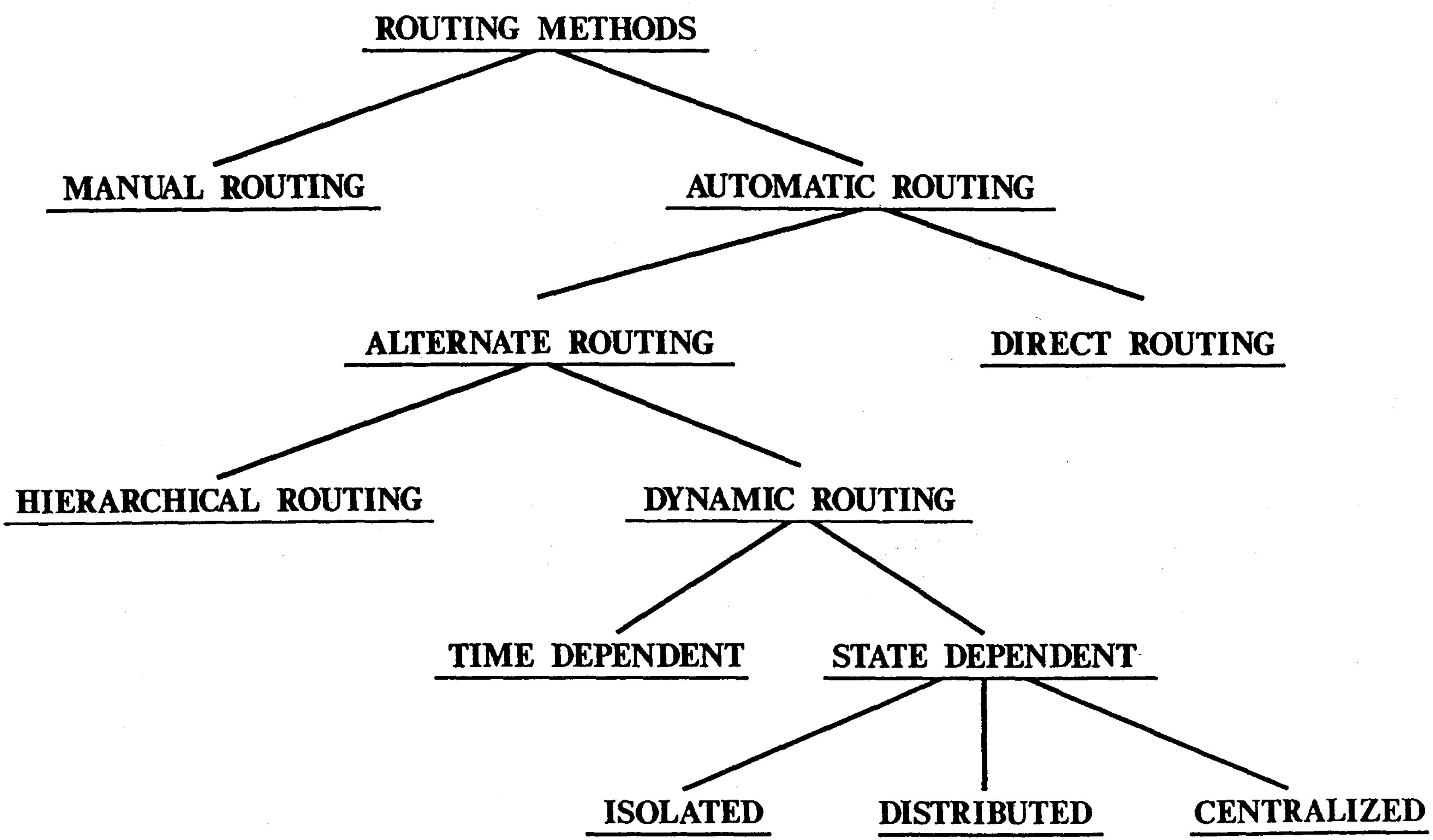


Figure 35. Routing alternatives.

optional features. These two categories are further subdivided into system features, attendant features, and station set features. The features and functions given for this switch are not unlike those available from other PBXs.

System features are available at the system level for maintenance, management, configuration, and control. They include loop testing, call detail recording and a control console for system reconfiguration and monitoring. System features are the domain of the service provider/managers--not the user. Billing information such as call start time, duration, caller's ID, destination ID, date, etc., is typically put into separate ledger accounts so charges to specific groups or divisions can be made.

Attendant features are available to intermittent operators, for instance, receptionist and secretary, but are not available on all phones. Features include transferring calls, paging, and overriding calls. Other on-line operators monitor network status and perform network management functions.

User station features include call waiting, call forwarding, camp-on, speed dialing, and many others listed in Appendix A. These features are usually implemented in software and include a standard set plus an optional menu from which one can select the features that meet specific needs. Lists are included in Appendix A for several different station sets. The number of available options illustrates the complexity of selecting a switch.

No attempt has been made to distinguish between what is available, what is needed, and what is currently used. The status of all of these change quite rapidly. Critical requirements and unique features and functions could be assessed in terms of where they are performed. For example, call processing functions performed by the four major elements of a switch (signaling, control, switching, and interface) are summarized in Table 8.

For each element, the pertinent functions are divided into three categories as follows:

Per-line functions:	required on a continuous basis.
Per-call functions:	required only during the information transfer time.
Per-setup functions:	required only during access and disengagement times.

Table 8. Call Processing Functions Performed by Circuit Switch Elements

	Signaling	Control Unit	Switching Matrix	Interface
Per-Line Functions (Continuous)	Attending (Service Request Detection)	Input Scanning		Battery Feed Overload Protection Hybrid
Per-Call Functions	Supervising (Call Completion Detection)		Interconnection	Codec Supervision (Answer and clear)
Per-Setup Functions	Addressing (Sending and Receiving) Alerting (Dial Tone, Ringing, Busy etc.)	Registration Translation Output Distribution Path Selecting Routing Busy Test Establish Connection Release Connection	Establish Connection Release Connection	Ring Access Test Access

5. NETWORK EVOLUTIONARY FORCES AND FUTURE PROJECTIONS

In order to assess the future course of telecommunications in the U.S. and to develop future architectural concepts, it is useful to examine the critical events that have taken place in the past. For this purpose we have divided the evolution of telecommunications into four epochs--the age of creation (1850-1900), the age of ubiquity (1900-1950), the age of diversity (1950-2000), and the age of utilization (2000-2050). The age of creation is when the critical underlying inventions occurred (e.g., the telegraph, the telephone, and the wireless). Near the end of this period, the Bell patents expired and competition in telecommunications really began.

In the early 1900's, a universal service was the major goal. Over 90% of American households had radios by 1950 and telephones by 1970. The Congress passed the Communications Act of 1934 enabling the FCC. Until the mid-1950s, the FCC regulated telephone service on the assumption that a telephone network could best serve the public as a monopoly. Universal telephone service would be provided by rate averaging and affordable service would result from the economies of scale.

Around 1960, the government began to consciously follow a different policy--that of promoting competition in the industry. Milestones in this era include a landmark antitrust decision in 1968 that expanded the terminal equipment market, an FCC decision in 1969 resulting in a specialized carrier industry, another antitrust suit in 1974 against AT&T leading to BOC divestiture in 1984, FCC Computer Decisions I, II, and III that defined jurisdictional responsibilities as communications technology and computer technology merged, and the Presidential task force report known as the Rastow report which formed the basis for U.S. telecommunication policy after 1968. For more information on these and other milestones, see Martin (1970), NTIA (1988), FCC (1971, 1977, 1986), and Fowler et al., (1986).

Just to complete this evolutionary picture, we have included the age of utilization covering the period 2000-2050. In this period we could apply the tremendous information base available via telecommunications to expand knowledge and enter the so called "information age."

These four epochs and the critical technical and political events that occurred within each one are tabulated in Table 9.

Table 9. Periods in Telecommunications Development

EVOLUTIONARY AGE	YEAR	TECHNOLOGY	POLICY
		1842 - Telegraph	
CREATION	1850		
		1876 - Telephone	
		1886 - Wireless Telegraph	1893 - Bell patents expire (Start of competition)
UBIQUITY	1900		1907 - AT&T refuses interconnection
			1910 - Mann-Elkins Act (ICC Regulation)
			1913 - Kingsbury Commitment (Interconnection Required)
		1921 - Mobile Phone	1927 - Radio Act
			1934 - Communications Act enabling FCC
			1949 - AT&T antitrust suit
DIVERSITY	1950	1950 - Computers (Univac)	
		1950 - Microwaves	
		1954 - Transistor	1956 - Consent decree
		1955 - CATV	1962 - Communications Satellite Act
		1957 - Satellites	1962 - All Channel TV Receiver Act
		1960 - SPC Switch	1966 - Computer Inquiry I
		1964 - Carterphone	1968 - Equipment interconnection (Carterphone)
		1970 - Microelectronics	1969 - Microwave Communications System approved
		1970 - Fiber Optics	1970 - Satellite policy
		1971 - Micro-electronics	1971 - Computer I Final Decision
			1974 - AT&T antitrust suit
			1980 - Computer II Final Decision
		1980 - Home Computers	1984 - Divestiture of AT&T
		1988 - ISDN	1986 - Computer III Inquiry
			1988 - Open Network Architecture plans
		199? - B-ISDN	
UTILIZATION	2000	- Artificial intelligence	
		- Widespread video telephony	- Telecommunications regulation ends or reduced
		- Integrated work-stations	
		- Home information centers	
		- Dynamic bandwidth allocations	
	2050		

Currently, there are new forces shaping network architectures and implementations--namely technological advances, market demands, and government regulatory policies. Each are discussed in the following sections.

5.1 Technical Advances

There are a number of technological advances that will almost certainly influence the provisioning of services over the next decade or two. Here we mention some of the recent advances. Often, a technology advance occurs before a real need or requirement exists.

Recent technological advances include the following:

- Synchronous optical networks (SONET)
- Advanced communication technology satellites (ACTS)
- Digital compression techniques
- Fiber distributed data interfaces (FDDI)
- LANs and WANs
- ISDN and B-ISDN
- Fast packet switching
- Photonic switching systems.

For still other advances and their impact on telecommunication industries and services, see Martin (1988) and NTIA (1988).

5.2 Market Demand

Market demand is difficult to define but it certainly impacts network design and restructuring. Any network restructuring process results in a constant change and growth of networks. It is largely due to a shift toward a more service-oriented economy in the United States. A service economy will require new resources involving the processing, storage, and transport of information.

Several trends can be observed as a result of market demands. Figure 36 illustrates the penetration of communication services in the public sector due to user demand for telephone, radio, television, and cable services. All are the result of user demand.

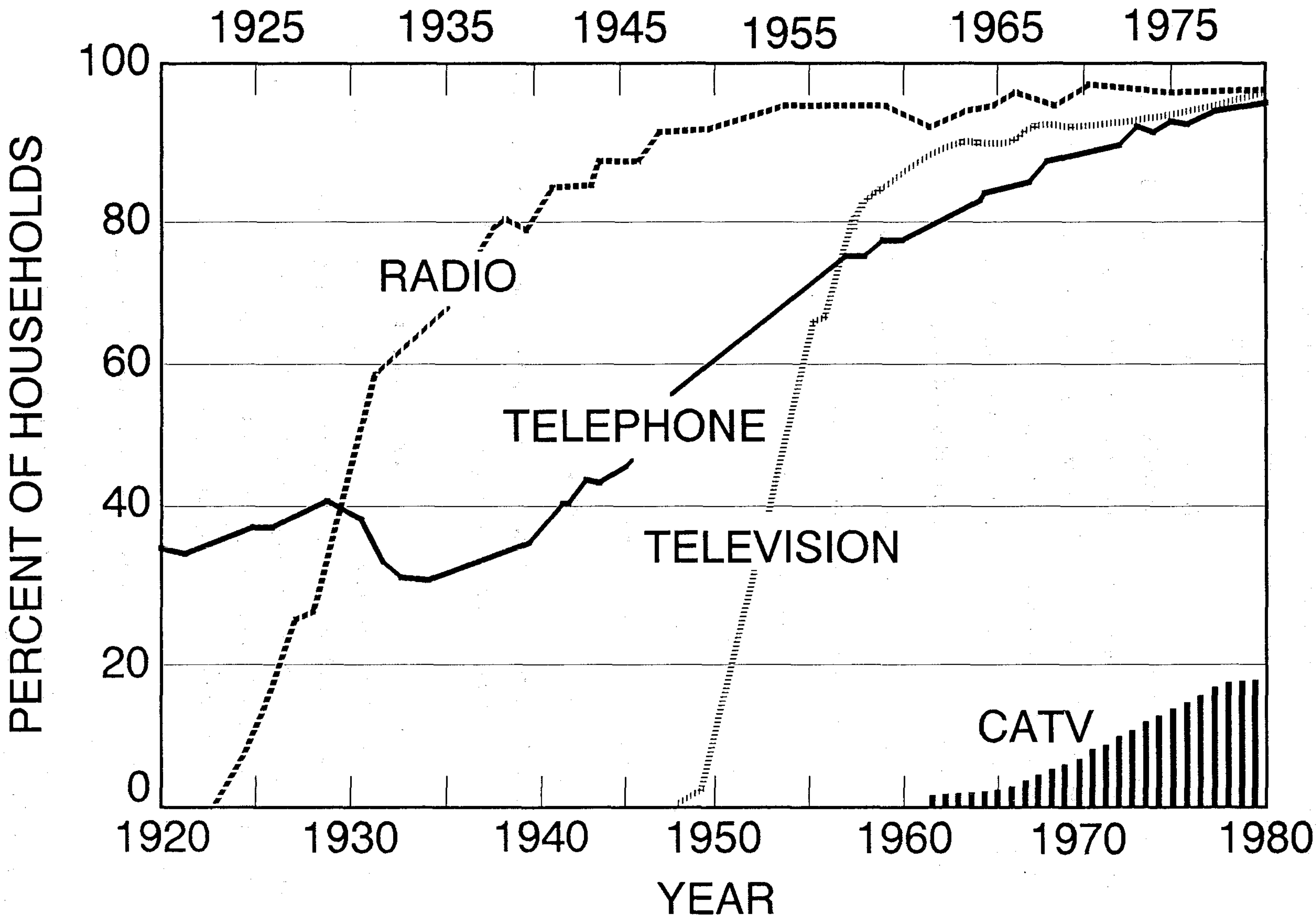


Figure 36. Penetration of telecommunication services in the public sector.

In 1990 the total U.S. market for telecommunications hardware, software, services, and support is expected to approach 335 billion dollars, representing six percent of the U.S. Gross National Product. Figure 37 illustrates the breakdown for this growth in terms of private networks, voice networks, and data networks.

Users are continuously demanding new services and more bandwidth. More bandwidth is needed for integrated voice and data transmission, high-speed data transfer, and video services. The nation is fast becoming laced with fiber optical transmission systems to support this demand and the capacity it requires.

5.3 Government Policy

Empowered by the Communications Act of 1934, the Federal Communications Commission (FCC) set out "to make available, so far as possible, to all the people of the United States a rapid, efficient, nationwide, and worldwide communication service with adequate facilities at reasonable charges," see U.S.C. (1982). This worthwhile goal had, in large measure, been achieved by the 1960's. By then the depth of penetration of plain old telephone service (POTS) far exceeded what was originally envisioned by the sponsors of the Act. In order to achieve this so-called, "universal" and "affordable" service, the FCC initially believed that the public would best be served by a monopoly where economies-of-scale would provide the affordable part, and rate averaging the universal part. About this same time, a new product was developing that would have far reaching effects, not only on the telecommunications environment, but on the FCC as well--namely the digital computer with stored program control (SPC).

By the middle 1970's, the distinction between computer processing and communications became blurred as these two technologies converged. It was apparent that any regulation based on the dichotomy between processing and communications could not long endure. Over the next two decades, the FCC conducted a series of inquiries known as Computer I, II, and III. As these inquiries progressed, the policy emphases of the FCC, the U.S. Congress, and the U.S. Justice Department changed. Rather than regulate and monopolize, the new outlook encouraged deregulation and competition. Depth of penetration of POTS would be supplemented with a new goal, namely, breadth of services. The competitive environment under marketplace control was envisioned to yield new

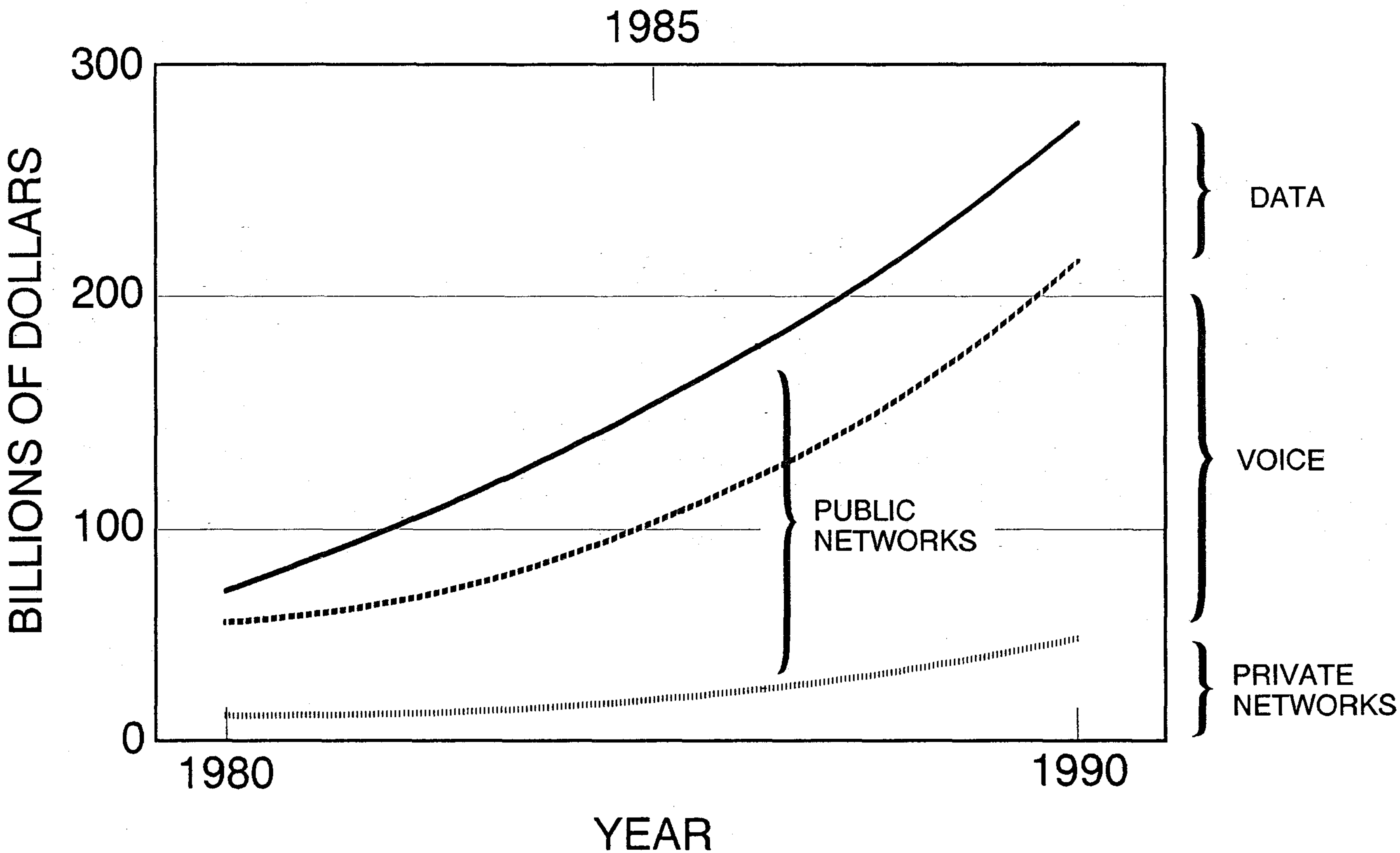


Figure 37. The growing United States market for telecommunications.

innovative features and functions that would meet the service demands of an emerging information society.

This new political climate in the nation's capitol resulted in deregulation of customer premises equipment (CPE) and enhanced services in 1981, the divestiture of AT&T in 1984, and the open network architecture concept in 1987. However, these changes have not come about without problems. Although many expected benefits have occurred, so have new issues arisen. Some of these issues are being resolved but others are still pending. See for example IEEE (1989), NTIA (1988), and Fowler et al., (1986).

After two decades of controversy over competition in the carrier industry perhaps the most dramatic organizational change occurred on January 1, 1984, when the Modified Final Judgment (1983) resulted in dividing what was then the largest corporation in the world (American Telephone and Telegraph Company) with some $150 billion in assets serving over 100 million subscribers into eight independent companies, seven regional Bell Operating Companies (RBOCs) and AT&T. This "divestiture" culminated a series of government deregulatory, pro-competitive initiatives involving all three branches of government.

The FCC, DoJ, and NTIA are still debating the responsibilities imposed by divestiture. Additional information on the impact of the divestiture on the U.S. telephone industry is given by Bell (1990) and Fowler et al., (1986). Also see NTIA (1988).

5.4 Future Projections

In summary, the impact of technical advances, market demands, and government policy on the telecommunications environment has been profound. Some of the advantages and disadvantages of this new telecommunications environment are given in Table 10.

Table 11 lists some architectural projections, both near-term (1995) and far-term (2005), along with designated transition architectures and goal architectures.

As we enter the 1990's it is clear that network management including automation will be a major concern. As voice, data, video services, and facilities become integrated, their administration, operation, and maintenance takes on paramount importance. Enhanced control of these complex multifunctional networks is needed to keep them working. Ultimately the

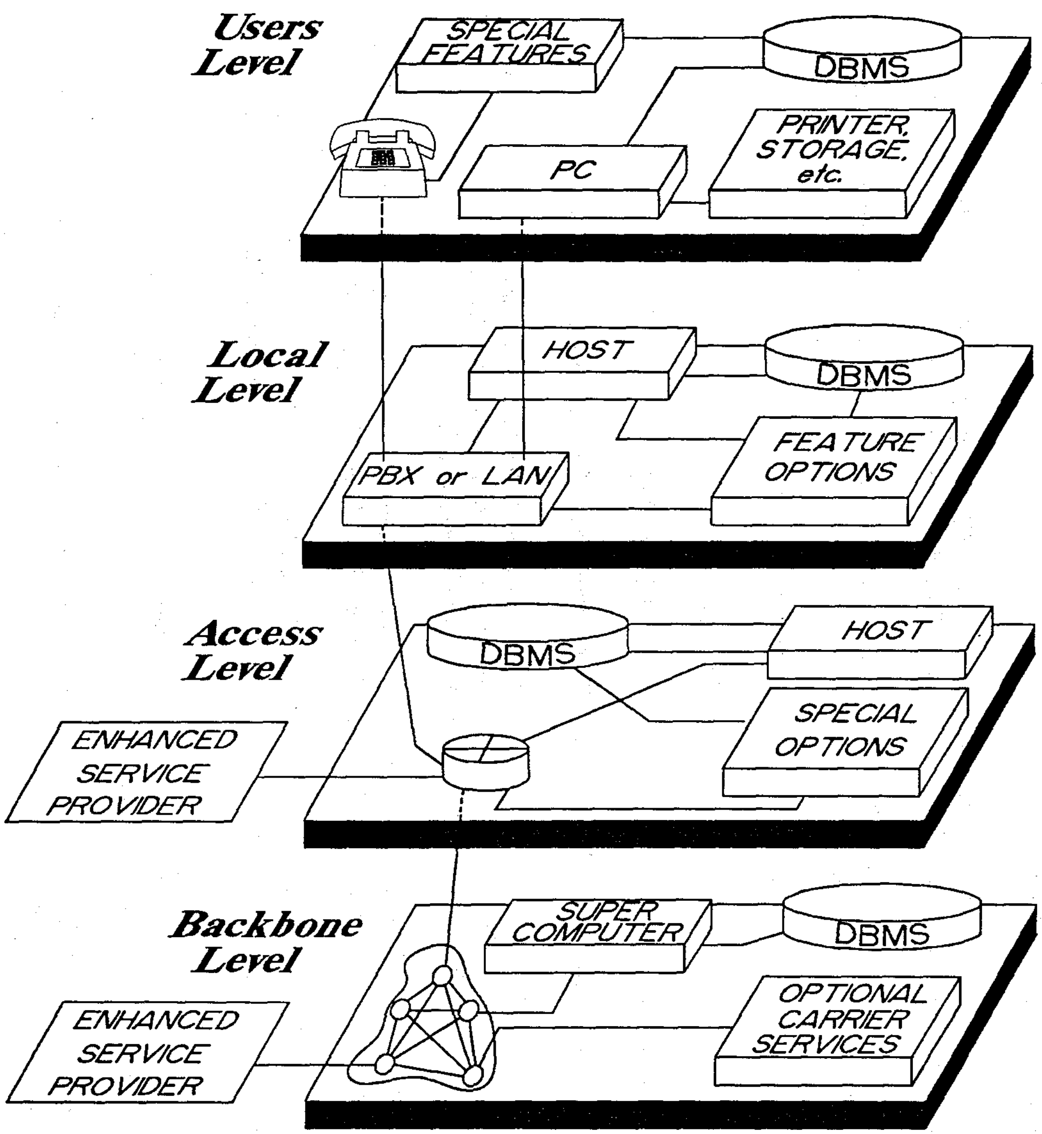
Table 10. Telecommunications Impact on Network Technology

Telecommunications Environment	Advantages	Disadvantages
Deregulated services and equipment	Diversity of facilities	Increasing interoperability issues
Competing vendors	Innovative systems and reduced costs	Procurement and maintenance difficulties with a need for more interface standards
New technologies (e.g., digital networks, fiber)	Enhanced performance at lower cost	Transition problems
Novel features and functions	Increased productivity and mission matches	Uncertainty about user reaction
Divestiture	Competing ICs, reduced long haul costs, and service-oriented procurements	Increased local costs and diagnostic and maintenance responsibility
Access standards	Service integration and open system interconnections	Need for sub-optimum compromised solutions to interface issues

Table 11. Architecture Projections

1995 Transitioning Architectures	2005 Goal Architectures
- Increased use of private networks (e.g., VPLNs) with expanded use by large corporations	- Widespread interconnections of LANs via PBXs, central offices, and MANs
- Adoption of functional procurement procedures (e.g., FTS 2000)	- Super microcomputers serving distributed user applications
- Installation of a PC on every desk interconnected by LANs and some MANs	- Video workstations available and in use
- Digital telephones and digital local distribution networking	- Integrated data/voice/video terminals, switches, and transmission systems
- Narrowband ISDN expanding from local islands, ISDN type PBXs using standard rates of 2B+D and 23B+D	- Broadband ISDN expanding from local area islands
- Proliferations of fiber leading to bandwidth excess in public sector	- Synchronous optical networks for long haul transport
- Introduction of integrated voice and data terminals	- Intelligent service nodes distributed throughout the network
- Centralized and distributed network management with some automated AO&M	- Distributed network management systems using artificial intelligent systems
- Signaling System #7 introduced at local level	- Signaling and management systems integrated with information transmission in SDH transmission
- Multiprocessing systems closely coupled with each other	- Loosely coupled systems and devices with distributed processing

network itself might use artificial intelligence techniques for self-repair and fault-tolerant networking. Features and functions offered by telecommunications networks will undoubtably be distributed throughout the levels of structure in the network as illustrated in Figure 38. Parallel processing will use the network to loosely couple various processing systems. These so-called distributed systems may ultimately require much more connectivity among devices and systems. Wide spread data bases will become readily available at low cost through individual work stations.



TERMINAL

- WORD PROCESSING
- DBMS
- GRAPHICS
- SPREAD SHEET
- COMMUNICATIONS
- LOW SPEED PRINTING
- PREMISES TESTING

LOCAL SWITCH

- ORGANIZATIONAL DBMS
- LOCAL ELECTRONIC MAIL
- HIGH SPEED PRINTING
- REMOTE GRAPHICS
- VOICE MESSAGE SERVICE
- LOCAL AO & M/NM

REGIONAL SWITCH

- MAINFRAME COMPUTER
- EXTENDED DBMS
- DATA STORAGE
- ACCESS TO LONG HAUL
- REGIONAL AO &M/NM
- REGIONAL CONFERENCING

NATIONAL NETWORK

- NETWORK MANAGEMENT
- AO & M
- VIDEO CONFERENCE
- SUPER COMPUTER
- 800 SERVICE
- ELECTRONIC MAIL

Figure 38. Distribution of network features and functions.

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APPENDIX A: FEATURE AVAILABILITY MATRIX

This Appendix is reproduced from a Northern Telecom brochure describing the business features available for SL-1 switch. The SL-1 is a digital branch exchange that is widely used throughout the world. Originally introduced in 1975, the SL-1 provides voice and data services to between 30 and 5,000 voice and data terminals. The evolution of the SL-1 is described by Ahmad et al., (1986). The diversity of features and functions of this switch are not unlike those of many other modern PBXs.

A.1 References

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8.0 FEATURE AVAILABILITY MATRIX

The Feature Availability Matrix indicates which Meridian SL-1 features described in this document are available for each release of Software Generic X11. Definitions of the available features not described in this document are contained in the Feature Documents for ACD, ESN and IMS.

Changes associated with "Release 6"were rolled into "Release 7,"therefore, "Release 6"is not listed in the Feature Availability Matrix.

FEATURE AVAILABILITY MATRIX
GENERIC X11

I. BASIC PBX FEATURES	GENERIC RELEASE				
	#2	#3	#4	#5	#7
System Features					
Access to Paging	X	X	X	X	X
Access to Recorded Telephone Dictation	X	X	X	X	X
Access Restrictions	X	X	X	X	X
Add-On Data Module (ADM) Trunk Hunting	N/A	N/A	N/A	X	X
Automatic Daily Routines	X	X	X	X	X
Automatic Conversion	X	X	X	X	X
– Soft Memory Failure Recovery	X	X	X	X	X
Auxiliary Signaling	X	X	X	X	X
Bulk Data Load	X	X	X	X	X
Call Forward (No Answer)	X	X	X	X	X
– CFNA to Any DN	X	X	X	X	X
– Variable Timing	X	X	X	X	X
Called Party Disconnect Control	N/A	X	X	X	X
CCSA Access	X	X	X	X	X
Class of Service Restrictions	X	X	X	X	X
Code Restrictions	X	X	X	X	X
Common Equipment Enhancement	N/A	N/A	X	X	X
Conditional Data Dump	X	X	X	X	X
Data Port Hunting	N/A	N/A	N/A	X	X
Data Transmission	X	X	X	X	X
Dial Pulse to DTMF Conversion	X	X	X	X	X
DTMF Calling	X	X	X	X	X
DTMF to Dial Pulse Conversion	X	X	X	X	X
Direct Inward Dialing (DID)	X	X	X	X	X
Direct Outward Dialing (DOD)	X	X	X	X	X
Dual Central Processing Unit (Not available on Meridian SL-1S, MS, M)	X	X	X	X	X
Emergency Transfer Control	X	X	X	X	X
EPSCS Interface (Independent Start Signaling Arrangement)	N/A	N/A	N/A	X	X
Flexible Attendant DN	X	X	X	X	X
Flexible Numbering Plan	X	X	X	X	X
Flexible Outpulsing Delay	N/A	N/A	N/A	X	X
4-Wire E&M Trunk	X	X	X	X	X
Hunting – Circular, Linear, Secretarial, Short	X	X	X	X	X
Integrated Voice/Data Switching (IVDS)	X	X	X	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

I. BASIC PBX FEATURES	GENERIC RELEASE				
	#2	#3	#4	#5	#7
Intercept	X	X	X	X	X
Line Lockout	X	X	X	X	X
– Flexible Line Lockout	N/A	N/A	X	X	X
Manual Line Service	X	X	X	X	X
Manual Trunk Service	X	X	X	X	X
Memory Extension	N/A	N/A	N/A	X	X
Memory Management	X	X	X	X	X
Modem Trunks	X	X	X	X	X
Multiple Loop Directory Number	X	X	X	X	X
Near Immediate Ringing	X	X	X	X	X
Night Service	X	X	X	X	X
Outgoing Trunk Hunting	N/A	X	X	X	X
Off-Premise Extension (OPX)	X	X	X	X	X
Peripheral Equipment Enhancement	N/A	N/A	X	X	X
Power Failure Transfer	X	X	X	X	X
Private Line Service	X	X	X	X	X
Remote Administration	X	X	X	X	X
Reserve Power	X	X	X	X	X
Ring Validation Timing	X	X	X	X	X
Soft Memory Failure	X	X	X	X	X
Special Dial Tone	X	X	X	X	X
Station-To-Station Calling	X	X	X	X	X
Tandem Switching	X	X	X	X	X
Tie Trunks	X	X	X	X	X
Toll Restrictions	X	X	X	X	X
Traffic Measurement	X	X	X	X	X
Trunk Answer From Any Station (TAFAS)	X	X	X	X	X
Trunk Group Access Restrictions (TGAR)	X	X	X	X	X
Trunk Guard Timing	X	X	X	X	X
– Flexible Trunk Guard Timing	X	X	X	X	X
2-Wire E&M Trunk	X	X	X	X	X
4-Wire E&M Trunk	X	X	X	X	X
Uninterrupted Line Service	X	X	X	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

I. BASIC PBX FEATURES

Attendant Features	#2	#3	#4	#5	#7
Alarm Lamps	X	X	X	X	X
Attendant Console Expansion (Add-On Modules)	X	X	X	X	X
Attendant Console Jacks	X	X	X	X	X
Attendant Interpositional Calling	X	X	X	X	X
Attendant Interpositional Transfer	X	X	X	X	X
Automatic Dialing	X	X	X	X	X
Automatic Timed Reminders (Recalls)	X	X	X	X	X
Barge-In	X	X	X	X	X
Busy Lamp Field	X	X	X	X	X
Busy Verify	X	X	X	X	X
Call Selection	X	X	X	X	X
Calls Waiting Indication	X	X	X	X	X
Camp-On (with indication)	X	X	X	X	X
Conference 6	X	X	X	X	X
Console Digit Display	X	X	X	X	X
Control of Trunk Group Access (Trunk Group Busy)	X	X	X	X	X
Display Calls Waiting	X	X	X	X	X
Display/Change Date	X	X	X	X	X
Display/Change Time	X	X	X	X	X
Emergency Transfer Control	X	X	X	X	X
Headset/Handset Operation	X	X	X	X	X
Incoming Call Identification (ICI)	X	X	X	X	X
Key Sending	X	X	X	X	X
Light Emitting Diode (LED) Indicators	X	X	X	X	X
Lockout	X	X	X	X	X
Multiple Console Operation	X	X	X	X	X
Multiple Listed Directory Numbers	X	X	X	X	X
– Internal Call Type Identification	X	X	X	X	X
Night Service Control	X	X	X	X	X
Non-Delayed Operation	X	X	X	X	X
Non-Locking Keys	X	X	X	X	X
Position Busy	X	X	X	X	X
Pushbutton Dialing	X	X	X	X	X
Secrecy	X	X	X	X	X
Speed Call	X	X	X	X	X
Splitting	X	X	X	X	X
Switched Loop Termination	X	X	X	X	X
Through Dialing	X	X	X	X	X
Trunk Group Busy Indication	X	X	X	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

I. BASIC PBX FEATURES	GENERIC RELEASE				
	#2	#3	#4	#5	#7
QSU Station Set Features					
Attendant Recall	X	X	X	X	X
Automatic Dialing	X	X	X	X	X
Automatic Preselection of Prime DN	X	X	X	X	X
Busy Lamp Field	X	X	X	X	X
Call Forward (All Calls)	X	X	X	X	X
- Secretarial Filtering	X	X	X	X	X
Call Forward Busy	X	X	X	X	X
Call Pick-up	X	X	X	X	X
Call Status Indication	X	X	X	X	X
Call Transfer	X	X	X	X	X
Call Waiting	X	X	X	X	X
Common Audible Signaling	X	X	X	X	X
Conference 3	X	X	X	X	X
Conference 6	X	X	X	X	X
Handsfree Operation	X	X	X	X	X
Headset Operation	X	X	X	X	X
Hold	X	X	X	X	X
Light Emitting Diode (LED) Indicators	X	X	X	X	X
Loudspeaker/Amplifier	X	X	X	X	X
Manual Signaling (Buzz)	X	X	X	X	X
Multiple Appearance Directory Number					
- Multiple Call Arrangement	X	X	X	X	X
- Single Call Arrangement	X	X	X	X	X
- Ringing or Non-ringing	X	X	X	X	X
- Loop Restriction Removal	X	X	X	X	X
Non-Locking Keys	X	X	X	X	X
On-Hook Dialing	X	X	X	X	X
Override	X	X	X	X	X
Prime Directory Number (PDN)	X	X	X	X	X
Privacy	X	X	X	X	X
- Privacy Override	N/A	N/A	N/A	X	X
Privacy Release	X	X	X	X	X
Pushbutton Dialing	X	X	X	X	X
Release	X	X	X	X	X
Ring Again	X	X	X	X	X
Six-Wire Line Cord	X	X	X	X	X
QSU Set Range Extender	X	X	X	X	X
Speed Call	X	X	X	X	X
Station Set Expansion (Add-On Modules)	X	X	X	X	X
TELADAPT Connectorization	X	X	X	X	X
Tone Buzzing	X	X	X	X	X
Tone Ringing	X	X	X	X	X
Voice Call	X	X	X	X	X
Volume Control	X	X	X	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

I. BASIC PBX FEATURES

	GENERIC RELEASE				
	#2	#3	#4	#5	#7
500/2500/Unity Telephone Set Features					
Attendant Recall	X	X	X	X	X
Bridging	X	X	X	X	X
Call Forward (Busy)	X	X	X	X	X
Call Pick-up	X	X	X	X	X
Call Transfer	X	X	X	X	X
Call Waiting	X	X	X	X	X
Conference 3	X	X	X	X	X
– Conference Control	X	X	X	X	X
Dial Access to Features and Services	X	X	X	X	X
Manual Line Service	X	X	X	X	X
Multiple Appearance Directory Number (SCR/SCN)	X	X	X	X	X
– Loop Restriction Removal	X	X	X	X	X
Off-Premise Extension (OPX)	X	X	X	X	X
Ring Again	X	X	X	X	X
Switchhook Flash	X	X	X	X	X
Meridian 2000 Telephone Features					
Attendant Recall	N/A	N/A	N/A	N/A	X
Automatic Dialing	N/A	N/A	N/A	N/A	X
Automatic Preselection of Prime DN	N/A	N/A	N/A	N/A	X
Call Forward (All Calls)	N/A	N/A	N/A	N/A	X
– Secretarial Filtering	N/A	N/A	N/A	N/A	X
Call Forward (Busy)	N/A	N/A	N/A	N/A	X
Call Pickup	N/A	N/A	N/A	N/A	X
Call Status Indication	N/A	N/A	N/A	N/A	X
Call Transfer	N/A	N/A	N/A	N/A	X
Call Waiting	N/A	N/A	N/A	N/A	X
Common Audible Signaling	N/A	N/A	N/A	N/A	X
Conference 3	N/A	N/A	N/A	N/A	X
Conference 6	N/A	N/A	N/A	N/A	X
Hold	N/A	N/A	N/A	N/A	X
Liquid Crystal Display (LCD) Indicators	N/A	N/A	N/A	N/A	X
Loudspeaker/Amplifier	N/A	N/A	N/A	N/A	X
Manual Signaling (Buzz)	N/A	N/A	N/A	N/A	X
Multiple Appearance Directory Number	N/A	N/A	N/A	N/A	X
– Multiple Call Arrangement	N/A	N/A	N/A	N/A	X
– Ringing or Non-Ringing	N/A	N/A	N/A	N/A	X
– Single Call Arrangement	N/A	N/A	N/A	N/A	X
Non-Locking Keys	N/A	N/A	N/A	N/A	X
On-Hook Dialing	N/A	N/A	N/A	N/A	X
Override	N/A	N/A	N/A	N/A	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

I. BASIC PBX FEATURES

	GENERIC RELEASE #2	#3	#4	#5	#7
Meridian 2000 Telephone Features (cont'd)					
Prime Directory Number (PDN)	N/A	N/A	N/A	N/A	X
Privacy	N/A	N/A	N/A	N/A	X
Privacy Override	N/A	N/A	N/A	N/A	X
Privace Release	N/A	N/A	N/A	N/A	X
Pushbutton Dialing	N/A	N/A	N/A	N/A	X
Release	N/A	N/A	N/A	N/A	X
Ring Again	N/A	N/A	N/A	N/A	X
Six-Wire Line Cord	N/A	N/A	N/A	N/A	X
Speed Call	N/A	N/A	N/A	N/A	X
Tone Buzzing	N/A	N/A	N/A	N/A	X
Tone Ringing	N/A	N/A	N/A	N/A	X
Voice Call	N/A	N/A	N/A	N/A	X
Volume Control	N/A	N/A	N/A	N/A	X
Meridian M3000 Touchphone Features:					
Attendant Recall	N/A	N/A	N/A	N/A	X
Automatic Dialing	N/A	N/A	N/A	N/A	X
Automatic Preselection of Prime DN	N/A	N/A	N/A	N/A	X
Call Forward (All Calls)	N/A	N/A	N/A	N/A	X
- Secreterial Filtering	N/A	N/A	N/A	N/A	X
Call Forward (Busy)	N/A	N/A	N/A	N/A	X
Call Pickup	N/A	N/A	N/A	N/A	X
Call Status Indication	N/A	N/A	N/A	N/A	X
Call Transfer	N/A	N/A	N/A	N/A	X
Call Waiting	N/A	N/A	N/A	N/A	X
Common Audible Signaling	N/A	N/A	N/A	N/A	X
Conference 3	N/A	N/A	N/A	N/A	X
Conference 6	N/A	N/A	N/A	N/A	X
Handsfree Operation	N/A	N/A	N/A	N/A	X
Handset Operation	N/A	N/A	N/A	N/A	X
Hold	N/A	N/A	N/A	N/A	X
Icons	N/A	N/A	N/A	N/A	X
Loudspeaker/Amplifier	N/A	N/A	N/A	N/A	X
Manual Signaling (Buzz)	N/A	N/A	N/A	N/A	X
Multiple Appearance Directory Number	N/A	N/A	N/A	N/A	X
- Multiple Call Arrangement	N/A	N/A	N/A	N/A	X
- Ringing or Non-Ringing	N/A	N/A	N/A	N/A	X
- Single Call Arrangement	N/A	N/A	N/A	N/A	X
Touch Sensitive Keys	N/A	N/A	N/A	N/A	X
On-Hook Dialing	N/A	N/A	N/A	N/A	X
Override	N/A	N/A	N/A	N/A	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

I. BASIC PBX FEATURES

	GENERIC RELEASE				
	#2	#3	#4	#5	#7
Prime Directory Number (PDN)	N/A	N/A	N/A	N/A	X
Privacy	N/A	N/A	N/A	N/A	X
Privacy Override	N/A	N/A	N/A	N/A	X
Privacy Release	N/A	N/A	N/A	N/A	X
Touch Sensitive Dialing	N/A	N/A	N/A	N/A	X
Release	N/A	N/A	N/A	N/A	X
Ring Again	N/A	N/A	N/A	N/A	X
Four-Wire Line Cord	N/A	N/A	N/A	N/A	X
Speed Call	N/A	N/A	N/A	N/A	X
System Speed Call	N/A	N/A	N/A	N/A	X
Tone Buzzing	N/A	N/A	N/A	N/A	X
Tone Ringing	N/A	N/A	N/A	N/A	X
Volume Control					

Unique Meridian M3000 Touchphone Features

	#2	#3	#4	#5	#7
Call Waiting Held	N/A	N/A	N/A	N/A	X
Complete	N/A	N/A	N/A	N/A	X
Consult	N/A	N/A	N/A	N/A	X
Contrast	N/A	N/A	N/A	N/A	X
Data Call	N/A	N/A	N/A	N/A	X
Directory	N/A	N/A	N/A	N/A	X
Held Conference	N/A	N/A	N/A	N/A	X
Held Transfer	N/A	N/A	N/A	N/A	X
Last # Redial	N/A	N/A	N/A	N/A	X
More	N/A	N/A	N/A	N/A	X
Predial mode	N/A	N/A	N/A	N/A	X
Return to Held Party	N/A	N/A	N/A	N/A	X
Ring Again Ready	N/A	N/A	N/A	N/A	X
Save the Number	N/A	N/A	N/A	N/A	X
Services	N/A	N/A	N/A	N/A	X
Setup	N/A	N/A	N/A	N/A	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

II. OPTIONAL FEATURES

	GENERIC RELEASE				
	#2	#3	#4	#5	#7
System Features					
Attendant Administration (AA)	X	X	X	X	X
Attendant Overflow (AOP)	X	X	X	X	X
Attendant Overflow Pos. Busy	X	X	X	X	X
Authorization Code (BAUT)	X	X	X	X	X
Automated Modem Pooling	N/A	N/A	N/A	X	X
Automatic Identification of Outward Dialing (AIOD)	X	X	X	X	X
Automatic Call Distribution (ACD)					
– Basic Package (ACDA)	X	X	X	X	X
– Advanced Features Option (ACDB)	X	X	X	X	X
– Management Reports (ACDC)	X	X	X	X	X
– Fifteen Minute Reporting Option	N/A	X	X	X	X
– Load Management (LMAN)	X	X	X	X	X
– Auxiliary Data System (ACDD)	X	X	X	X	X
Automatic Line Selection (LSEL)	N/A	X	X	X	X
Automatic Number Identification (ANI)					
– KP Option	X	X	X	X	X
– Number of Digits	X	X	X	X	X
– Route Selection (ANIR)	X	X	X	X	X
– Super Trunk Group Support	X	X	X	X	X
– Trunk Test	X	X	X	X	X
AUTOVON (ATVN)					
– Attendant Precedence Calling	N/A	N/A	X	X	X
– AUTOVON Incoming Call Indications	N/A	N/A	X	X	X
– AUTOVON Night Service	N/A	N/A	X	X	X
– CDR Enhancement	N/A	N/A	X	X	X
– Completion to Busy	N/A	N/A	X	X	X
– Incoming Preemption	N/A	N/A	X	X	X
– Mutually Exclusive Packaging	N/A	N/A	N/A	N/A	X
– Outgoing Preemption	N/A	N/A	X	X	X
– Precedence Distinctive Ringing	N/A	N/A	X	X	X
– Precedence Intercept	N/A	N/A	X	X	X
– Station Precedence Calling	N/A	N/A	X	X	X
– Trunk Interface	N/A	N/A	X	X	X
– Authcode Precedence Call Placement	N/A	N/A	X	X	X
– Flexible Hot Line	N/A	N/A	X	X	X
– Line Preference	N/A	N/A	X	X	X
– Deluxe Hold	N/A	N/A	X	X	X
Basic Authorization Code (BAUT)	X	X	X	X	X
Basic Automatic Route Selection (BARS)	X	X	X	X	X
– Queuing (BQUE)	X	X	X	X	X
– Traffic (NTRF)	X	X	X	X	X
– Offnet Number Recognition	N/A	N/A	N/A	X	X
– Incoming Trunk Group Exclusion	N/A	N/A	N/A	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

II. OPTIONAL FEATURES

	GENERIC RELEASE				
	#2	#3	#4	#5	#7
Call Detail Recording (CDR)					
– Calling Party Number (PCN)	X	X	X	X	X
– CDR – Link	X	X	X	X	X
– CDR – TTY	X	X	X	X	X
– Charge Account (CHG)	X	X	X	X	X
– ESN Enhancement	X	X	X	X	X
– Forced Charge Account (FCA)	X	X	X	X	X
– Mini-CDR	X	X	X	X	X
– OMNI-FACTS	X	X	X	X	X
– Parallel Ports	X	X	X	X	X
– Q Option	N/A	X	X	X	X
– 911 CDR Improvement	N/A	X	X	X	X
Centralized Attendant Service (CAS)	X	X	X	X	X
Chiangi Feature					
– Flexible Code Restriction	X	X	X	X	X
– Recorded Overflow Announcement	X	X	X	X	X
CMAC-A Interface	X	X	X	X	X
Common Equipment Modification (CEM)	N/A	N/A	X	X	X
Digital Trunk Interface (DTI)	N/A	N/A	N/A	X	X
Direct Inward System Access (DISA)	X	X	X	X	X
Distinctive Ringing	N/A	N/A	N/A	X	X
Dump at Midnight	X	X	X	X	X
Enhanced End-to-End Signaling	N/A	N/A	N/A	X	X
Enhanced Message Waiting Indication	N/A	N/A	N/A	N/A	X
Exclusive Hold	N/A	N/A	N/A	X	X
Flexible Hot Line	N/A	N/A	X	X	X
Flexible Line Lock Out	N/A	N/A	X	X	X
History File	X	X	X	X	X
Hong Kong Features					
– Network Blocking for DID calls	X	X	X	X	X
– Trunk Group Busy (unique tone)	X	X	X	X	X
Incoming Trunk Group Exclusion	N/A	N/A	N/A	X	X
Individual Hold	N/A	N/A	X	X	X
Integrated Messaging Service (IMS)	X	X	X	X	X
Integrated Voice/Data Switching (IVDS)	X	X	X	X	X
Integrated Voice/Messaging System (IVMS)	N/A	N/A	X	X	X
Line Lockout Treatment Enhancement	N/A	N/A	X	X	X
Line Preference	N/A	N/A	X	X	X
Manual Trunk Maintenance	X	X	X	X	X
MNA Restriction Removal	X	X	X	X	X
Multi-customer Operation	X	X	X	X	X
Multi-Tenant Service	N/A	N/A	N/A	N/A	X
Multiple DID Office Code Screening	N/A	N/A	N/A	X	X
Multiple Message Center	X	X	X	X	X
Music Package	X	X	X	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

II. OPTIONAL FEATURES

	GENERIC RELEASE				
	#2	#3	#4	#5	#7
Office Data Administration System (ODAS)	X	X	X	X	X
Outgoing Trunk Hunting					
– Linear	X	X	X	X	X
– Round-Robin	X	X	X	X	X
Peripheral Equipment Modification (PEM)	N/A	N/A	X	X	X
Recorded Announcement (RAN)	X	X	X	X	X
Remote Peripheral Equipment (RPE)	X	X	X	X	X
Satellite Link Control	N/A	X	X	X	X
Set Relocation	X	X	X	X	X
SMART	X	X	X	X	X
Supplemental Digit Restriction/					
– Recognition (SDDR)	X	X	X	X	X
Test Lines	X	X	X	X	X
Traffic Measurements (TRF)	X	X	X	X	X
Trunk Group Distinctive Ringing	N/A	N/A	X	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

II. OPTIONAL FEATURES

	GENERIC RELEASE				
	#2	#3	#4	#5	#7
Attendant Features					
Call Park/Page	X	X	X	X	X
Console for the Blind	X	X	X	X	X
Departmental LDN	N/A	N/A	N/A	X	X
Do Not Disturb (Individual/Group)	X	X	X	X	X
– DND Intercept Treatment	X	X	X	X	X
Station Category Indication	N/A	N/A	N/A	N/A	X
Stored Number Redial (SNR)	N/A	X	X	X	X
System Speed Call (SSC)	X	X	X	X	X
QSU Telephone Set Features					
Audible Message Waiting	X	X	X	X	X
Automatic Answerback (AAB)	X	X	X	X	X
Call Forward No Answer to Any DN (CFNA)	X	X	X	X	X
Call Park/Page	X	X	X	X	X
Controlled Class of Service	N/A	N/A	N/A	N/A	X
Dial Intercom Group	X	X	X	X	X
Digit Display (DDSP)	X	X	X	X	X
Group Call	X	X	X	X	X
Make Set Busy (MSB)	X	X	X	X	X
Stored Number Redial (SNR)	N/A	X	X	X	X
System Speed Call (SSC)	X	X	X	X	X
Time and Date (TAD)	X	X	X	X	X
2500 Telephone Set Features					
Audible Message Waiting	X	X	X	X	X
Call Forward (All Calls)	X	X	X	X	X
– Secretarial Filtering	N/A	X	X	X	X
Call Forward No Answer to Any DN (CFNA)	X	X	X	X	X
Call Park/Page	X	X	X	X	X
Permanent Hold	X	X	X	X	X
Speed Call	X	X	X	X	X
Stored Number Redial (SNR)	N/A	X	X	X	X
System Speed Call (SSC)	X	X	X	X	X

FEATURE AVAILABILITY MATRIX
GENERIC X11

II. OPTIONAL FEATURES	GENERIC RELEASE				
	#2	#3	#4	#5	#7
500 Telephone Set Features					
Audible Message Waiting	X	X	X	X	X
Call Forward (All (Calls)	N/A	N/A	X	X	X
– Secretarial Filtering	N/A	N/A	X	X	X
Call Forward No Answer to Any DN (CFNA)	X	X	X	X	X
Call Park/Page	X	X	X	X	X
Permanent Hold	N/A	N/A	X	X	X
Speed Call	N/A	N/A	X	X	X
Stored Number Redial (SNR)	N/A	X	X	X	X
System Speed Call (SSC)	X	X	X	X	X
Meridian M2000 Features					
Audible Message Waiting	N/A	N/A	N/A	N/A	X
Automatic Answerback (AAB)	N/A	N/A	N/A	N/A	X
Call Forward No Answer to Any DN (CFNA)	N/A	N/A	N/A	N/A	X
Call Park/Page	N/A	N/A	N/A	N/A	N/A
Controlled Class of Service	N/A	N/A	N/A	N/A	X
Digit Display	N/A	N/A	N/A	N/A	N/A
Dial Intercom Group	N/A	N/A	N/A	N/A	X
Group Call	N/A	N/A	N/A	N/A	X
Make Set Busy (MSB)	N/A	N/A	N/A	N/A	X
Stored Number Redial (SNR)	N/A	N/A	N/A	N/A	X
System Speed Call (SSC)	N/A	N/A	N/A	N/A	X
Time and Date (TAD)	N/A	N/A	N/A	N/A	X
Meridian M3000 Touchphone Features					
Audible Message Waiting	N/A	N/A	N/A	N/A	X
Automatic Answerback (AAB)	N/A	N/A	N/A	N/A	X
Call Forward No Answer to Any DN (CFNA)	N/A	N/A	N/A	N/A	X
Call Park/Page	N/A	N/A	N/A	N/A	X
Digit Display	N/A	N/A	N/A	N/A	X
Dial Intercom Group	N/A	N/A	N/A	N/A	X
Make Set Busy (MSB)	N/A	N/A	N/A	N/A	X
System Speed Call (SSC)	N/A	N/A	N/A	N/A	X

FEATURE AVAILABILITY MATRIX

GENERIC X11

II. OPTIONAL FEATURES

ESN Features	GENERIC RELEASE #2	#3	#4	#5	#7
Electronic Switching Network					
– Basic Automatic Route Selection (BARS)	X	X	X	X	X
– Coordinated Dialing Plan (CDP)	X	X	X	X	X
– ESN Signaling	X	X	X	X	X
– (999 Loc)	N/A	N/A	X	X	X
– Flexible Call Back Queuing (FCBQ)	X	X	X	X	X
– Free Calling Area Screening (FCAS)	X	X	X	X	X
– Network Authorization Code (NAUT)	X	X	X	X	X
– Network Alternate Route Selection (NARS)	X	X	X	X	X
– Network Control (NCOS, TCOS)	X	X	X	X	X
– Network Routing Controls	X	X	X	X	X
– Network Speed Call (NSC)	X	X	X	X	X
– Network Transfer/Conference 3	N/A	X	X	X	X
– Offhook Queue (OHQ)	X	X	X	X	X
– Offnet Number Recognition	N/A	N/A	N/A	X	X
– Priority Queueing (PQUE)	X	X	X	X	X
– Queueing (Main CBQ, CCBQ)	X	X	X	X	X
– SCC Access	N/A	X	X	X	X
– Tone Detection	N/A	X	X	X	X
– 1+dialing	N/A	N/A	X	X	X

FEATURE AVAILABILITY MATRIX

GENERIC X11

III. SYSTEM CAPACITY IMPROVEMENTS

	GENERIC RELEASE #2	#3	#4	#5	#7
128 Trunk Groups	X	X	X	X	X
X11 Template Enhancement	N/A	N/A	N/A	N/A	X
Call Register Enhancement	N/A	N/A	N/A	X	X
Network Enhancement	N/A	N/A	X	X	X
Software Package Increase	X	X	X	X	X
Software Pricing	N/A	N/A	X	X	X
Tape Capacity	N/A	N/A	X	X	X

APPENDIX B: EXAMPLES OF BROADBAND SERVICES

Table A-1/I.121 contains examples of possible services, their applications, and some possible attribute values describing the main characteristics of the services. From CCITT (1989). These are for worldwide services that may require transmission rates greater than 1.544 Mb/s.

B.1 Reference

CCITT (1989), Recommendations of the IXth Plenary Assembly, Blue Books on ISDN, Fascicles III.7, III.8, and III.9, Geneva, Switzerland.

Table A-1/I.121. Possible Broadband Services in ISDN[a)]

Service classes	Type of information	Examples of broadband services	Applications	Some possible attribute values [g), h)]
Conversational services	Moving pictures (video) and sound	Broadband [b), c)] video-telephony	Communication for the transfer of voice (sound), moving pictures, and video scanned still images and documents between two locations (person-to-person) [c)] – Tele-education – Tele-shopping – Tele-advertising	– Demand/reserved/permanent – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric – (Value for information transfer rate is under study)
		Broadband [b), c)] videoconference	Multipoint communication for the transfer of voice (sound), moving pictures, and video scanned still images and documents between two or more locations (personne-to-group, group-to-group [c)] – Tele-education – Tele-shopping – Tele-advertising	– Demand/reserved/permanent – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric
		Video-surveillance	– Building security – Traffic monitoring	– Demand/reserved/permanent – Point-to-point/multipoint – Bidirectional symmetric/ unidirectional
		Video/audio information transmission service	– TV signal transfer – Video/audio dialogue – Contribution of information	– Demand/reserved/permanent – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric
	Sound	Multiple sound-programme signals	– Multilingual commentary channels – Multiple programme transfers	– Demand/reserved/permanent – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric
	Data	High speed unrestricted digital information transmission service	– High speed data transfer – LAN (local area network) interconnection – Computer-computer interconnection – Transfer of video and other information types – Still image transfer – Multi-site interactive CAD/ CAM	– Demand/reserved/permanent – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric
		High volume file transfer service	– Data file transfer	– Demand – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric

Table A-1/I.121 (continued)

Service classes	Type of information	Examples of broadband services	Applications	Some possible attribute values [g), h)]
Conversational services *(continued)*	Data *(continued)*	High speed teleaction	– Realtime control – Telemetry – Alarms	
	Document	High speed Telefax	User-to-user transfer of text, images, drawings, etc.	– Demand – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric
		High resolution image communication service	– Professional images – Medical images – Remote games and game networks	
		Document communication service	User-to-user transfer of mixed documents [d)]	– Demand – Point-to-point/multipoint – Bidirectional symmetric/bidirectional asymmetric
Messaging services	Moving pictures (video) and sound	Video mail service	Electronic mailbox service for the transfer of moving pictures and accompanying sound	– Demand – Point-to-point/multipoint – Bidirectional symmetric/uni directional (for further study)
	Document	Document mail service	Electronic mailbox service for mixed documents [d)]	– Demand – Point-to-point/multipoint – Bidirectional symmetric/uni directional (for further study)
Retrieval services	Text, data, graphics, sound, still images, moving pictures	Broadband videotex	– Videotex including moving pictures – Remote education and training – Telesoftware – Tele-shopping – Tele-advertising – News retrieval	– Demand – Point-to-point – Bidirectional asymmetric
		Video retrieval service	– Entertainment purposes – Remote education and training	– Demand/reserved – Point-to-point/multipoint [f)] – Bidirectional asymmetric
		High resolution image retrieval service	– Entertainment purposes – Remote education and training – Professional image communications – Medical image communications	– Demand/reserved – Point-to-point/multipoint [f)] – Bidirectional asymmetric
		Document retrieval service	"Mixed documents" retrieval from information centres, archives, etc. [d), e)]	– Demand – Point-to-point/multipoint [f)] – Bidirectional asymmetric
		Data retrieval service	Telesoftware	

Table A-1/I.121 (continued)

Service classes	Type of information	Examples of broadband services	Applications	Some possible attribute values [g), h)]
Distribution services without user individual presentation control	Video	Existing quality TV distribution service (PAL, SECAM, NTSC)	TV programme distribution	– Demand (selection)/permanent – Broadcast – Bidirectional asymmetric/ unidirectional
		Extended quality TV distribution service – Enchanced definition TV distribution service – High quality TV	TV programme distribution	– Demand (selection)/permanent – Broadcast – Bidirectional asymmetric/ unidirectional
		High definition TV distribution service	TV programme distribution	– Demand (selection)/permanent – Broadcast – Bidirectional asymmetric/ unidirectional
		Pay-TV (pay-per-view, pay-per-channel)	TV programme distribution	– Demand (selection)/permanent – Broadcast/multipoint – Bidirectional asymmetric/ unidirectional
	Text, graphics, still images	Document distribution service	– Electronic newspaper – Electronic publishing	– Demand (selection/permanent – Broadcast/multipoint [f)] – Bidirectional asymmetric/ unidirectional
	Data	High speed unrestricted digital information distribution service	– Distribution of unrestricted data	– Permanent – Broadcast – Unidirectional
	Moving pictures and sound	Video information distribution service	– Distribution of video/audio signals	– Permanent – Broadcast – Unidirectional
Distribution services with user individual presentation control	Text, graphics, sound, still images	Full channel broadcast videography	– Remote education and training – Tele-advertising – News retrieval – Telesoftware	– Permanent – Broadcast – Unidirectional

Notes to Table A-1/I.121:

[a] In this table only those broadband services are considered which may require higher transfer capacity than that of the H_1 capacity. Services for sound retrieval, main sound applications and visual services with reduced or highly reduced resolutions are not listed.

[b] This terminology indicates that a re-definition regarding existing terms has taken place. The new terms may or may not exist for a transition period.

[c] The realization of the different applications may require the definition of different quality classes.

[d] "Mixed document" means that a document may contain text, graphic, still and moving picture information as well as voice annotation.

[e] Special high layer functions are necessary if post-processing after retrieval is required.

[f] Further study is required to indicate whether the point-to-multipoint connection represents in this case a main application.

[g] At present, the packet mode is dedicated to non-realtime applications. Depending on the final definition of the packet transfer mode, further applications may appear. The application of this attribute value requires further study.

[h] For the moment this column merely highlights some possible attribute values to give a general indication of the characteristics of these services. The full specification of these services will require a listing of all values which will be defined for broadband services in Recommendations of the I.200-Series.

APPENDIX C: LAYERED STRUCTURE CONCEPTS

The layered structure concept is diagrammed in Figure C-1 for three functional entities, (N-1), (N), and (N+1). Entities at the lower levels provide services to the upper levels using functions specified by protocols and implemented in each entity's layer. Interfaces between adjacent entities provide the means for transferring interface control information (ICI) and interface data (ID) via an interface data unit (IDU). The ICI portion of an IDU is exchanged between adjacent entities to ensure correct interface operation, to request actions from the lower entity and to report status to the upper entity. The ID typically contains the peer data unit (PDU) which consists of peer-control-information (PCI) and user-data (UD) destined for entities at higher protocol levels. Thus we have:

(N-1) IDU = (N-1) ICI + (N-1) ID = (N-1) ICI + (N) PDU.

The stated purpose of the open system interconnection (OSI) architecture which could evolve from the OSI reference model is to allow 'open' interconnection capabilities (i.e., any subscriber to any subscriber). This open architectural concept is illustrated in Figure C-2. Any subscriber (which could be an aggregate user such as another independent network) can access the open system structure at any functional level. For example, an A-type subscriber requiring an (N-1) level service provided by the open system can access the structure at an (N-1) to (N) interface as shown in Figure C-2. This A-type subscriber must use either an (N-1) to (N) interface protocol or convert his own protocol (using box C) in order to achieve access. However, the A subscriber's peer protocol may not be the same as the (N) peer protocol. The A subscriber's interface data unit before the conversion is,

(A) IDU = (A1) ICI + (A1) ID = (A1) ICI + (A) PDU

which after conversion becomes,

(A) IDU = (N-1) ICI + (A-1) ID = (N-1) ICI + (A) PDU

This A-type subscriber may communicate with any other A-type subscriber on the same functional level. After conversion, the interface data unit, (A) IDU, contains two types of information: the interface control information, (N-1) ICI, and the peer data unit, (A) PDU.

It is also of interest to examine the interfaces where two subscribers access the open system structure at different functional levels (e.g., the

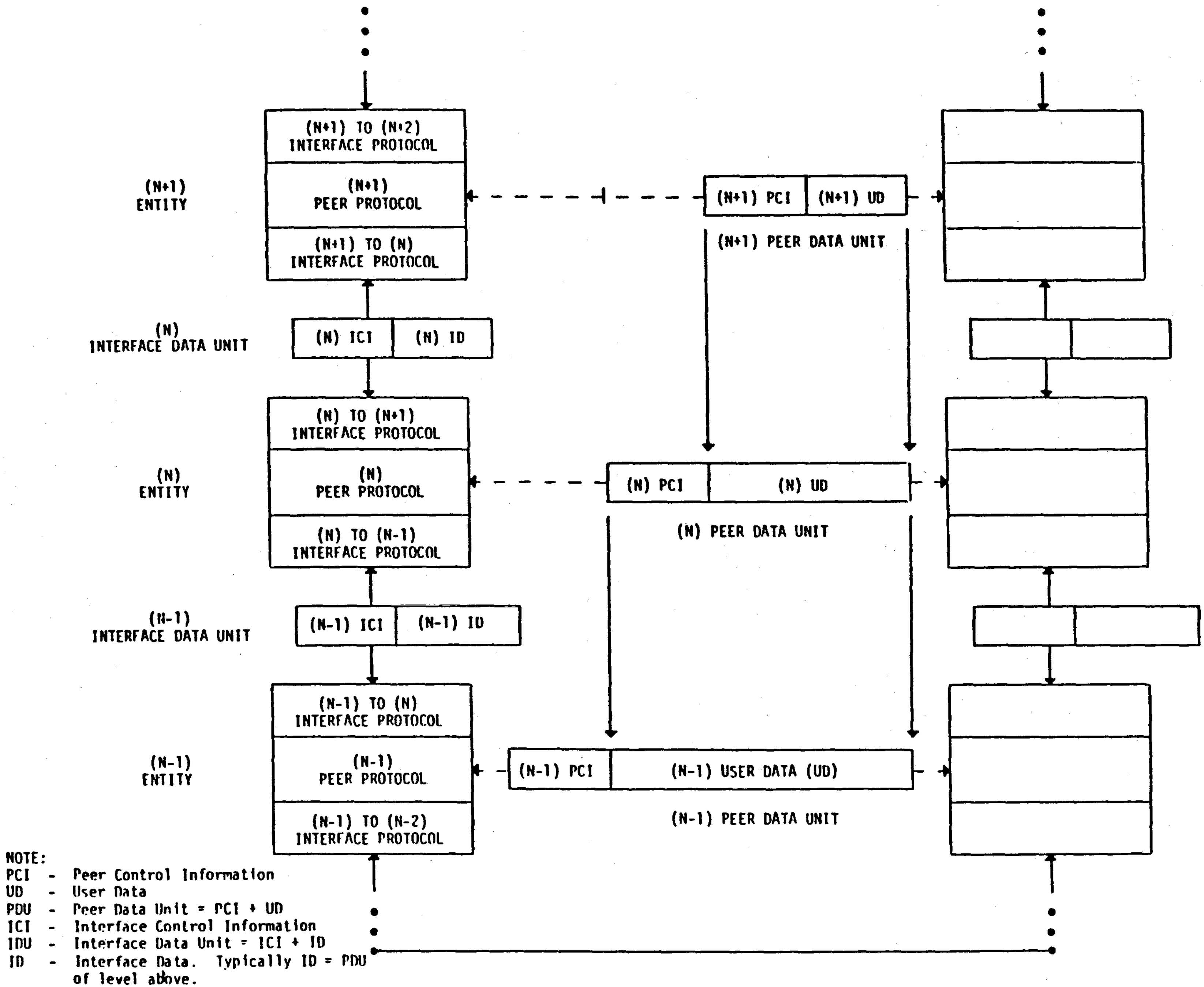

Figure C-1. Model for a layered architecture.

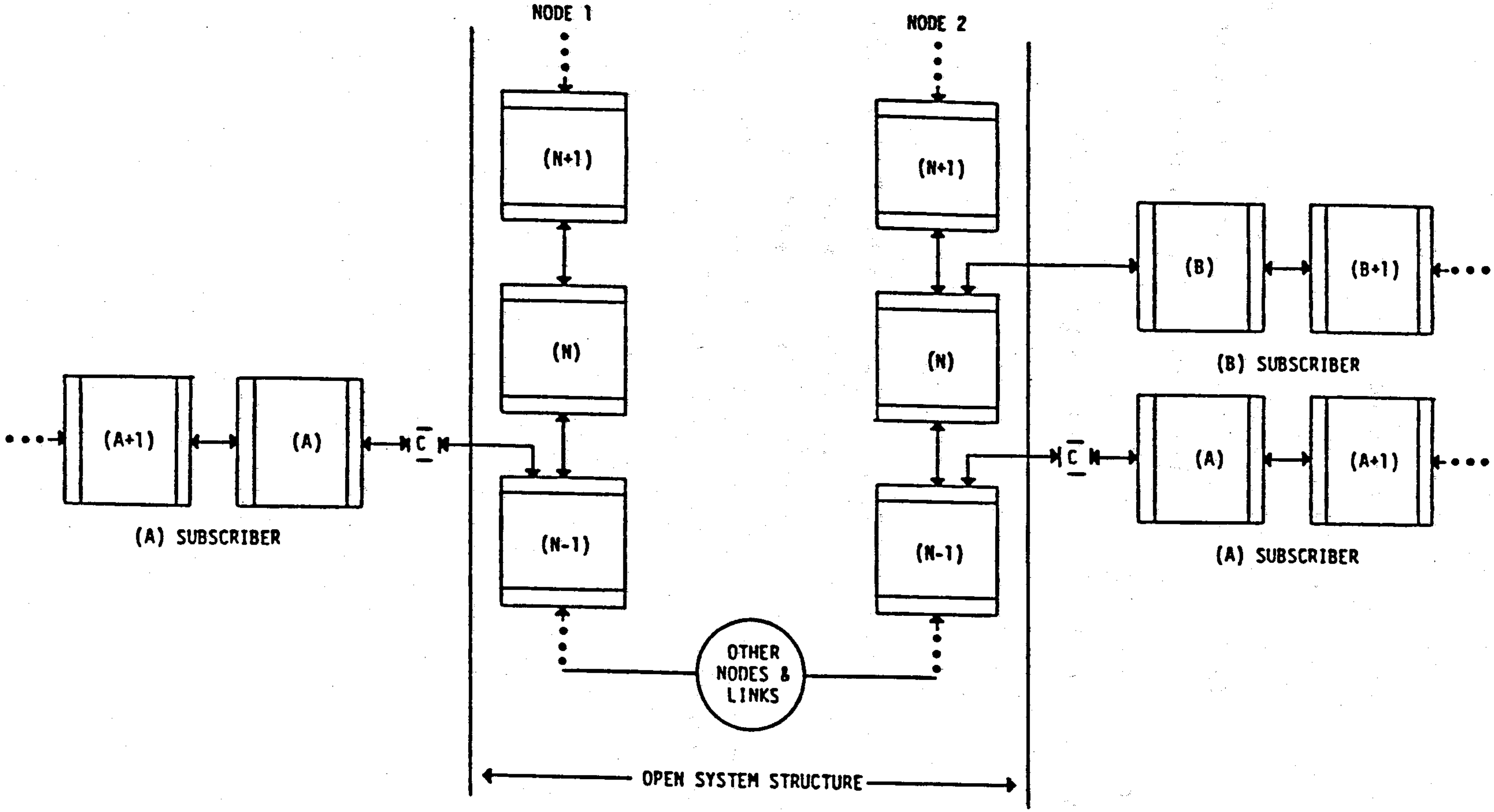

Figure C-2. Open system interconnections.

A-type and B-type subscribers in Figure C-2). As shown before, the A-type subscriber's interface data unit is:

(A) IDU = (N-1) ICI + (A) PDU

and the B-type subscriber's interface data unit is:

(B) IDU = (N) ICI + (B) PDU.

In order for the A-type subscriber to communicate with the B-type subscriber the (A) PDU must contain (N) peer control information and a (B) interface data unit. The (B) interface data unit contains (B) peer control information and (B) user data. Therefore:

A(IDU) = (N-1) ICI + (N) PCI + B (PCI) + (B) UD

and

B(IDU) = (N) ICI + (B) PCI + (B) UD

The interface data units crossing the two subscriber interfaces are not the same; the differences are in the carrier network's control information, i.e., all terms involving (N) or (N-1). The (N) peer control information is required to enable the A-type and B-type subscribers to communicate even though they are each accessing the network at different functional levels.

FORM **NTIA-29** (4-80)

U.S. DEPARTMENT OF COMMERCE
NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

	1. PUBLICATION NO.	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE
Telecommunications Networks: Services, Architectures, and Implementations

5. Publication Date
December 1990

6. Performing Organization Code
NTIA/ITS.N

7. AUTHOR(S)
Robert F. Linfield

8. PERFORMING ORGANIZATION NAME AND ADDRESS
National Telecommunications and Information Admin.
Institute for Telecommunication Sciences
325 Broadway
Boulder, CO 80303-3328

9. Project/Task/Work Unit No.

10. Contract/Grant No.

11. Sponsoring Organization Name and Address
National Telecommunications and Information Admin.
Herbert C. Hoover Building
14th and Constitution Avenue, NW
Washington, DC 20230

12. Type of Report and Period Covered

13.

14. SUPPLEMENTARY NOTES

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.)*

Telecommunications networks are shown to exhibit three attributes that distinguish them from each other, namely, the service offered, the functional architecture necessary to provide this service, and the hardware and software that implements this architecture. For each service there are many possible architectures and for each architecture there are many possible implementations. This report provides a basic understanding of the services, architectures and technologies that are the foundation of advanced telecommunications networks.

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

broadband ISDN; layer architecture; narrowband ISDN; network management; physical architectures; protocols; services, telecommunications networks

17. AVAILABILITY STATEMENT	18. Security Class. *(This report)*	20. Number of pages
☒ UNLIMITED.	Unclassified	120
☐ FOR OFFICIAL DISTRIBUTION.	19. Security Class. *(This page)* Unclassified	21. Price:

☆U.S. GOVERNMENT PRINTING OFFICE: 1991-573-002/21028