7. THE EVOLUTION OF NETWORKS

> *"This planet is currently laced with many types of computer/communication networks at all levels. There are wide area networks, packet switched networks, circuit switched networks, satellite networks, packet radio networks, cellular radio networks, and more and they are mostly incompatible with each other."*
>
> *L. Kleinrock (1985), Chairman of Computer Science at UCLA*

Kleinrock's seven-year-old quote still applies, except that today one should add broadband networks, personal communication networks, software-defined networks, virtual private line networks, and intelligent networks to his list and note that bridges, routers, gateways, and new standards have reduced some of the incompatibilities. However, new vendors in today's multi vendor environment coupled with advancing technologies have introduced still more incompatibilities as the network infrastructure continues to evolve. The following subsections describe the evolutionary processes occurring today and the networks resulting therefrom.

7.1 Globalization of Telecommunications Service

As the world moves toward an international economy dominated by globalization of production and markets, the transport and telecommunications infrastructures will play major roles in the success of global enterprise structures. The global networks of the future can extend traditional voice and data services across national boundaries to both residential and business markets. New service opportunities such as HDTV, electronic data interchange (EDI), imaging, video conferencing, and personal communication services (PCS) could be added. PCS would offer unprecedented mobility and ubiquity by delivering a service over both wireless and wireline facilities to any subscriber, at any time, and at any place. Networks are expected to evolve gradually over time as analog and copper-based systems are replaced with digital fiber-based intelligent systems, as cells replace packets, and broadband replaces narrowband.

Major factors impacting not only this globalization process but the evolution of the entire telecommunications infrastructure are discussed below. These factors are digitization, integration, packetization, privatization, and standardization. Again, keep in mind that the speed of evolution is influenced by the installed base and the impact of amortization on the implementation of any new technologies.

7.1.1 Digitization

There are a number of advantages to digital transmission that have led to its continuous replacement for analog circuits. These advantages include improved quality particularly for long-haul circuits, reduced cost due to increased transmission efficiency, and increased security using bulk encryption techniques.

Since the AT&T divestiture in 1984, the amount of long-distance traffic has increased 2.5 times with most of that due to the addition of digital facilities. Figure 7-1 indicates the analog and digital portions of long-distance traffic in terms of billions of minutes per year for the period 1983 through 1989. Only four years ago approximately half the long-distance voice traffic was still analog.

After divestiture, the regional Bell operating companies (RBOCs) continued to digitize their offices. Figure 7-2 shows the percent of lines served by digital offices in 1991. The average approaches 50% for the RBOCs and over 85% for the independents.

The migration toward digital systems not only enhances performance due to excellent reproduction, but digital systems provide opportunities for new service features and for user participation in network management and control.

7.1.2 Integration

There are various ways that integration may take place in a network. Figure 7-3 shows how the integration process can evolve in switching and transmission. Figure 7-3a depicts the conventional analog, circuit-switched system which was designed primarily for plain old telephone service (POTS) operating over a 4 kHz bandwidth. Digital data were converted into tones that could be transmitted over 4 kHz analog channels using modems (M). Subsequently, packet switched networks evolved to carry digital data more efficiently. These packet networks permitted computers to communicate reliably at considerably less cost than the circuit-switched systems. With suitable controls to minimize delays, packet networks could carry analog voice signals with coder and decoder functions performed by codecs (C) as in Figure 7-3b.

Currently, there are still many circuit-switched public telephone networks that co-exist with separate packet-switched public data networks (PDNs) as in Figure 7-3c.

Integration of voice and data in either switching, terminals, or transmission now exists as in Figure 7-3d, e, and f. Integration of both switching and transmission facilities exists in many

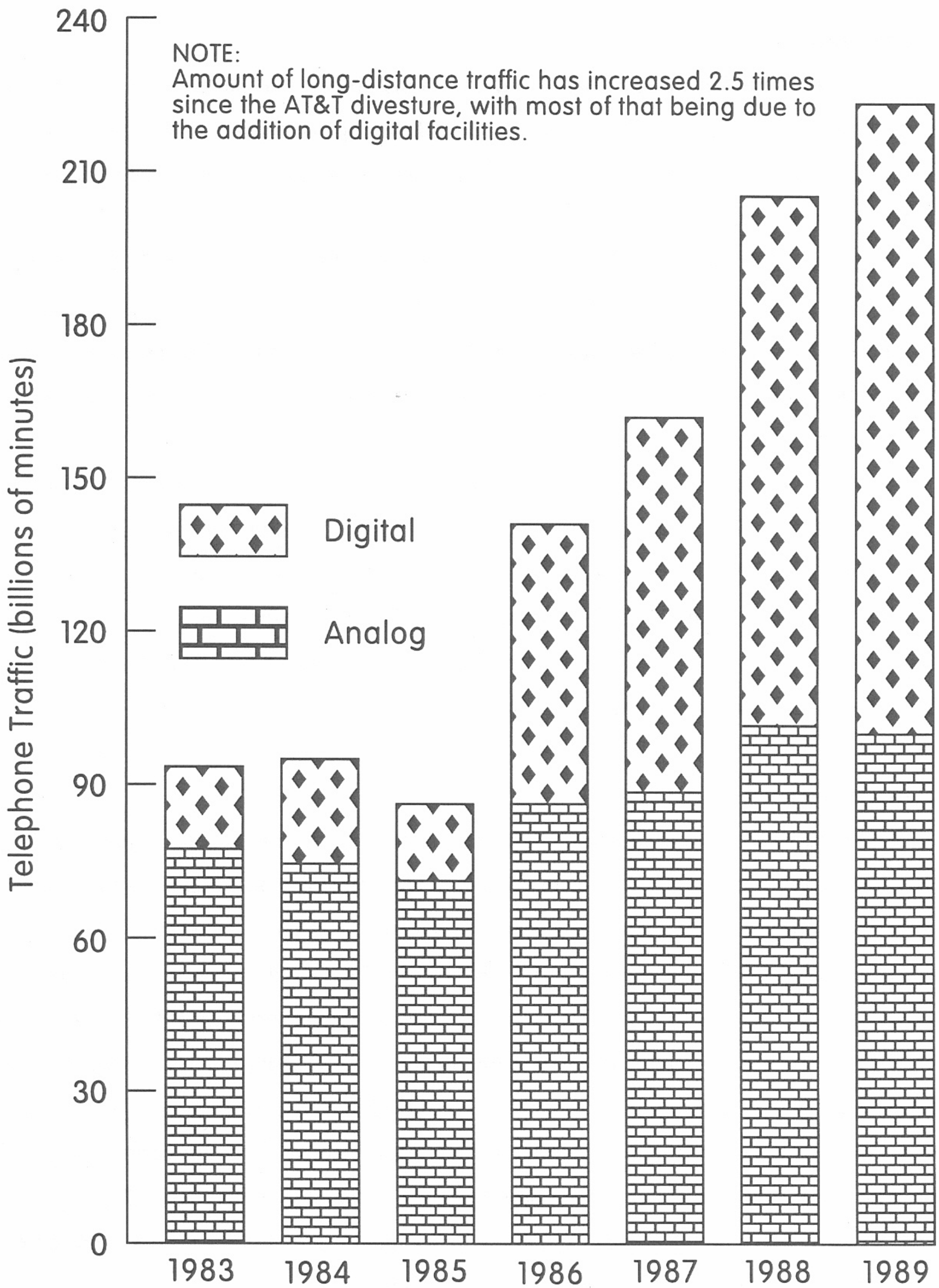


Figure 7-1. Long distance annual telephone traffic.

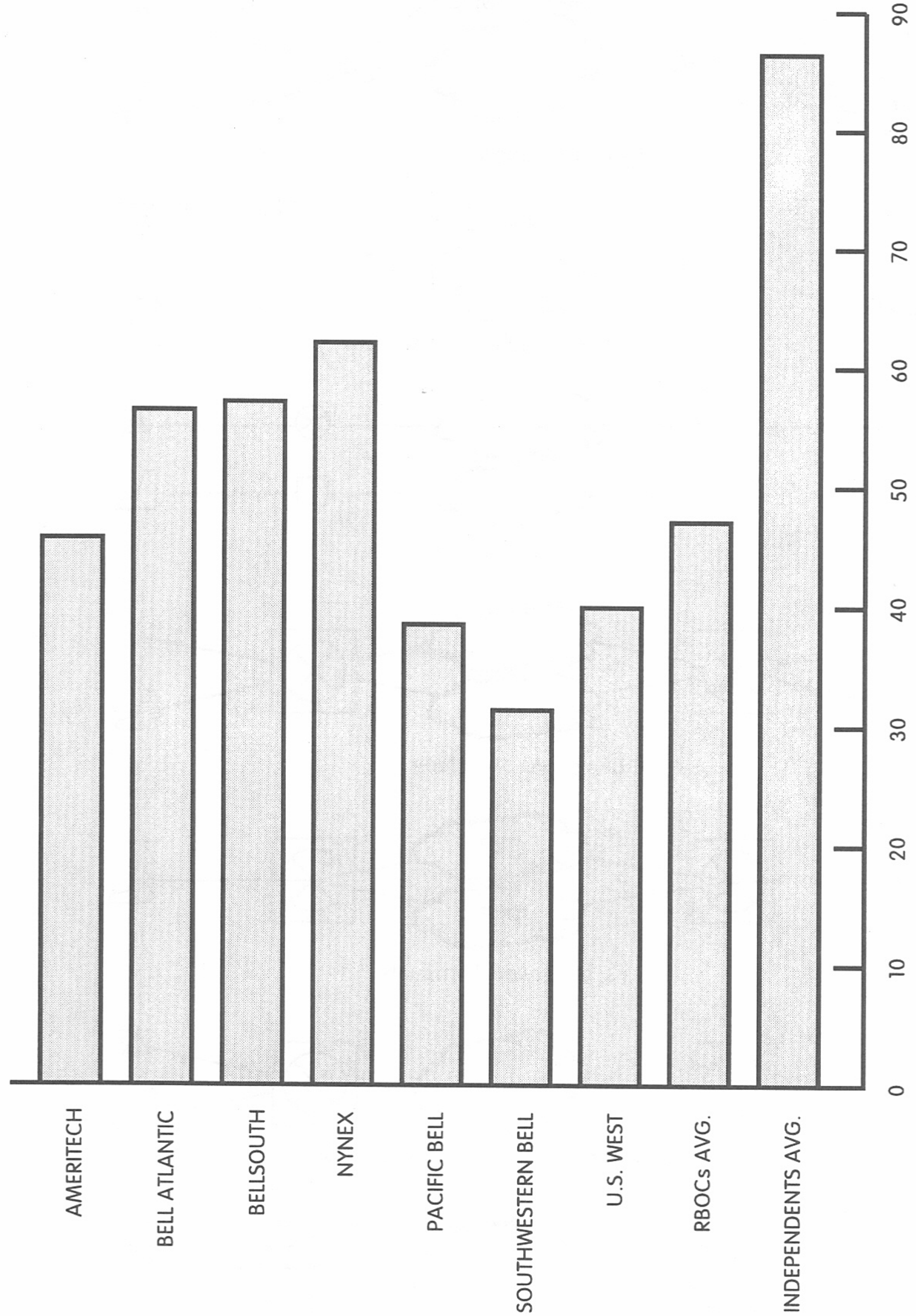


Figure 7-2. Percent of lines served by digital offices in 1991 (Smith, 1992).

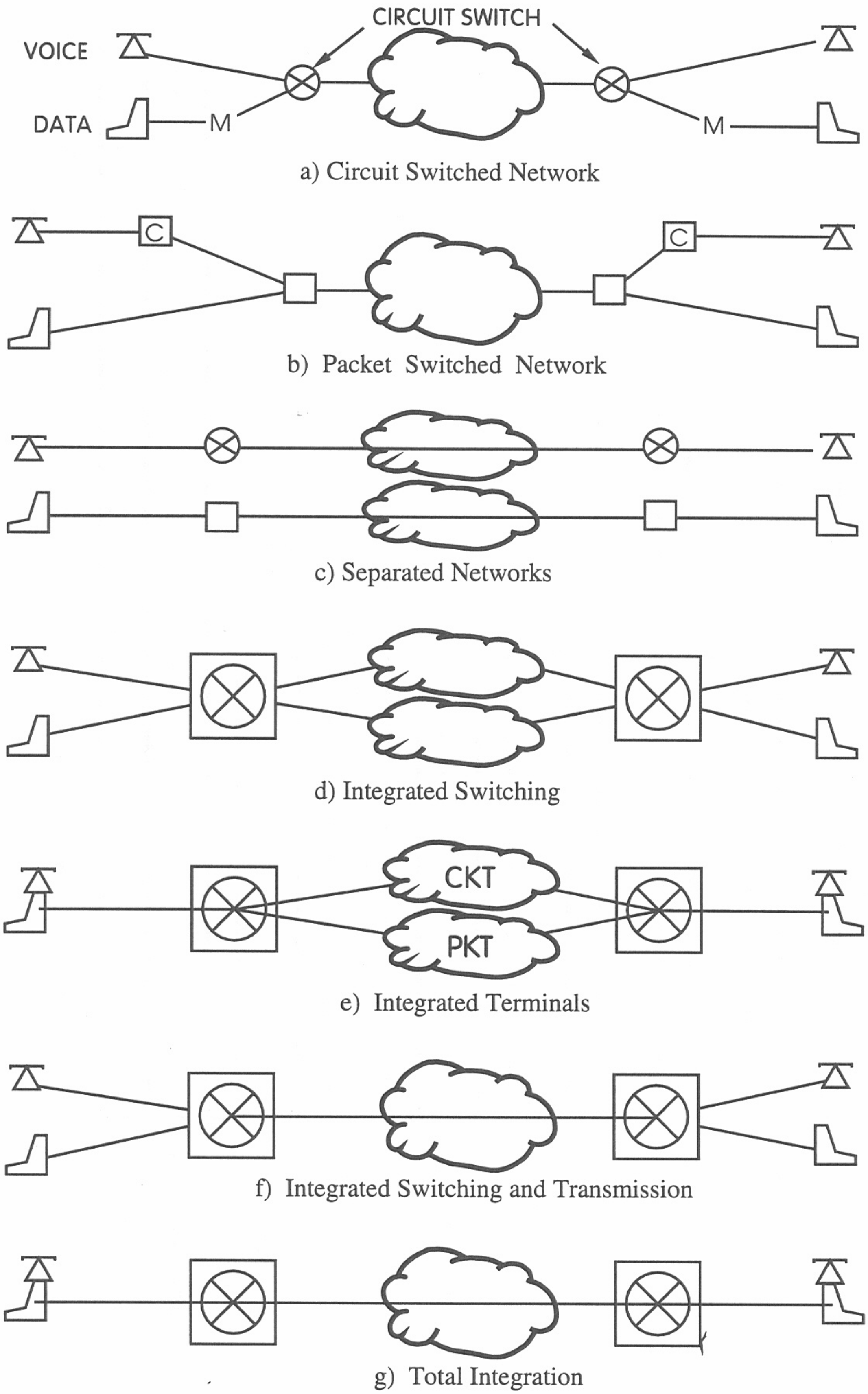


Figure 7-3. Architectural configurations and their evolutionary process.

networks (Figure 7-3f) and total integration (Figure 7-3g) on a few others. The ATM/SONET concept using cell relay provides either circuit switched or packet switched modes. Users desiring low delay, circuit switched service are guaranteed cell transmission at a given rate. Packet mode users contend for the remaining cells with queuing and buffering determined by the traffic. Thus, the cell relay concept provides an inherent circuit-packet integration. One manufacturer's switching system[**] handles dedicated circuit switch service, connection-oriented (CO) packet switch service, and connectionless (CL) LAN service as shown in Figure 7-4.

7.1.3 Packetization

Packet switching has been used in the past primarily to achieve greater efficiency by time-sharing expensive transmission facilities used to transport bursty data traffic. The traditional packet switching technology is being supplanted with fast packet switching to take advantage of the large bandwidth and reliability of optical fibers. It is useful to compare the concepts of time division multiplexing (TDM), as used in digital circuit switching, and packet multiplexing as used in fast packet switching.

In TDM, the transport stream of bits is divided into frames of time slots and each slot in the frame is allocated to a particular user's data stream. Slot position in the frame identifies the user. In packet multiplexing, the bit stream is divided into packets and each packet labeled with a virtual channel identifier (VCI). The VCI identifies the packet allocated to a particular user. The ATM concept described in Section 3.4.4 is a special case of packet multiplexing where packets are all the same size, and are called "cells." The effective information transfer rate for a given user depends on the number of cells assigned to that user and not a recurring time slot. Therefore, the effective bit rate for a given user can be varied dynamically from zero to the full channel rate. An ATM network can, therefore, support a wide range of services as well as the traditional narrowband services in use today. It also conveniently handles bursty traffic by allocating bandwidth on demand.

[**] Siemens Stromberg-Carlsons' Electronic World Switching Digital (EWSC) System.

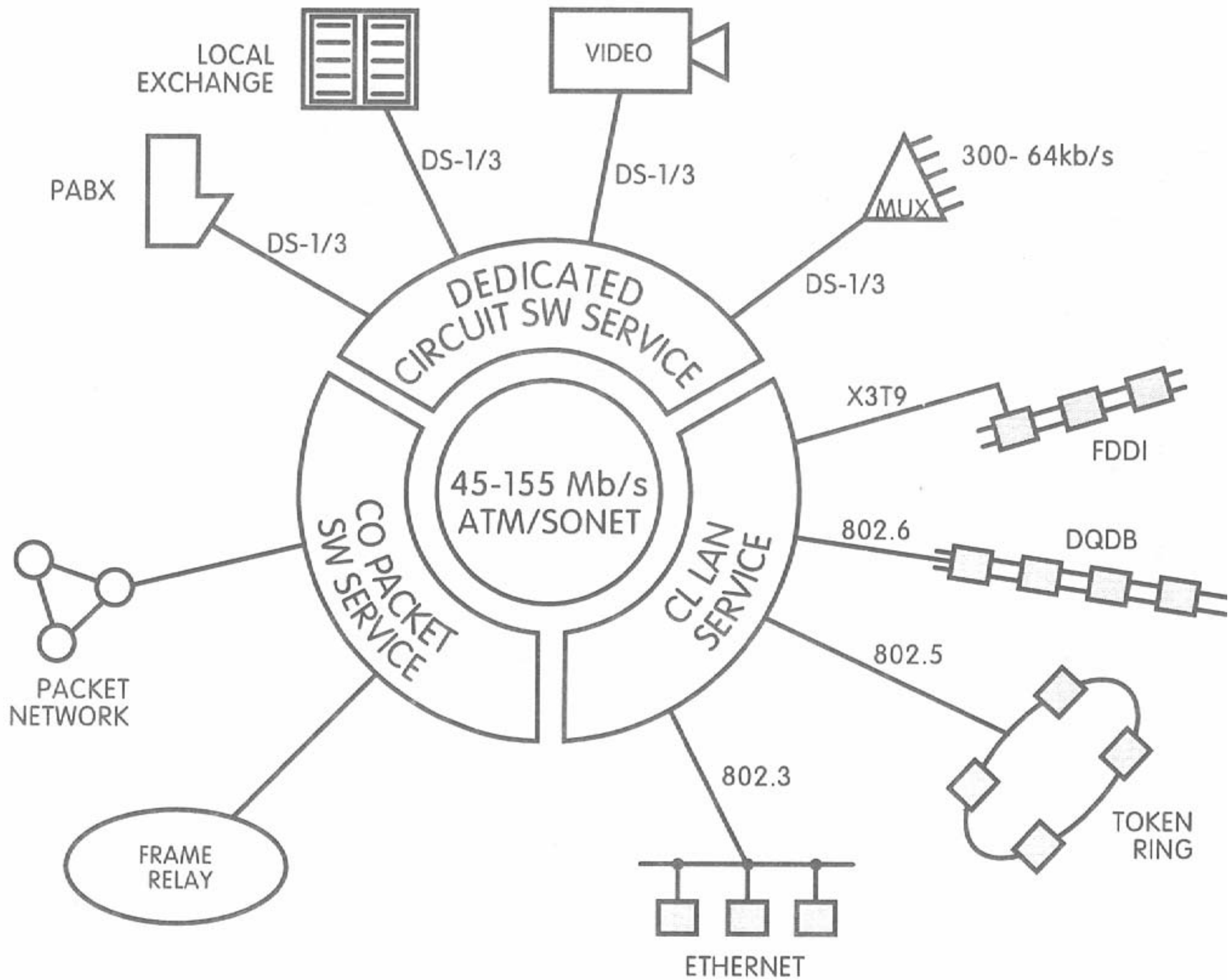


Figure 7-4. Services offered by one commercial switching system.

7.1.4 Privatization

Deregulation has led to the creation of private and virtual private networks for large businesses, and to competing providers of private network services. Virtual private networks appear to be private but are actually embedded (by software) in the public switched network.

There seems to be a number of reasons for the continuing proliferation of private networks. One reason is user requirements. In many cases, these requirements can only be met by developing a private network. Reliability, privacy, and security are three such requirements. Service quality, maintainability, customer control, and cost are others. There are several ways users can bypass the local exchange carrier, such as the use of satellite and microwave radio, in order to meet these requirements. A discussion of virtual private line networks (VPLN) and software defined networks (SDN) is given in Section 7.3.1.

According to Ryan (1991), there has been some shift back to the public network by larger enterprises for their communication and information processing because of the advanced capabilities of ISDN.

7.1.5 Standardization

The globalization of the economy has led to a need for international telecommunications standards. Many countries including the United States are extending their standards-making processes to the international arena. Figure 7-5 illustrates the evolution of a standard from a perceived need to the international standards area. Also see Section 4.2.

There are numerous standardizing efforts, both national and international, underway. The international efforts are key to the successful implementation of a truly global infrastructure. National variations to international standards, as well as different options and incompleteness of the standards themselves, still cause incompatibilities and make seamless networking across national boundaries difficult. Resolving these differences and incompatibilities continues to be a challenge to the standards community.

Figure 7-6 depicts how the Telecommunications Standards Committee T1 interacts with the U.S. CCITT National Committees to submit contributions for consideration by the International CCITT study groups and ultimately the Plenary Assembly. This shows the long and laborious process necessary to develop an international recommendation.

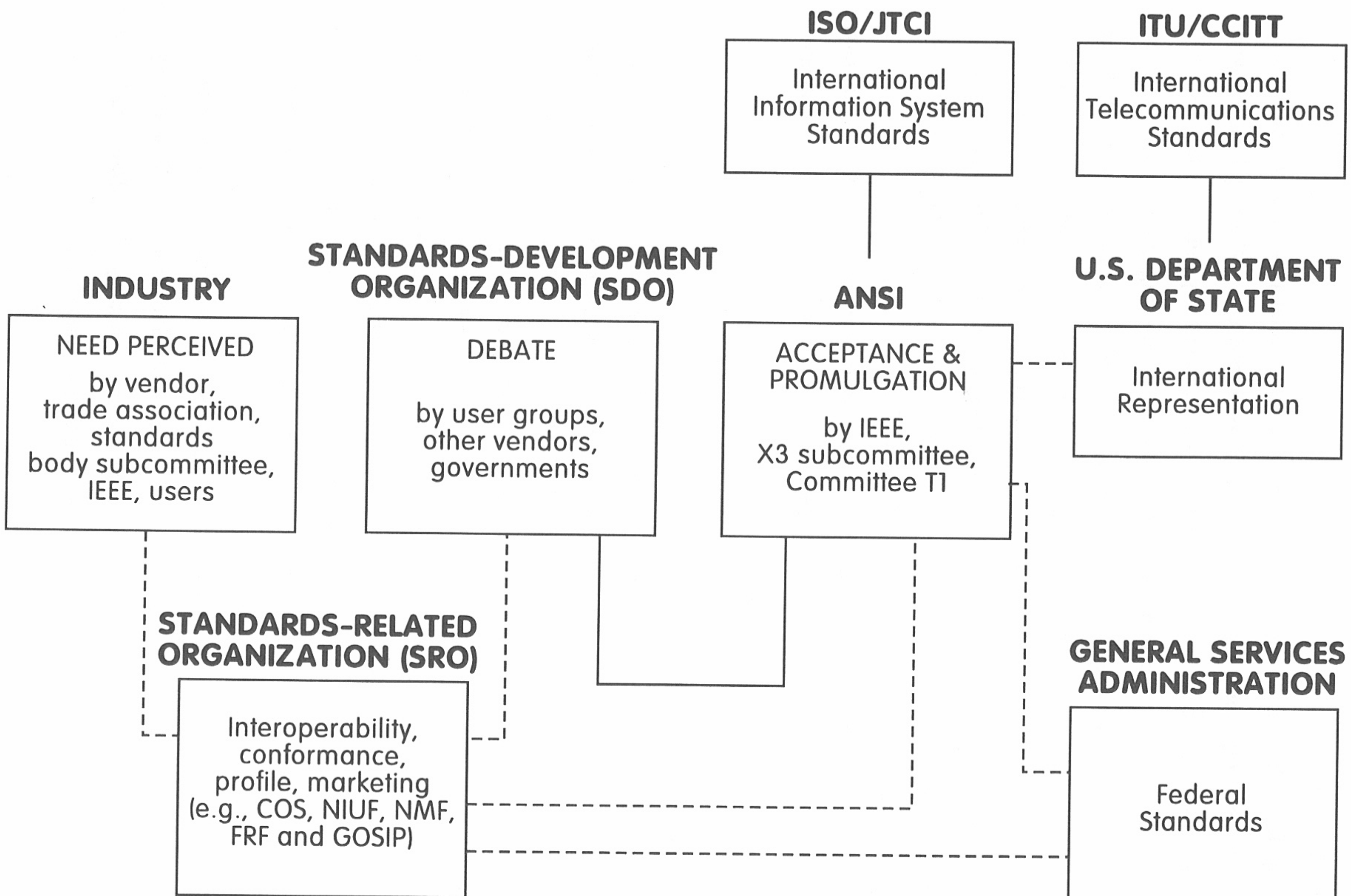


Figure 7-5. The evolution of a standard.

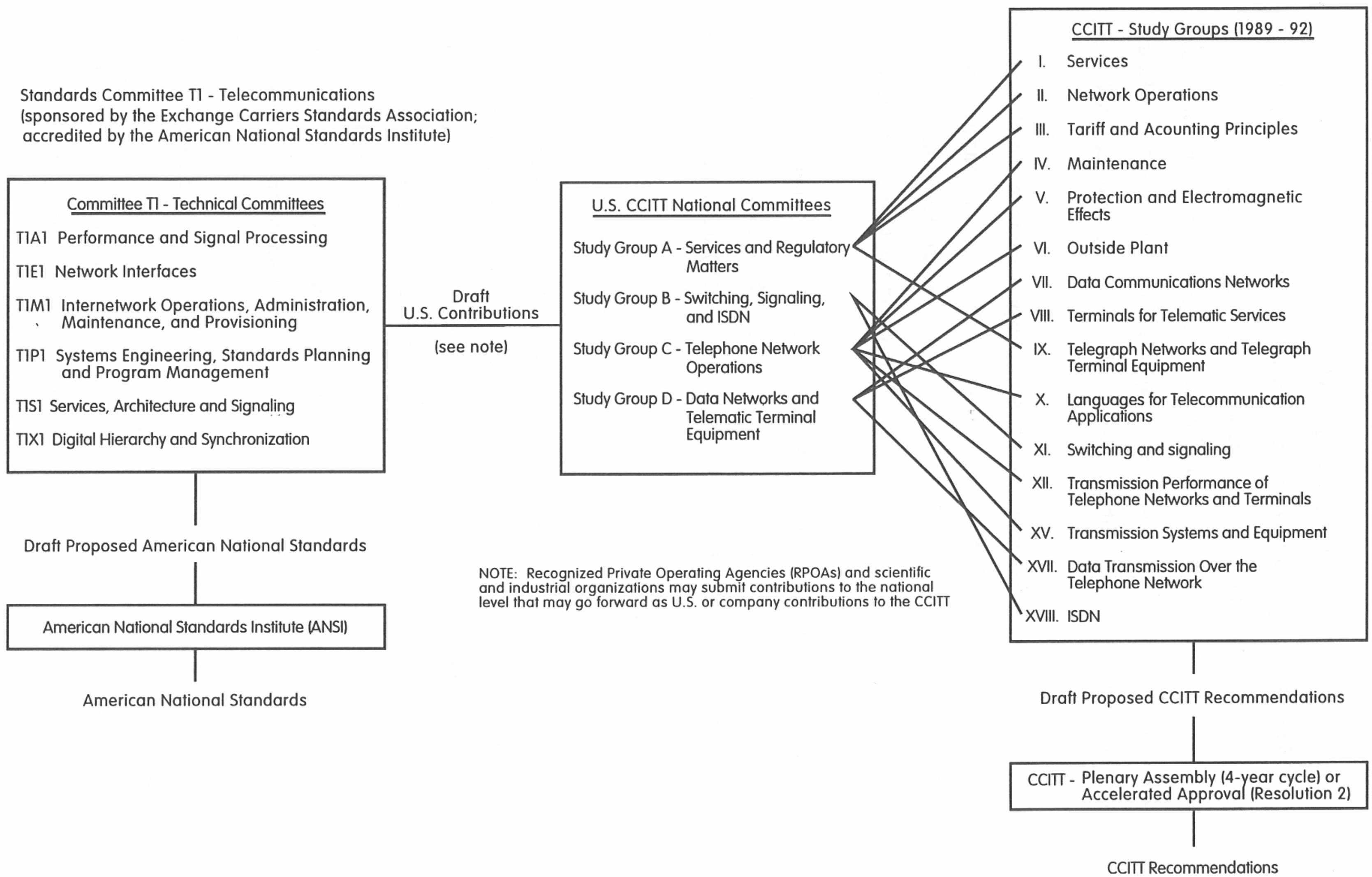


Figure 7-6. Development of ANSI standards and CCITT recommendations.

7.2 LANs, MANs, and WANs

Local area networks (LANs), metropolitan area networks (MANs), and wide area networks (WANs) are in common use today and may be expected to continue to proliferate tomorrow. A LAN is typically defined as a nonpublic network for direct communication between data terminals on a user premises, whereas MANs and WANs may be public or private networks that provide integrated services over larger geographic areas. MANs may interconnect LANs, and WANs may interconnect MANs.

All users of a given LAN or MAN share the chosen transport medium which may be twisted wire pair (WP), fiber optic cable (FO), or coaxial cable. This medium-sharing concept usually requires users to transmit one at a time. This is in contrast to parallel switching systems (e.g., asychronous transfer mode (ATM) switching) which support multiple users transmitting simultaneously.

Under the auspices of the IEEE 802 project, a number of standards relating to LANs and MANs have been developed or are currently under development. These are discussed in the following subsection along with the fiber distributed data interface (FDDI) standard promulgated by the American National Standards Institute (ANSI).

7.2.1 Local Area Networks (LANs)

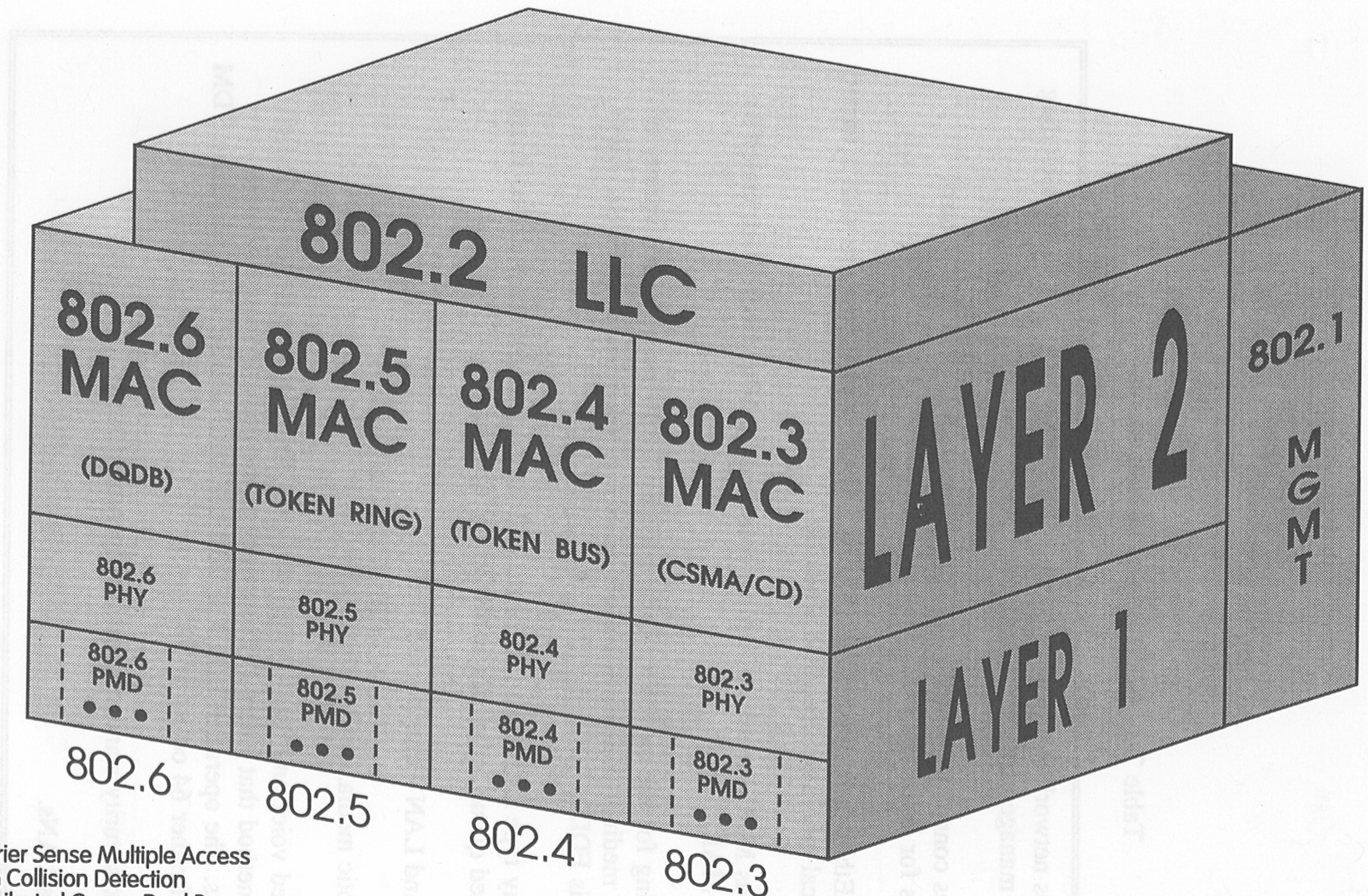
Table 7-1 lists the IEEE Project 802 standards for various LANs. These LANs are distinguishable by the medium used (twisted wire pair, optical fiber, or coaxial cable), by the topology (bus, ring, star), by the medium access control (carrier sense, token passing), etc. Most LANs today operate at "baseband" and carry digital data traffic. There are, however, a few "broadband" LANs and MANs which modulate a carrier with either AM or FM. These broadband systems carry many signals (voice, data, and video) simultaneously, e.g., cable TV.

Figure 7-7 shows the OSI layer 1 and 2 protocol stack for some important LANs in use today.

Since the typical office worker usually requires access to both voice and data services, there is a growing trend to integrate voice and data (IVD) services to the desktop. These IVD services may include facsimile, image transfer, and even video services in some instances. This desktop integration of such services can be provided economically using existing twisted wire pair. The provision of these so called IVD services in public networks is the concern of CCITT

Table 7-1. IEEE Project 802 Standards

802.1	Describes network architecture concepts applicable to all networks including network management.
802.2	Describes connection-oriented and connectionless logical link control functions for layer 2.
802.3	Defines Ethernet protocol suite. Uses CSMA/CD MAC for use with a variety of physical medium dependent protocols.
802.4	Token bus MAC for use on 1 Mb/s coax and 20 Mb/s fiber. Originated by GM for MAP.
802.5	Token ring for use on TWP. Originated by IBM for use with a variety of physical medium dependent protocols for 1 Mb/s, 4 Mb/s, 16 Mb/s. Fiber version is FDDI.
802.6	Cell relay type LAN using 53 octets/cell for operating over dual bus using distributed queue for media access to the dual bus.
802.7	Broadband LAN - unapproved draft.
802.8	Fiber optic media.
802.9	Integrated voice and data (IVD) interface. This standard defines a unified access method that offers IVD services to the desktop from backbone networks. The operation is at 4 to 20 Mb/s over twisted wire pair using TDM frame of either 64 octets or 320 octets.
802.10	Network security standards for interoperable LANs.
802.11	Wireless LANs.



CSMA/CD: Carrier Sense Multiple Access with Collision Detection
DQDB: Distributed Queue Dual Bus
LLC: Logical Link Control
MAC: Medium Access Control
MGMT: Management
PHY: Physical (medium independent)
PMD: Physical (medium dependent)

Figure 7-7. Protocol stack for LANs and MANs in use today.

through the ISDN standards work. The LAN standards for IVD services are being developed by the IEEE 802.9 working group which is working to develop a standard for layer 1 and layer 2 with unshielded twisted wire pair as the transmission medium.

The IEEE 802.10 working group is concerned with defining a standard for interoperable LAN security including the secure data exchange protocol key management, and system security management.

The IEEE 802.11 group is developing a standard for wireless LANs. Wireless LANs operate without the traditional cabling techniques used today, but instead use radio links or AC power outlets to interconnect user terminals. Early systems operated in the upper UHF and SHF bands at approximately 900, 2,400, and 5,800 MHz using spread spectrum technology (SST). Power was limited to 1 watt which resulted in transmission distances of less than 1,000 feet.

At still higher frequencies (18-19 GHz), transmission speeds of 100 Mb/s are obtainable for digital termination service (DTS). Infrared wireless LANs are also feasible operating within line-of-sight.

Low-frequency carriers are used for radio systems that use the AC power facilities in a building. Maximum rates achievable are on the order of 100 kb/s.

In addition to these LANs, the ANSI Standard X3T9 defines a fiber distributed data interface (FDDI) for use as a LAN or MAN. This standard for optical fiber media defines physical and data link protocols for a dual counter-rotating token-ring type LAN operating at 100 Mb/s and capable of accommodating up to 500 nodes with a total distance of 100 km (about 62 miles) around the rings. A FDDI network is depicted in Figure 7-8 for a typical LAN application. Other example applications include interconnecting low-speed LANs that are dispersed in a campus-like environment, for interconnecting mainframe computers to mass storage devices and other peripheral devices, and for connecting integrated voice/data PBXs, computer hosts, and digitized video sources into a composite network for accessing ISDN.

The ANSI committee is also seeking to develop a single standard for 100 Mb/s FDDI signaling over both shielded twisted pair (STP) and unshielded twisted-pair (UTP) wiring (McLacklan, 1992).

Private automatic branch exchanges (PABXs) may also be used in lieu of a LAN. Located on a customer’s premises, a PABX is basically a switch, star-connected to the customer

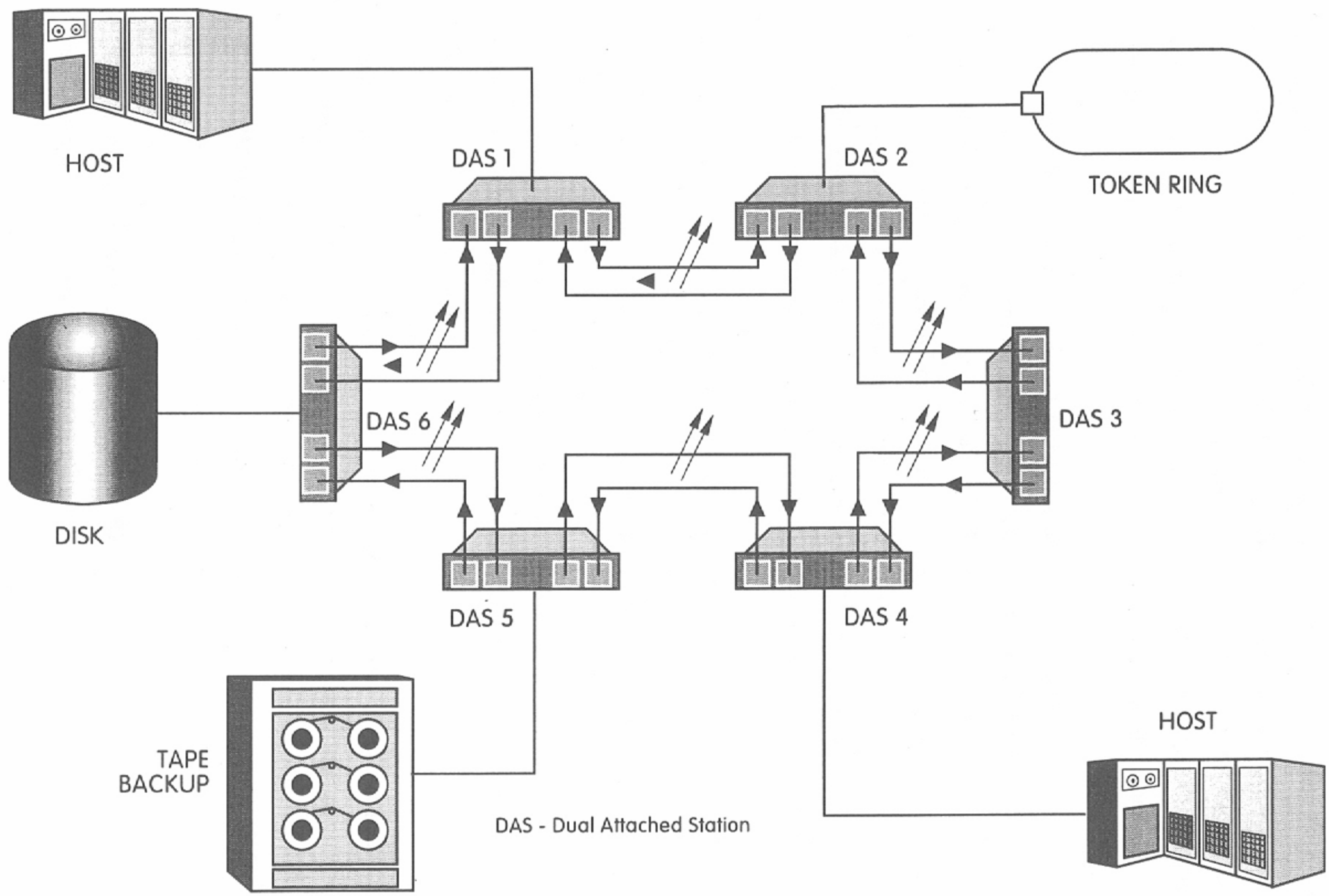


Figure 7-8. FDDI architecture with dual, counter-rotating ring.

terminals. Most PABXs today offer only telephone service but could support PC interconnections as well in the near future.

7.2.2 Metropolitan Area Networks (MANs)

MANs are used to interconnect LANs or to provide access to WANs. MANs are often commercial facilities that may be shared by several enterprises. MANs have the capability to allocate and deallocate vast amounts of bandwidths in extremely short time frames. They appear as a high-capacity line but users are charged only for the times when they are actually transmitting data. In the near term, technologies and services such as frame relay and IEEE 802.6-based SMDS offer the needed service, while broadband ISDN with ATM and SONET should provide the future service (Taylor, 1992). The IEEE 802.6 protocol suite for connecting LANs together over dual 45 Mb/s buses is available today. Bandwidth is 2 x 45 Mb/s now and expected to be 2 x 150 Mb/s in the future. Table 7-2 summarizes the important characteristics of major LANs and MANs in use today and in the foreseeable future.

7.2.3 Wide Area Networks (WANs)

WANs are the networks that interconnect LANs, MANs, or telecommunications terminals that are spread over large geographic areas, including global distributions. They are not defined by any single standard. Local exchange carriers (LECs) and interexchange carriers (IXCs) are considered WANs along with private corporate networks. WAN services range from dial-up analog services to ISDN. The switched multimegabit data service (SMDS) operating at 45 Mb/s is a switched data service available in the near term as a MAN and available in the future as a WAN. The synchronous optical network (SONET) operating up to 600 Mb/s and possibly higher is being standardized for future commercial service as a MAN or WAN. The SMDS concept is discussed in the following paragraphs. SONET was described in Section 3.4.5.

SMDS is a connectionless, cell-oriented, packet-switching service offered by a public network carrier. It is based on the distributed-queue-dual-bus (DQDB) concept of the IEEE 802.6 standard. Initially the SMDS will provide MAN-type service to interconnect LANs with high-speed (45 Mb/s) links. Eventually SMDS may provide wide-area network service for connections between local access transport areas (LATAs). The cell structure ensures compatibility with the future asynchronous transport mode (ATM) of the B-ISDN. Existing digital transmission

Table 7-2. LANs and MANs Characteristics

	Today				Tomorrow					
Characteristic / Identifier	802.3 CSMA/CD	802.4 Token Bus	802.5 Token Ring	SMDS	802.6 DQDB	ANSI X3T9 FDDI	SMDS Phase 3 (1995)	ATM/SONET	Wireless LANs	Wireless MAN
Architecture	Bus 10 Mb/s	Bus 1, 10, 20, Mb/s	Ring 1, 4, 16 Mb/s	Public High-Speed Data Service from LECs, 45 Mb/s (1992)	Looped Buses 45 Mb/s (50 Mb/s Capacity)	Dual Counter-Rotating Rings 100 Mb/s	DS-1, DS-3, National Service via LECs and IECs, 150 Mb/s	National/ International Service and B-ISDN	Digital Cordless Data Terminals	Cellular Voice and Data
Access Control	CSMA/CD	Token Passing (Logical Ring)	Token Passing	SMDS Interface Protocol (SIP)	Distributed Queue Dual Bus (DQDB)	Token Ring MAC	SMDS Interface Protocol (SIP)	ATM Protocol (Link Layer)	CDMA or TDMA	CDMA and TDMA
Transmission Medium	• Coax • CATV Coax • Twisted Pair	• CATV Coax • Fiber	• Shielded Twisted Pair • Cable	• DS-1, DS-3 • SONET (future)	DS-3	Multimode Fiber	SONET (Fiber)	Fiber	Radio Frequency TBD	Radio (1.8-2.2 GHz, 400 and 800 MHz Bands)
Transmission Mode	• Baseband • Broadband • MAC Frames	• Broadband • MAC Frames ≤ 8140 Octets	Baseband	Baseband 53-Octet Cells (< 9188-Octet Packets)	Fixed-Length 53-Octets Cells	≤ 4500-Octet Frames	≤ 9188-Octet Packets of 53-Octet Cells	53-Octet Cells No Packetizing or Framing Required	Digital	Dual-Mode Digital and Analog Channels
Traffic Types	Computer Data	Computer Data or Manufacture Control	Computer Data	Images, Data, LAN Interconnect	Data with Hooks for Voice, Video	Data Only	Imagery, Data (LAN Interconnect)	Voice, Data, Video Multimedia	Data Only	Voice, Data
Service Types	Connectionless Logical Link Control (LLC)	Connectionless (LLC)	Connectionless (LLC)	Connectionless Network Service	Connectionless (LLC)	Connectionless (LLC)	Connectionless (LLC)	All (Connectionless, Connection-Oriented, and Circuit Switched)	?	Connection-Oriented (LLC)
Application	LAN Terminals	LAN for Manufacturing Automation	LAN	LAN/MAN Interconnect Service for Disaster Recovery	Private Networks on Customer Premises and as Alternative Access Provider or pubic–SMDS	High-Speed LAN for up to 500 Users	LAN/MAN Interconnect Service	B-ISDN Voice/Data/Video LAN/MAN Interconnect	Cordless PC Networking for LANs	Mobile Telephony and PCN
Comments	Commonly Known as Ethernet and Widely Used Today	GM Development Targeted for Industry/ Manufacturing	IBM Concept Developed for Twisted Wire Pairs	Compatible with Existing LANs and Future B-ISDN Evolution	Well Matched to SONET	Campus Network to WANs	Based on 802.6 DQDB as Public Service Offering	Selected as International Standard for B-ISDN	New Technology; Low Penetration	6000 Cells and 6 Million Users in 1991

facilities operating at DS-l (1.5 Mb/s) and DS-3 (45 Mb/s) rates are currently used. Eventually 155 Mb/s and even rates up to 600 Mb/s could be used to carry SMDS via SONET. SMOS is usually considered to be a public MAN. This contrasts with FDDI which is intended primarily as an on-premises (e.g., a campus) LAN. The two concepts are actually complementary. FDDI LANs connected by SMOS may be used in the 1994 time frame (Weissberger, 1991a and b).

7.2.4 Interworking Devices: Repeaters, Bridges, Routers, and Gateways

LANs, MANs, and even WANs may be interconnected to extend geographic coverage using one of four basic devices: repeaters, bridges, routers, and gateways. The distinguishing characteristics between these devices are a function of the layer of the OSI at which they operate, as indicated in Figure 7-9. This seven-layer OSI model may be interconnected at layers 1, 2, and 3 using repeaters, bridges, or routers, respectively, or using gateways.

Repeaters operate at the physical level and simply regenerate signals transmitted across the network. They can interconnect LANs that use the same protocols. Bridges operating at level 2 connect networks such as LANs that use the same physical and link layer protocols. They generally have some intelligence for filtering and routing link layer frames to other network segments. Routers operating at level 3 have still more intelligence and can optimize packet routing to reduce congestion. Gateways permit the coexistence of OSI-based and proprietary products. The gateway connects different network architectures by performing a conversion at the application level. The gateway must utilize all of the layers of the proprietary architecture according to Stallings (1989).

7.3 Advanced Network Architectures

7.3.1 Virtual Private Line Networks (VPLN) and Software Defined Networks (SON)

A VPLN is a private network provided on an as-needed basis to support a customer's application. The VPLN exists in the software embedded in the public switched network and may sometimes be called a SDN. One tariffed form of a SDN is offered by AT&T, and a software defined broadband network (SDBN) is planned for the near future (Wallace, 1992). For either, VPLN, SDN, or SDBN, the basic networking concept is time-sharing to make the public network appear private to the user. The advantages relative to leasing private lines are reduced cost and higher efficiency.

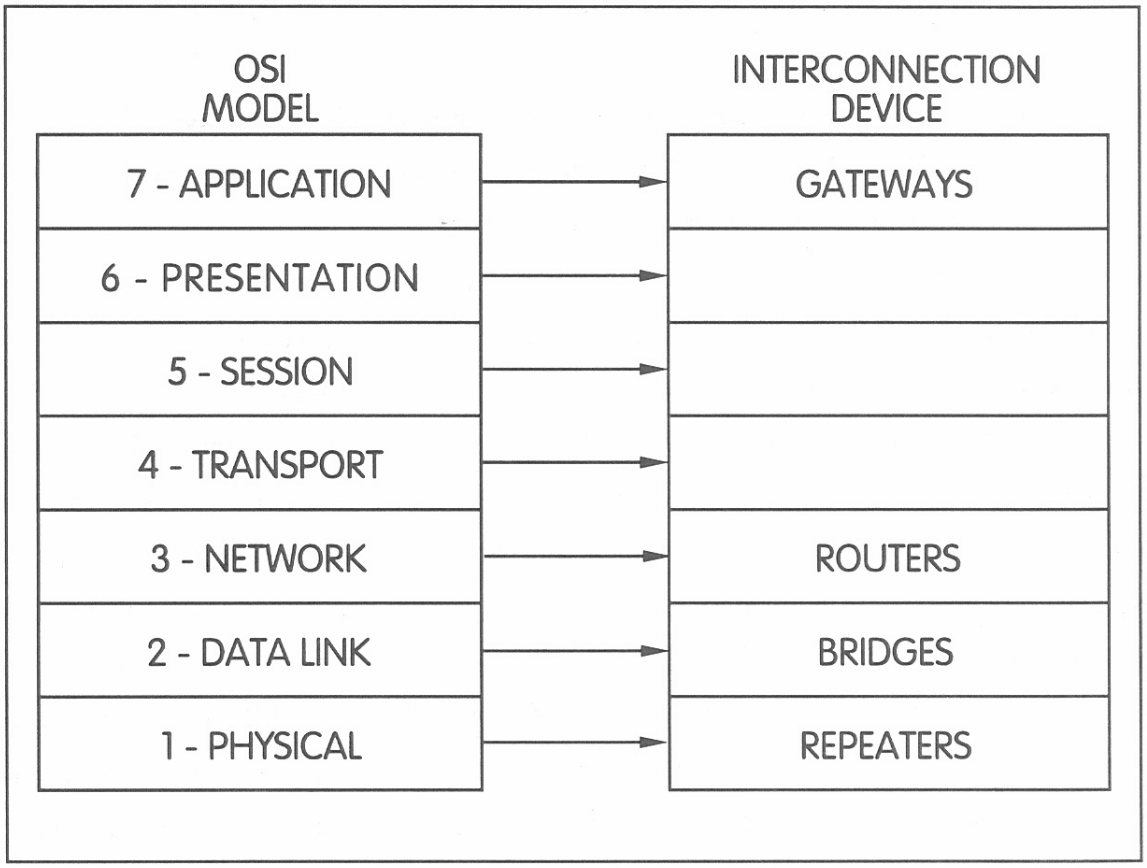


Figure 7-9. Mapping layers of the OSI model to corresponding interconnection devices.

Other transport systems that allocate and deallocate large amounts of bandwidth in extremely short times are expected to be needed in the future. This requirement has led to fast packet solutions for LANs, MANs, and WANs. A description of these bandwidth-on-demand transport systems was given in Section 7.2.

7.3.2 Intelligent Networks (IN) and Advanced Intelligent Networks (AIN)

The IN is a telecommunications network evolving from the public switched telephone network (PSTN) where service provisioning is provided by a service control architecture as depicted in Figure 7-10. The basic switching network contains a number of service switching points (SSPs) for switching user terminals. These SSPs are interconnected by Signaling System No. 7 (SS7). See Section 7.3.7 for a description of SS7. At call set-up, the SSP requests information about specific call handling from the network intelligence residing in service control points (SCP). The SCPs in turn are linked to a service management system (SMS) which is usually a commercial computer system with a number of remote peripherals. The SMS enables the network operator to manage and operate network services. The SMS may also be accessed by service providers to control, monitor, or modify service offerings.

Previously, when new services were offered by the switching system, it involved changes to thousands of different kinds of switches and took a long time. The IN allows new services to be introduced rapidly and efficiently through software changes to the centralized data bases and their associated operations support systems (OSS). The intelligence resides in on-line, real-time, centralized data bases, rather than in every switch, and is accessed through a packet-switched signaling network called SS7. Signaling networks based on SS7 provide the transport for IN services and call processing in local and backbone networks. The SS7 combines high performance, high reliability, and can respond rapidly to possible processor or link failures and congestion in the network. The infrastructure of IN is described by Robrock (1991) and by Claus et al. (1991).

The CCITT (1992) is developing draft recommendations for IN known as Capability Set 1 (CS-1). The CS-1 will permit the introduction of a wide range of advanced services with rapid service implementations and customization capabilities. Benchmark services being addressed by CS-1 are listed in Table 7-3. Features of CS-1 services which make up a service or represent a full service are listed in Table 7-4.

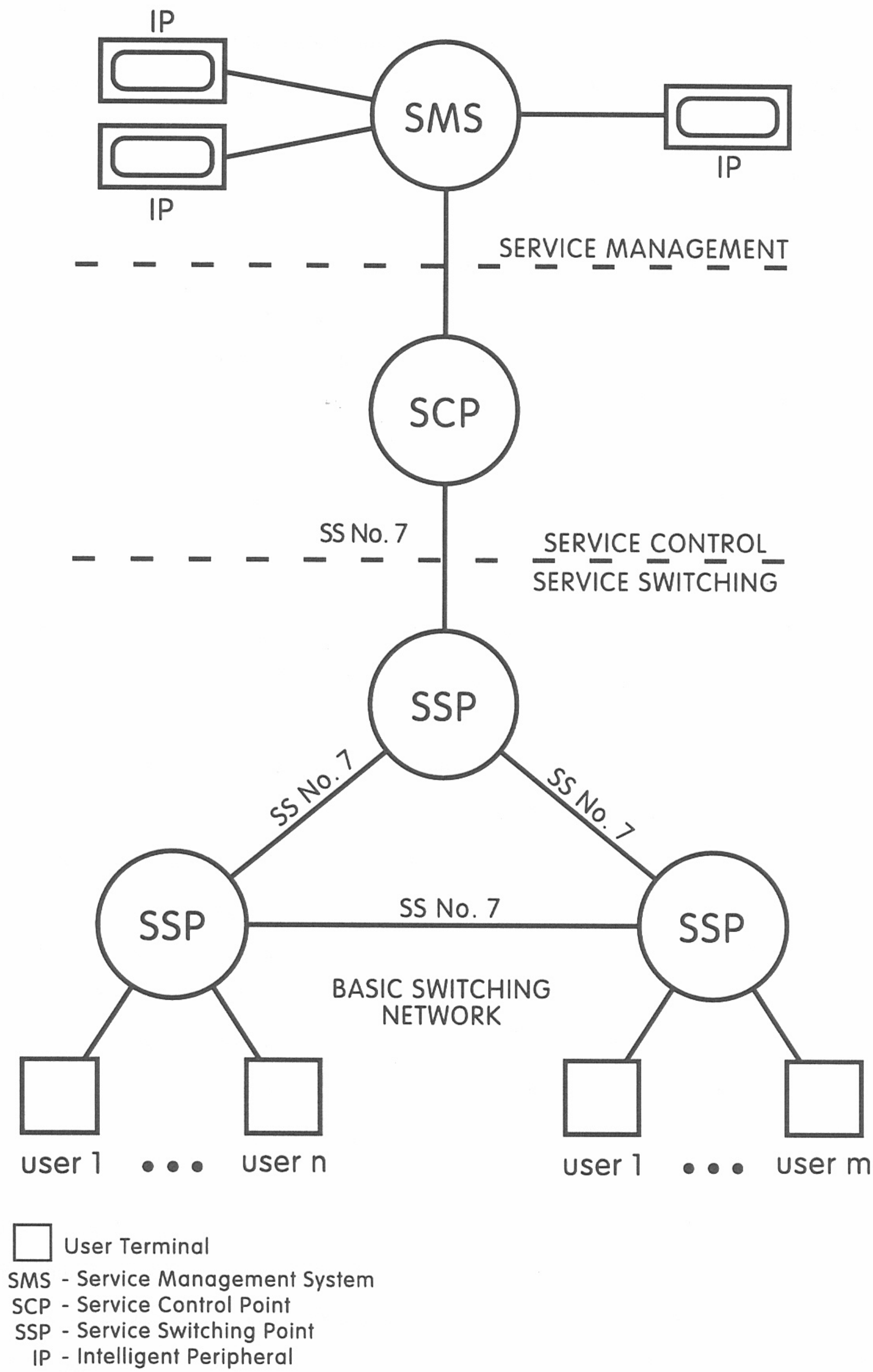


Figure 7-10. Intelligent network implementation.

Table 7-3. Benchmark CS-1 Services

Freephone (FPH)	Virtual Private Network (VPN)
User-Defined Routing (UDR)	Abbreviated Dialing (ABD)
Originating Call Screening (OCS)	Terminating Call Screening (TCS)
Call Forwarding (CF)	Call Distribution (CD)
Destination Call Routing (DCR)	Televoting (VOT)
Security Screening (SEC)	Premium Rate (PRM)
Split Charging (SPL)	Account Card Calling (ACC)
Credit Card Calling (CCC)	Automatic Alternative Billing (AAB)
Mass Calling (MAS)	Follow-Me-Diversion (FMD)
Conference Calling (CON)	Universal Access Number (UAN)
Malicious Call Identification (MCI)	
Completion of Call to Busy Subscriber (CCBS)	
Call Rerouting Distribution (CRD)	
Selective Call Forward on Busy/Don’t Answer (SCF)	
Universal Personal Telecommunications (UPT)	

Table 7-4. Features of CS-1 Services

Reverse Charging	Call Distribution
Call Gapping	Call Limiter
Call Queuing	Call Screening (outgoing)
Call Screening (incoming)	Closed User Group
Customer Profile Management	Follow-Me Diversion
Origin-Dependent Routing	Customized Recorded Announcement
Time-Dependent Routing	User Prompter
Abbreviated Dialing	Authentication
Authorization Code	Off-Net Access
Off-Net Calling	Attendant
Mass Calling	Split Charging
Premium Charging	Private Numbering Plan
One Number	Customized Ringing
Call Logging	Personal Numbering
Call Forwarding	Multi-Way Calling
Call Waiting	Call Transfer
Meet-Me Conference	Consultation Calling
Call Hold with Announcement	
Automatic Call Back	

A paper by Duran and Visser (1992) describes the objectives of IN and includes an overview of CS-1. Work on future capability is expected to continue in order to include services that could occur during the active phase of a call, multimedia services, and for supporting topology management. A goal of the IN is to design standard interfaces which will facilitate the introduction of Open Network Architecture (ONA) into the public switched network in the United States. In the U.S., the pioneering work on IN was mostly done by Bell Communications Research (Bellcore) beginning in 1984. In 1989, Bellcore proposed an Advanced Intelligent Network (AIN) concept for the 1995 time scale (Bellcore, 1990). Implementing an IN or AIN concept is essential to future PCS and UPT systems discussed in Section 7.3.6.

7.3.3 Integrated Services Digital Network (ISDN)

The CCITT (1988a) 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 non-voice services, to which users have access by a limited set of standard, multi-purpose user-network interfaces."

The ISDN recommendations define two interface rates for ISDN: a primary rate interface (PRI) and a basic rate interface (BRI). Both interfaces support simultaneous full-duplex voice and data using circuit-switched (voice) and packet-switched (data) connections on the same channel. Figure 7-11 indicates the ISDN interfaces.

The PRI is typically used to interconnect high-bandwidth devices such as mainframe computers, PBXs, and groups of lower bandwidth, basic rate lines with the central office digital exchange. The North American PRI is based on the DS1 transmission rate of 1.544 Mb/s. It consists of 23 64-kb/s B channels for voice and data, and one 64-kb/s D channel for signaling. Because a single D channel is used to handle all signaling, the other 23 channels are available for user data and voice transmission.

European PRI specifies 32 total channels (30B+ID+1 control) with an aggregate data rate of 2.048 Mb/s.

The BRI, which provides a composite bandwidth of 144 kb/s, is typically used to carry data to and from small end-user systems, such as voice/data workstations and terminal adapters for non-ISDN devices. It consists of two 64 kb/s information channels (B channels), which are used for voice and data, and one 16 kb/s packet-switched data channel (D channel), which can

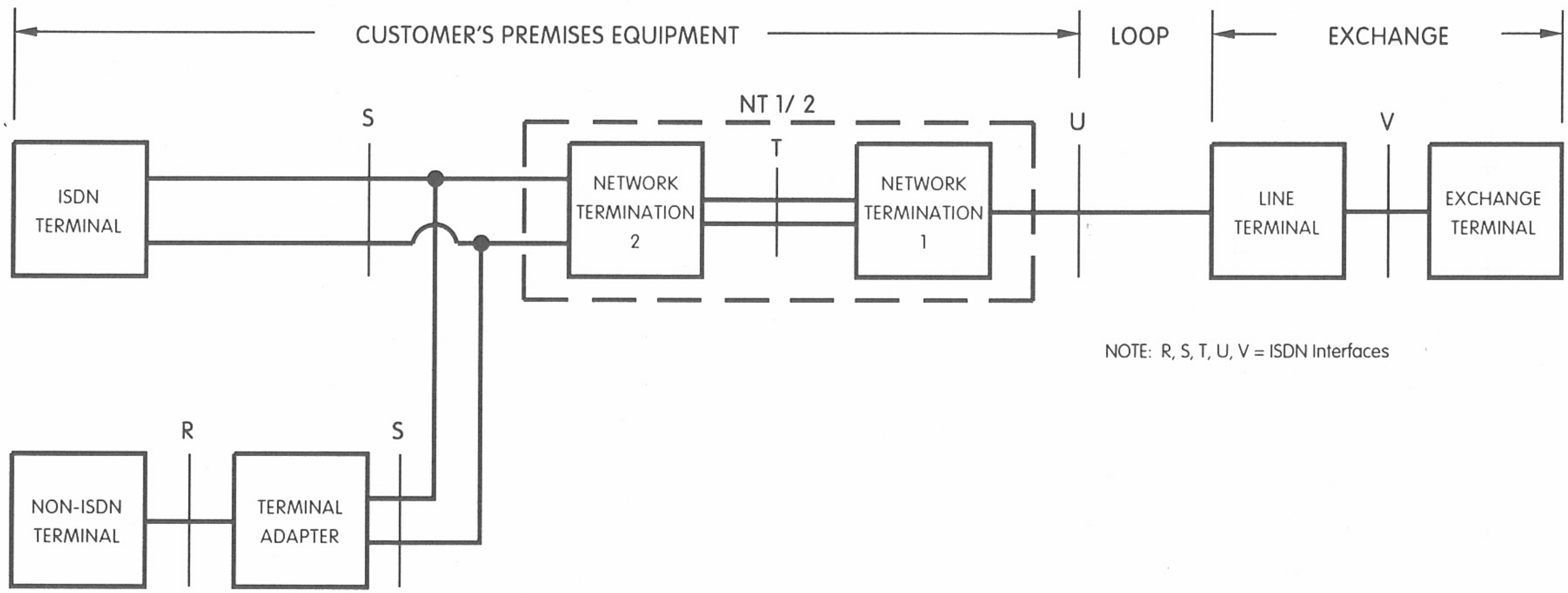


Figure 7-11. Recommendations for ISDN interfaces.

be used to carry either data or signaling information (such as call setup and takedown). The B and D channels are full-duplex bit streams, and are time-division multiplexed (2B+D) into a common stream that contains both user and signaling information.

The BRI consists of both a four-wire S/T interface and a two-wire U interface. The S/T interface standard is a four-wire connection that is wired inside the customer's home or office. Using the standard wall plug, this interface links customer equipment such as telephones, fax machines, and computer terminals with the ISDN network. Up to eight devices may be connected to this four-wire interface, which forms a passive bus.

The U-Interface (U) is a two-wire interface that connects the local telephone lines to the customer's home or office. The U interface is used in the network termination that links the customer premises with the local telephone line, in the line termination that links the telephone line with either a PRI or the central office digital exchange, and in two-wire terminal equipment.

Bellcore (1991) outlines the schedule for ISDN deployment by the seven RBOCs. This report estimates that by 1994, 61.9 million lines nationwide can provide ISDN service. Table 7-5 shows the implementation plan for the 1991 to 1994 period. Figure 7-12 indicates the availability of Signaling System No. 7 (SS7) and ISDN from 1990 to 1994.

According to the FCC, the first part of the decade will see the burgeoning of SS7 availability through BOC central offices. In 1990, 2,083 central offices were equipped for SS7, as were 36,706 access lines, which represent 34.7% of all lines. By 1994, 73% of BOC access lines will be equipped for SS7. The figures for ISDN are growing, but much more slowly. In 1990, 426 central offices and 496 access lines (0.5%) were equipped for ISDN. By 1994, 2,269 central offices and 2,218 access lines (1.9%) will be ISDN-equipped.

National ISDN-1 is a set of approximately 50 technical references developed by Bellcore that address the first three layers of the OSI model for ISDN. Layer 3 provides functional call control. The carriers began implementing ISDN-1 services on the public network for verification purposes in 1992. At the same time, CPE vendors are providing ISDN-1 terminals to customers. Implementation is expected to increase as software becomes generally available (Jones, 1991).

7.3.4 Broadband ISDN (B-ISDN)

The architecture model for B-ISDN is described by CCITT (l988a) in Recommendation I.327. According to this recommendation, B-ISDN includes the 64 kb/s-based ISDN capabilities,

Table 7-5. ISDN Implementation Plan

	1991		1992		1993		1994	
	LINES (MILLIONS)	% OF TOTAL LINES	LINES (MILLIONS)	% OF TOTAL LINES	LINES (MILLIONS)	% OF TOTAL LINES	LINES (MILLIONS)	% OF TOTAL LINES
Ameritech	2.2	15	3.36	22	8.0	51	11.15	70
Bell Atlantic	6.9	38	14.8	79	15.8	82	17.1	87
Bell South	3.1	17	5.6	30	8.0	41	10.5	52
NYNEX	1.3	8.3	3.88	24.5	5.27	32	5.47	33
Pacific Telesis	4.1	30	4.7	33	5.8	39	7.5	50
Southwestern Bell	1.6	12.9	2.0	15.6	2.1	15.9	2.2	16.3
US West	3.7	29	6.7	45	7.6	55	8.0	59

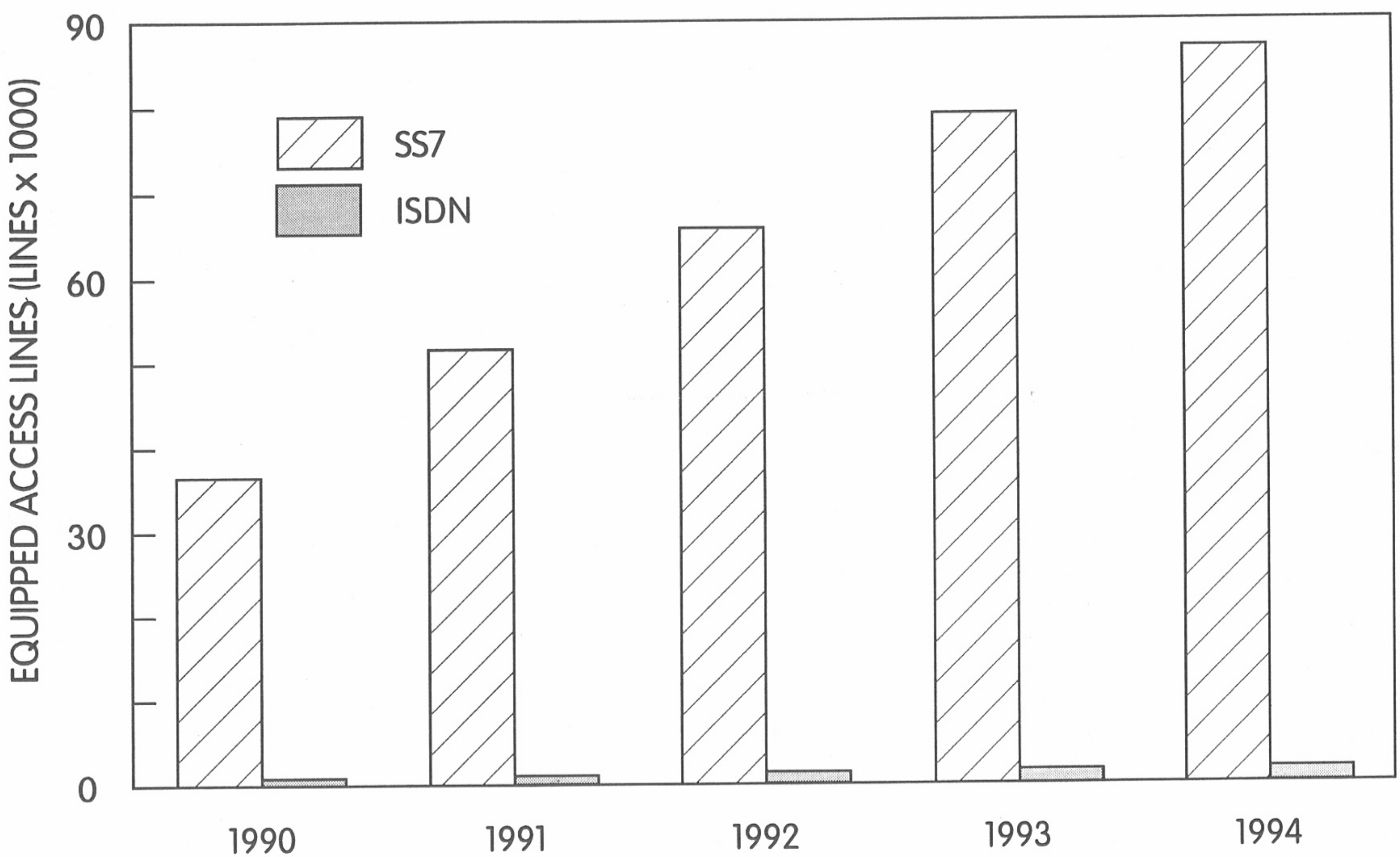


Figure 7-12. Availability of Signaling System 7 and ISDN central offices.

broadband capabilities, and control signaling from user to user, user to network, and between exchanges, as illustrated in Figure 7-13.

The B-ISDN is an ATM-based network. Transmission of B-ISDN signals in the access network is predominately over optical fiber using the synchronous digital hierarchy (SDH) defined by CCITT Recommendations G.707, 708, and 709 (CCITT, 1988e). These recommendations provide bit rates of approximately 155 Mb/s (STM-1), 622 Mb/s (STM-4), and 2.5 Gb/s (STM-16). Lower rates of 1.5 Mb/s and 45 Mb/s may be used initially to support ATM cell transport. The ATM multiplexor or switch adapts cell timing of incoming signals to the internal timing so that transmission links need not, in principal, be synchronized. However, initial implementations of ATM networks must support currently existing synchronous transport modes. The ATM/SONET concept was described in Section 3.4.

The B-ISDN trunk network consists of the following network elements: 1) virtual channel and virtual path switch (B-ISDN exchange), 2) ATM virtual path crossconnect, and 3) STM multiplexer crossconnect, as shown in Figure 7-14. A protocol reference model for B-ISDN is shown in Figure 7-15.

7.3.5 Internet and NREN

The Internet is a heterogeneous collection of computer networks organized in a hierarchy of networks connected through gateways, all using the transmission control protocol and internet protocol (TCP/IP), and all sharing common name and address spaces. Internet exists to facilitate the sharing of resources of participating organizations including government agencies, educational institutions, and private corporations. In January 1992, there were over 750,000 information processors on Internet linked by 5,000 networks with over 3 million users. The Internet evolved from ARPANET which was originally operated by DoD. The main backbone networks of Internet are MILNET and NSFNET which are mostly funded by Government grants, whereas the smaller networks are funded by other organizations. There are generally no per-user or per-message charges. Internet has grown almost exponentially since it first evolved in the late 1970’s. An Internet Activities Board (IAB) is the general technical and policy oversight body. The IAB is taking steps to integrate Open Systems Interconnection (OSI) protocols into the Internet. These OSI protocols will coexist with TCP/IP and interoperability between OSI and TCP/IP is to be provided (Cerf and Mills, 1990).

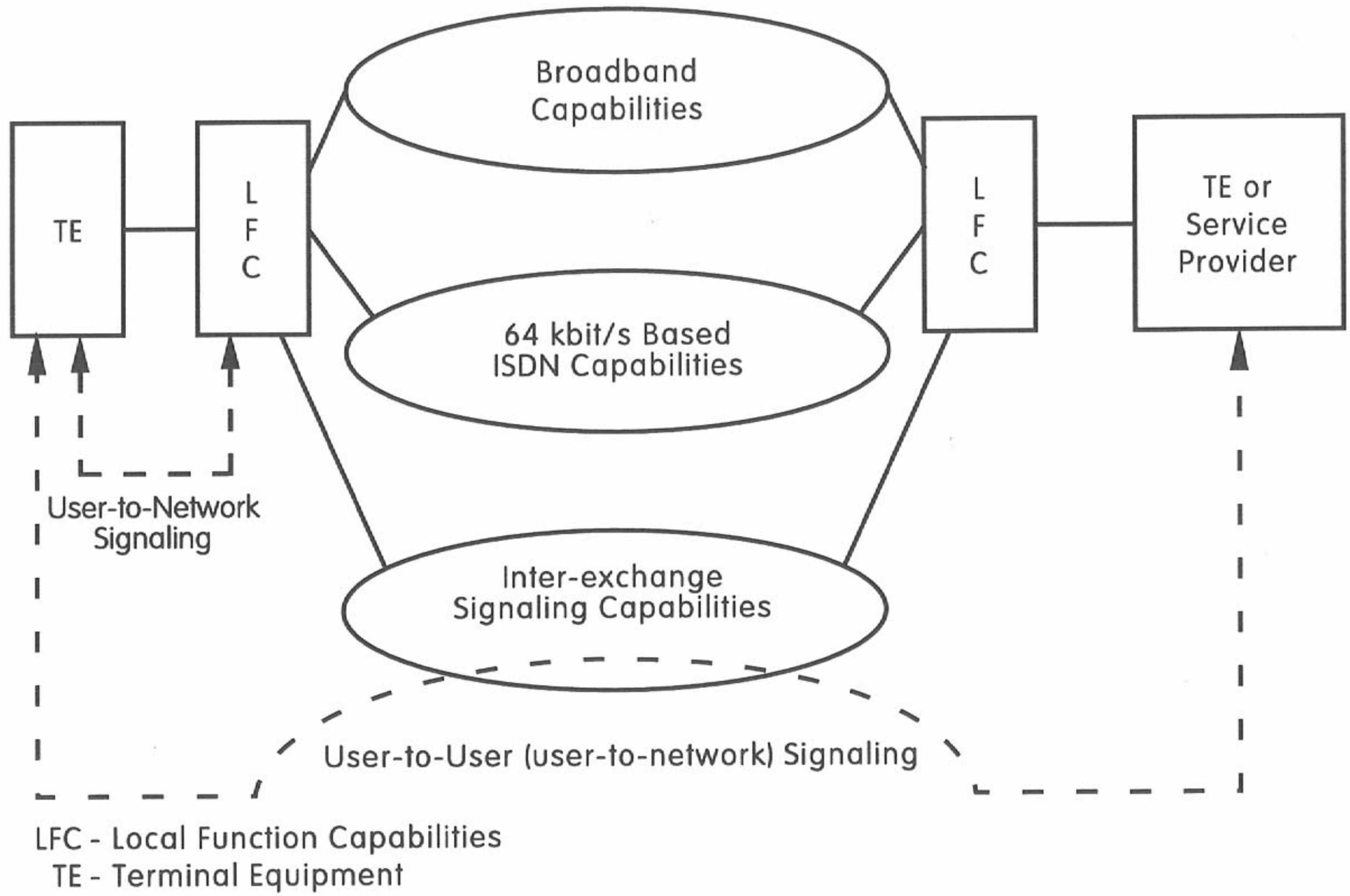


Figure 7-13. Architecture model for B-ISDN.

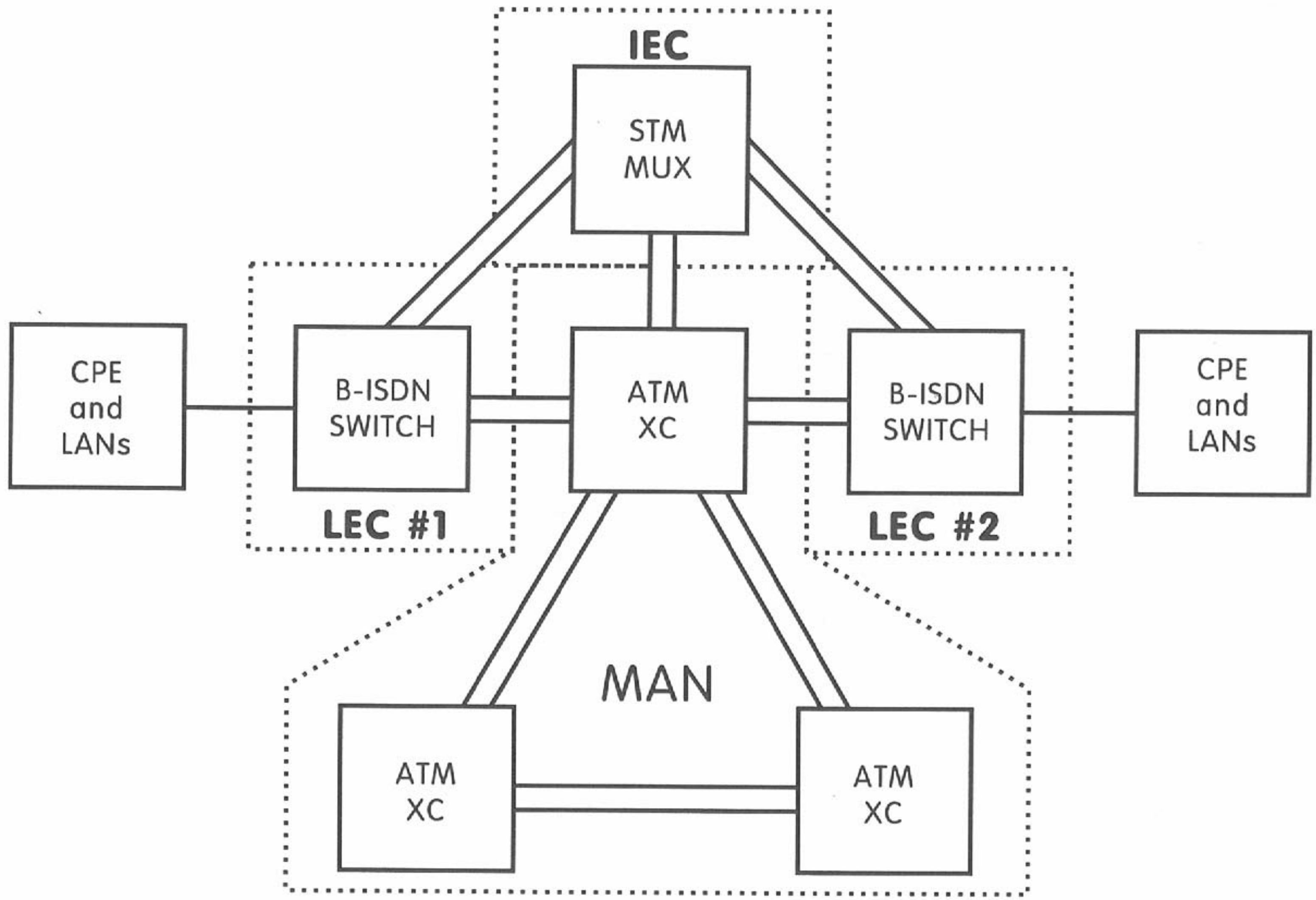


Figure 7-14. An example broadband ISDN (B-ISDN) trunk network.

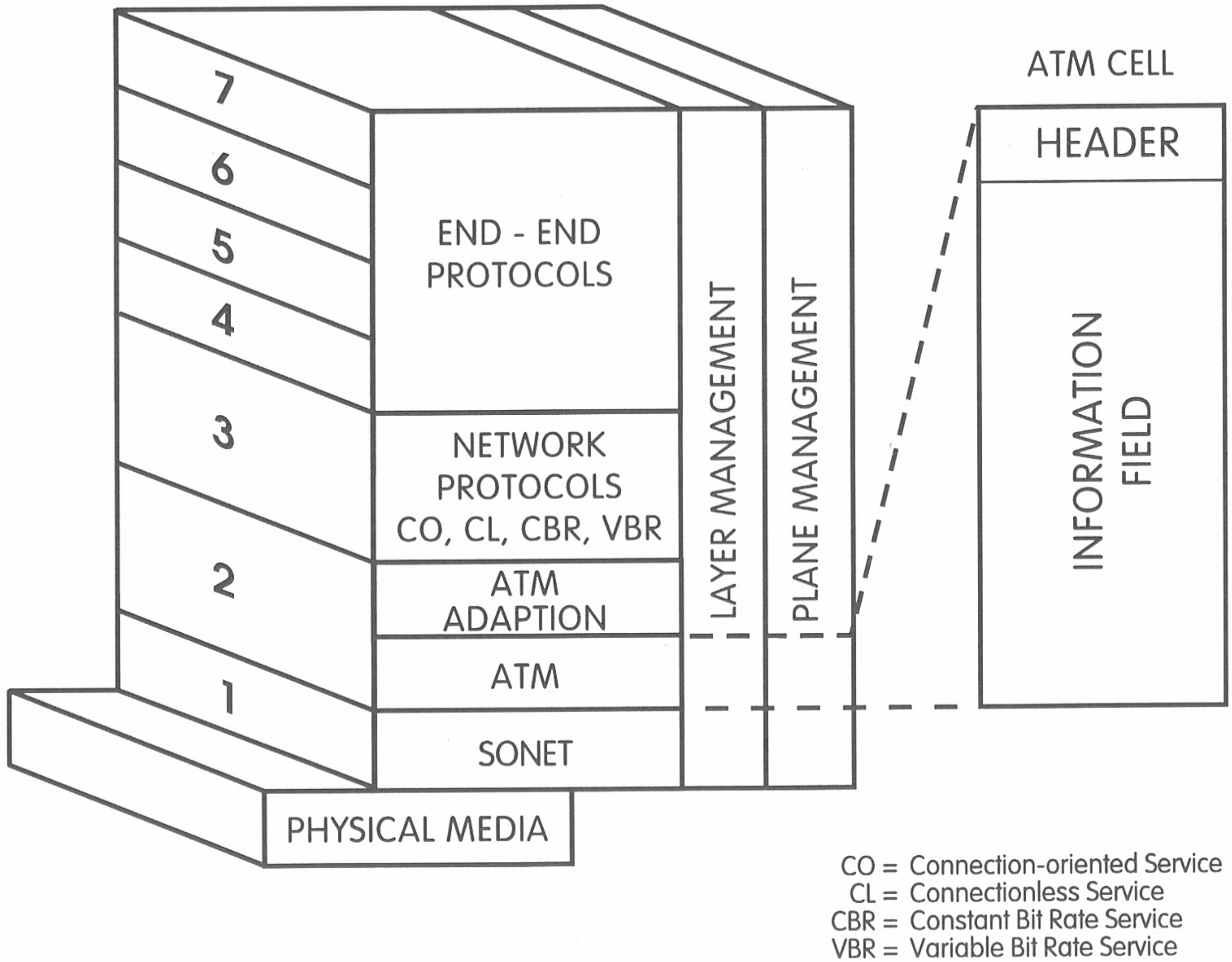


Figure 7-15. Protocol reference model for B-ISDN.

Martin (1991) lists the various resources, such as reference information, library documents, and other items available via Internet. In addition, the network provides services such as E-mail to a multitude of users. Finally, Clark et al. (1991) describes possible future directions for the Internet architecture and suggested steps towards the desired goals.

In the future, a multigigabit network known as the National Research and Education Network (NREN) may evolve from the existing Internet base. The description of NREN that follows was taken from Cerf (1990).

1. There will continue to be special-purpose and mission-oriented networks sponsored by the U.S. Government which will need to link with, if not directly support, the NREN.

2. The basic technical networking architecture of the NREN will include local area networks, metropolitan, regional, and wide area networks. Some nets will be organized to support transit traffic and others will be strictly parasitic.

3. Looking towards the end of the decade, some of the networks may be mobile (digital, cellular). A variety of technologies may be used, including, but not limited to, high speed Fiber Data Distributed Interface (FDDI) nets, Distributed Queue Dual Bus (DQDB) nets, Broadband Integrated Services Digital Networks (B-ISDN) utilizing Asynchronous Transfer Mode (ATM) switching fabrics as well as conventional Token Ring, Ethernet and other IEEE 802.x technology. Narrowband ISDN and X.25 packet switching technology network services are also likely play a role along with Switched Multi-megabit Data Service (SMDS) provided by telecommunications carriers. FTS-2000 might play in the system, at least in support of Government access to the NREN, and possibly in support of national agency network facilities.

4. The protocol architecture of the system will continue to exhibit a layered structure although the layering may vary from the present-day Internet and planned Open Systems Interconnection structures in some respects.

5. The system will include servers of varying kinds required to support the general operation of the system (for example, network management facilities, name servers of various types, e-mail, database and other kinds of information servers, multicast routers, cryptographic certificate servers) and collaboration support tools including video/teleconferencing systems and other "groupware" facilities. Accounting and access control mechanisms will be required.

6. The system will support multiple protocols on an end-to-end basis. At the least, full TCP/IP and OSI protocol stacks will be supported. Dealing with Connectionless and Connection-Oriented Network Services in the OSI area is an open issue (transport service bridges and application-level gateways are two possibilities).

7. Provision must be made for experimental research in networking to support the continued technical evolution of the system. The NREN can no more be a static, rigid system than the Internet has been since its inception. Interconnection of experimental facilities with the operational NREN must be supported.

8. The architecture must accommodate the use of commercial services, private, and Government-sponsored networks in the NREN system.

A review of the evolution of Internet and NREN is given by Hart et al. (1992).

7.3.6 Personal Communications Network (PCN) and Universal Personal Telecommunications (UPT)

PCN is a new network expected to evolve from cellular mobile technology as an independent network to support hand-held personal voice and low-speed data communications terminals. It will interwork with the PSTN and ISDN networks. UPT is a service expected to evolve from many intelligent networks that support portable person-to-person telecommunications for voice and data, and including broadband services such as high-quality voice, data, facsimile, and video. UPT subscribers will have a personnel telecommunications identifier (PTI) and be able to receive calls at any terminal anywhere to which the subscriber has directed his calls. Thus, UPT would be available globally, with personal mobility provided and with a number associated with the person rather than a terminal.

The key to UPT is the intelligent network concept described in Section 7.3.2. UPT is concerned with the overall mobility of the human user and not so much with user equipment. Implementation of UPT implies a number of network capabilities including user identification, personal mobility, personalization, security, and confidentiality as described by Claus et al. (1991).

Personal communications networks (PCNs), also known as personal communications services or personal communications systems (PCS) are expected to have explosive growth by the mid 1990s. By the end of the decade, the users of PCN and other wireless services may exceed 25% of the U.S. population. A number of issues must be resolved before low-power, low-cost, digital PCNs can be deployed on a large scale. One issue discussed by Barnes (1991) involves spectrum allocation. Another related issue is the access technology to be used. The access choices include code division multiple access (CDMA), time-division multiple access (TDMA), and frequency-division multiple access (FDMA). See Viterbi (1991) and Schilling et al. (1991).

The ultimate future of PCN depends on field experiments and on the initial service acceptance. Tests are currently underway that involve many users, cells, and transmission environments.

The FCC has granted licenses in the 1850-1990 MHz frequency band for testing PCN systems using CDMA. The tests are intended to show that this band can be shared with microwave transmission users. Studies have shown that the demands for spectrum could be enormous. For example, one study by A. D. Little projected 60 million users 10 years after deployment (Mason, 1991). Others projected the numbers of users to be only half as large, i.e., 30 million. This compares with 11 million cellular subscribers today.

PCNs are dependent on the existing public networks such as the IN and AIN in the United States to tie together the wireless islands of coverage. AIN would provide mobility to users and expand network services to roaming customers.

Standards work in the U.S. for PCN is currently occurring in the ANSI T1P1 committee. What standards will emerge are yet undetermined.

Mobile satellite communications systems can also impact PCN (Lodge, 1991). Satellites can provide mobile services to large regions that cannot be served by terrestrial means (e.g., oceanic areas and sparsely populated regions). Experimental satellites and systems are in the advanced stages of deployment that could provide basic communication services, such as voice and low-rate data to very small terminals including hand-held units. Examples of these experimental satellites are ACTS (see Section 3.5), and the Personal Access Satellite System (PASS) proposed by the Jet Propulsion Laboratory (Sue, 1990).

7.3.7 Signaling and Network Management

Signaling systems provide remote control of network switches. The primary function is call control for voice and data transmission services. However, modern signaling systems also provide a number of advanced features and functions to the network user. Signaling is normally provided by a packet-switched network that is separated from the networks carrying voice and data. The CCITT-recommended signaling protocol that is central to intelligent networks (IN), cellular telephony, and ISDN architectures is known as Signaling System Number 7 (SS7). It provides a number of advanced services via the signaling network databases (CCITT, 1988b).

The overall objective of SS7 is to provide an internationally standardized, general-purpose, common-channel signaling system with five primary characteristics. First, it is optimized for use in digital telecommunication networks in conjunction with digital stored program control exchanges utilizing 64 kb/s digital channels. Second, it is designed to meet present and future information transfer requirements for call control, remote control management, and maintenance. Third, it provides a reliable means for the transfer of information in the correct sequence without loss or duplication. Fourth, SS7 is suitable for operation over analog channels and at speeds below 64 kb/s (e.g., 4,800 b/s). Finally, it is suitable for use on point-to-point terrestrial and satellite links.

SS7 is basically a packetized data network designed for transferring control information between processors in a telecommunications network, and is fast becoming the predominate method for controlling global networks (Jabbari, 1991). It is also a key element to intelligent networks, ISDN, and for UPT (see Sections 7.3.2, 7.3.3, and 7.3.6). The availability of SS7 in central offices from 1990 to 1994 was shown previously in Figure 7-12 of Section 7.3.3.

Network management systems are used to manage network resources in contrast to signaling systems that control the switches. They may both use the same network elements or be completely separated. The International Standards Organization (ISO) has defined five essential network management functions as follows:

- Configuration management which manages the state of the network
- Fault management which handles faults in the network
- Accounting management (billing) which charges for network resource usage
- Security management which manages security facilities
- Performance management which takes care of network performance.

The CCITT (1988d) Recommendation M.30 describes network management. As telecommunication networks become more complex the need for an effective management structure becomes important. The CCITT is developing a standard telecommunications management network (TMN) for this purpose in Recommendation M.30. The basic concept behind the TMN is to provide an organized structure to interconnect various types of operating systems and telecommunication equipment using a common architecture with standardized protocols and interfaces. The general relationship of a TMN to the telecommunications network is shown in Figure 7-16. Network management concepts, standards, and products are also described by Jennings et al. (1993).

7.4 Summary of Capabilities and Applications

Table 7-6 summarizes many of the networks discussed previously. Some pertinent characteristics of major networks in use today, and contemplated for tomorrow, are shown in this table. Critical trends in network architectures expected by the next decade along with some of the major issues to be resolved are discussed in Section 8.

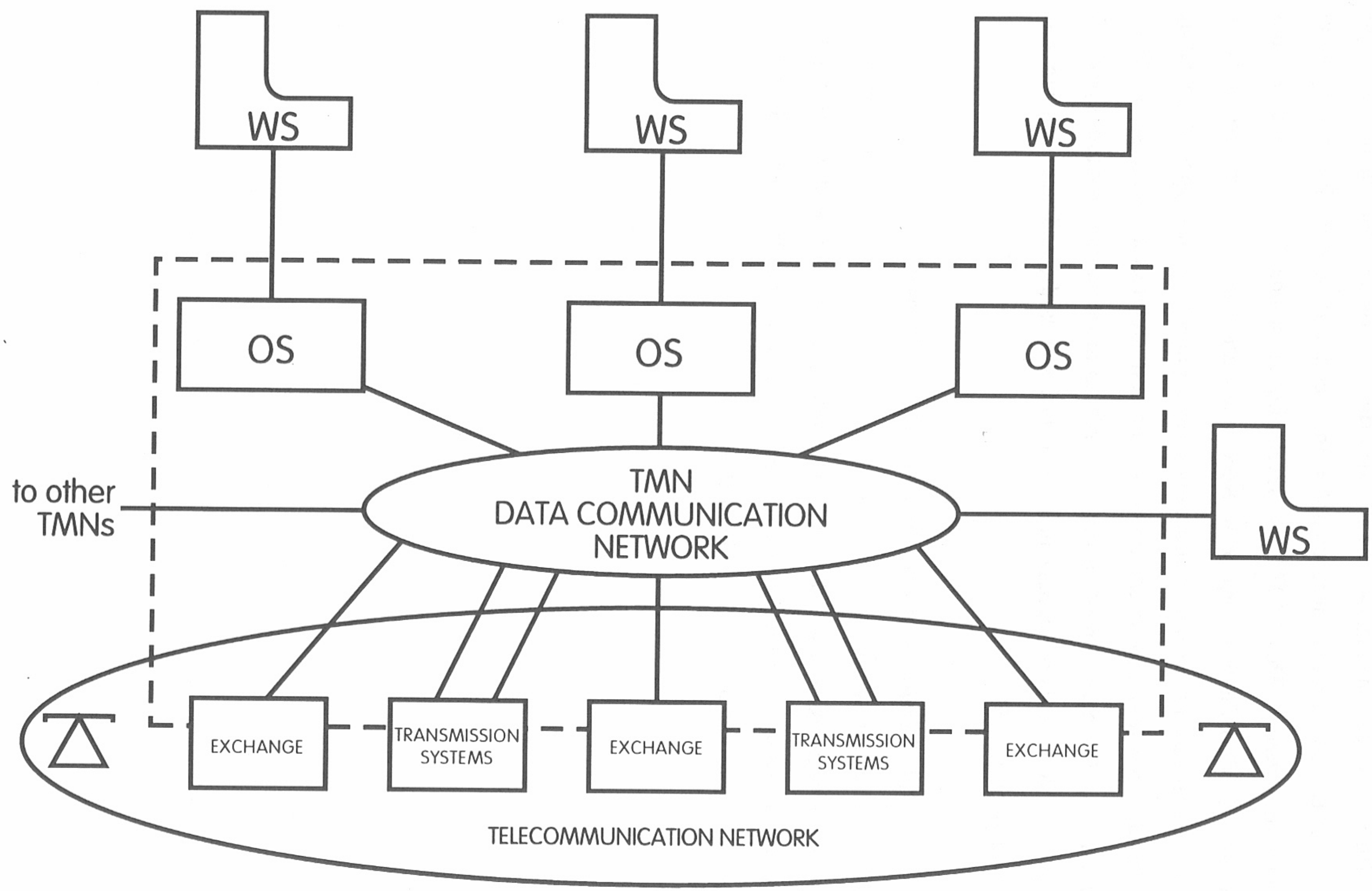


Figure 7-16. General relationship of a TMN to a telecommunication network.

Table 7-6. Major Network Evolution Summary

	Today					Tomorrow				
	PSTN	PDN X.25	ISDN	INTERNET	MOBILE RADIO	IN-1	SMDS	B-ISDN	NREN	PCN
Switching (packet, circuit, cell, or frame relay)	Analog and Digital (50% digital in 1991)	Packet Switch	Circuit, Packet	Packet Switch (Datagrams)		Circuit, Packet	Cell Relay	ATM Cell (Virtual) Circuit Switch at Link Layer	Not Yet Determined	
Transmission (fiber, copper, satellite, radio)	Copper, Fiber	Copper, Fiber Optic, Satellite	All (basic subscriber interface - 2B+D twisted pair)	All	Cellular Radio via Copper or Fiber Network	All Media	Fiber (45 Mb/s)	SONET/SDH Fiber (150 to 600 Mb/s)	Variety	Radio or Satellite with Fiber Interconnect
Signaling (in-band, SS7)	Analog #6	In-Band	SS7 20-70%	In-Band	In-Band	SS7	In-Band			
Penetration	135 Million Users in 1991	Unknown	RBOC Users 20-70% in 1994	3 Million Users Worldwide in 1990	6 Million Users in 1991	Unknown			Construction Beginning in 1993	
Nodes	~ 120 Nodes for AT&T	Unknown	Unknown	5000 Networks 570,000 Hosts	3 Million Users in 1992					
Subscriber Access and Data Rates	Data with Modems 300-9600 b/s	Dial-up: 9600 b/s Dedicated Lines: 56 kb/s to 1.5 Mb/s	$2B+D_1$ (B = 64 kb/s, D_1 = 16 kb/s) $23B+D_2$ (B = 64 kb/s, D_2 = 64 kb/s)	56 kb/s - 1.544 Mb/s Update to DS3, 45 Mb/s					Gb/s	
Network Layer Service [Connectionless (CL) or connection oriented (CO)]	CO	Primarily CO	CO/CL			CO	CL	CL and CO	Not Yet Determined	TDMA and CDMA
Service Offerings (voice, data, imagery, multimedia)	Primarily Voice; also Data via Modem	Data	Voice, Data	Data (file transfer, remote computing, E-mail)		Voice, Data with Special Features	Multimedia	Multimedia	Multimedia	Voice, Data to Mobile Users
Implementation Schedule	Currently Available 1993	Currently Available 1993	Currently Available 1993		Growth ~ 20% per Year	~ 1994	Available 1993	1995-2000	~ 1995	~ 1995