C H A P T E R 1

ATM Technology

This chapter describes the Asynchronous Transfer Mode (ATM) technology on which the Light-Stream 2020 multiservice ATM switch (LS2020 switch) is based.

You should read this chapter if you need a general understanding of ATM technology in relation to other networking technologies in widespread use today. To this end, this chapter contrasts the relative strengths and weaknesses of existing data communications and telecommunications technologies with the attributes unique to the new, emerging ATM cell relay technology.

In particular, this chapter focuses on how ATM devices efficiently process and transmit user traffic as discrete, fixed-length ATM cells at very high speeds.

ATM technology can be used in the following types of networking environments:

- Private workgroup or enterprise networks

- Large public networks

- Hybrid combinations of both private and public networks

ATM technology is rapidly being implemented in these networking environments to enable the seamless interconnection of local area networks (LANs) and wide area networks (WANs). Furthermore, ATM technology enables the switching and transport of multiple traffic types at comparatively high speeds in a single switching fabric.

In general, the LS2020 is the product of a standards-based implementation and development process. As a technical leadership product, however, the LS2020 ATM internal routing mechanisms were developed in advance of official industry standards and implementation agreements.

For this reason, the mechanisms that provide a path for setting up ATM virtual channel connections (VCCs) in an LS2020 network are Cisco proprietary and should be so regarded (see the section entitled "LS2020 ATM Internal Routing Mechanisms" later in this chapter).

Similarly, the LS2020 in its current implementation, does not support switched virtual connections (SVCs) by means of the ATM Forum UNI 3.0/3.1 signaling protocol. Nevertheless, an understanding of SVCs as an important ATM connection type is helpful to an overall understanding of ATM technology. Hence, SVCs are discussed in the following section and mentioned wherever appropriate throughout this chapter.

Overview

ATM is a high-bandwidth switching and multiplexing technology that combines the benefits of circuit switching (ensuring minimum transmission delay and guaranteed bandwidth) with the benefits of packet switching (providing flexibility and efficiency in handling intermittent traffic).

ATM technology supports the following types of communications services:

- **Circuit emulation (CE) services**—CE service is an on-demand, connection-oriented, constant bit rate ATM transport service. This service has stringent end-to-end timing requirements, and the user chooses the desired bandwidth and quality of services during connection setup. CE services traditionally provide the equivalent of a dedicated line for such communications applications as video conferencing and multimedia.

- **Frame Relay services**—Frame Relay is an industry-standard, switched data link layer protocol used for handling multiple virtual circuits by means of HDLC encapsulation between connected devices. Due to its relative efficiency, Frame Relay has to some extent superseded X.25 packet-switching technologies.

- **Switched Multimegabit Data Services (SMDS)**—SMDS is a high-speed, packet-switched, datagram-based WAN technology offered typically by telephone companies.

- **Cell relay services (CRS)**—CRS is a networking technology based on the use of small, fixed-length packets (cells) that can be processed and switched in hardware at very high speeds. CRS is the basis for several high-speed networking protocols, including ATM, SMDS, and IEEE 802.6.

Frame Relay, SMDS, and CRS are "fastpacket" transmission technologies that are playing a prominent role in communications of the 1990's. A generic ATM platform can support all three of these fastpacket technologies, as well as CE services.

A network that supports cell relay services is based on user data units called cells. Such cells are formatted according to a standard layout and sent sequentially in a connection-oriented manner (by means of an established communications path) to remote destinations in the network.

Cell relay services are being used for emerging multimedia and video conferencing applications that require both high transmission capacities and a guaranteed quality of service (QoS). For such applications, cell relay technology provides the most efficient means for transporting data expediently and reliably through the network.

Hence, cell relay services are generally regarded as the best data multiplexing technology available for today's current and emerging communications needs. ATM combines its unique strengths with those inherent in existing data communications and telecommunications applications.

Typically, cell relay services support two types of network connections:

- **Permanent virtual connections (PVCs)**—A PVC is a logical (rather than a physical) connection between two communicating ATM peers. Such a connection is typically established by a network administrator.

  Thus, a PVC is a non-switched connection that is established beforehand (pre-provisioned manually) to satisfy a standing need for network services. User applications that require an on-going, specific level of transmission bandwidth typically use PVCs for interconnectivity.

  Such connections are static in nature, that is, they remain in service until changed by the user, a network administrator, or a network management application.

  PVCs are typically used for interconnectivity between fixed corporate locations, data centers, or regional hubs engaged in traditional data communications applications. The network bandwidth required in this type of application tends to be more predictable and constant, enabling the physical transmission medium to be tailored to an expected volume of traffic, and vice versa.

- **Switched virtual connections (SVCs)**— An SVC is a switched connection that is established by means of a defined and standardized ATM signaling protocol. Such connections are set up dynamically ("on demand") across the network, as required by the user's communications applications.

  Thus, the transfer of information between network users by means of SVCs ordinarily occurs by means of shared network facilities, rather than through dedicated transmission lines or owned physical facilities.

  SVCs afford maximum networking flexibility in establishing connections dynamically to support a wide range of customer applications, particularly when customer sites are numerous or widely dispersed, or when required connectivity to certain sites is not pre-provisioned.

  SVCs are established and torn down "on the fly" using a flexible connection setup protocol that supports the various connection types required by today's communications applications.

ATM has evolved to its current state of prominence through the collaborative efforts of the following standards bodies:

- **International Telecommunications Union/Telecommunication Standardization Sector (ITU-T)**—This international body develops worldwide standards for telecommunications technologies.

Note The ITU-T carries out the functions of the former Consultative Committee for International Telegraph and Telephone (CCITT). CCITT, an international standards body, recently adopted the name *International Telecommunications Union/Telecommunications Standardization Sector* (ITU-T).

- **American National Standards Institute (ANSI)**—This voluntary organization, comprised of representatives from industry, commerce, and government, coordinates standards-related activities, approves U.S. national standards, and develops positions for the United States relative to international standards organizations.

- **ATM Forum**—This international consortium is chartered to accelerate the development and use of ATM products and services through the convergence and demonstration of interoperability specifications and the promotion of industry cooperation and awareness.

  The ATM Forum is not a standards body per se; rather, it works in cooperation with established standards bodies, such as ANSI and ITU-T, to develop and promote standards-based agreements for implementing ATM technology. The ATM Forum was founded jointly in 1991 by Cisco Systems, NET/ADAPTIVE, Northern Telecom, and Sprint.

The power and flexibility of ATM derive from two primary attributes:

- ATM supports very high-speed interfaces in a single data transmission and switching fabric

- ATM supports the multiplexing of multiple traffic types—data, voice, and video

Consequently, ATM affords the following benefits to network users:

- Provides flexible access to and efficient use of network resources

- Provides scalable framework for growing the network

- Enables highly integrated communications capabilities and services

The following sections contrast ATM cell relay technology with other data communications and telecommunications technologies of historical significance. Also discussed are the underlying principles, concepts, and implementation techniques on which ATM cell relay technology is based.

Communications Technologies Compared

Three major communications technologies are in use in industry and commerce today:

- Data communications
- Telecommunications
- ATM cell relay

This section contrasts the uses, characteristics, and relative benefits of these communications technologies.

Data Communications Technology

Data communications typically involve Ethernet, Token Ring, FDDI, Frame Relay, and X.25 data transmission services, all of which employ variable-length packets for data transfer. For these services, variable-length packets make more efficient use of communications channels than is the case with the time-division multiplexing (TDM) techniques commonly used in telecommunications applications (see next section).

Each of these data communications technologies addresses specific networking needs. For example, FDDI offers high transmission speeds, but typically requires users to pay a premium for 100 Mbps, fiber-based network access. Frame Relay, a protocol designed expressly for transferring LAN traffic, takes advantage of today's high quality, fiber-based networks to deliver data in a virtually error-free manner. X.25, a well-established communications protocol, is inherently slower than either Frame Relay or ATM and typically employs noisy, trouble-prone analog circuits for data transport.

All these *packet switching* technologies employ connectionless protocols that typically generate traffic at irregular or "bursty" intervals. In a connectionless service, no predetermined path or link is established over which information is transferred. Rather, the packets themselves contain sufficient addressing information to reach their destinations without establishing prior connections between the data senders and receivers. This connectionless service is also sometimes referred to as "packet transfer mode" (PTM).

In a connectionless service, nodes simply transmit data over the network whenever required (using network resources on a shared-access basis) without first establishing connections between themselves. However, a characteristic of data communications technology is that it introduces indeterminate delays or latencies in the data transport processes.

Telecommunications Technology

Telecommunications technologies typically use dedicated physical lines, circuit switching techniques, and small, fixed-size *frames* to carry voice traffic. This connection-oriented, *circuit switching* technology generates traffic of uniform length at regular, time-sensitive intervals. Hence, TDM techniques are typically used for handling voice traffic.

TDM uses communications channels that are segmented into fixed periods of time called frames. Frames are further divided into a fixed number of time slots of equal duration (see Figure 1-1). Each user is assigned one or more time slots within each frame for exclusive use. For example, Figure 1-1 shows that User A is allocated two time slots per frame.

Figure 1-1   User Assignments on TDM Communications Channel
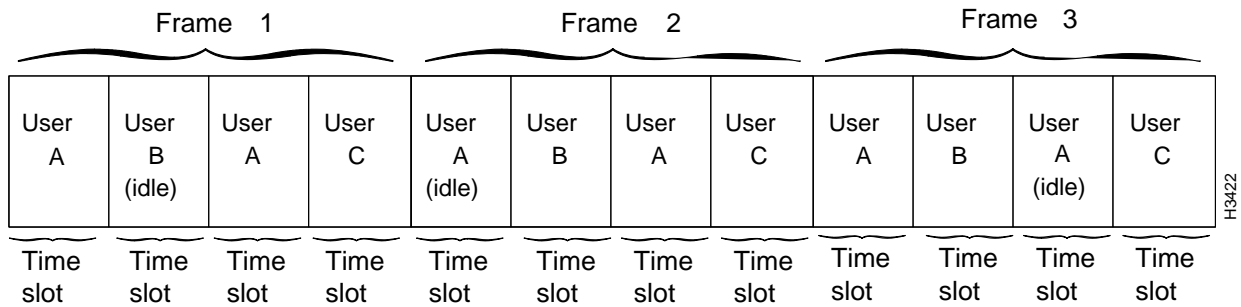
The time slots allocated for each user occur at precisely the same time in every frame. Since the time slots are synchronous, TDM is sometimes referred to as synchronous transfer mode (STM).

A user can access the TDM communications channel only when time slots allocated to it are available. If no user traffic is ready to send when the designated time slot occurs, that time slot is simply unused.

Similarly, a user sending a burst of traffic that exceeds the capacity of the designated time slots in any given frame cannot use additional slots, even if such slots are idle. Consequently, a delay will occur before the remaining user traffic can be transferred.

The continuing shift in emphasis from older data processing techniques to faster digital switching techniques, combined with the increasing availability of high bandwidth fiber optic cable, have brought dramatic changes in the nature of telecommunications networks. These advances have brought about the following changes:

- Fostered larger and more complex networks

- Improved the number and types of network services offered

- Enhanced the quality of network services.

However, as important as these advances are, they do not provide the most efficient solutions to today's communications needs. For example, carrying nonvoice data over telecommunications networks is very inefficient, requiring telecommunications users to acquire more dedicated bandwidth capacity for their voice applications than they typically use on a regular basis.

Thus, increasing bandwidth and adding special facilities to relieve network bottlenecks create expensive idle capacity during periods of low network utilization. Moreover, such changes may quickly become obsolete in the face of periodic organizational realignments that significantly alter the patterns of communication within the enterprise.

The solutions to these kinds of problems are found in ATM cell relay technology.

ATM Cell Relay Technology

ATM cell relay technology typically supports multiple traffic types (data, voice, and video) while addressing many of the pressing concerns of users of both public and private networks, such as the following:

- Need for flexibility and diversity of communications applications

- Need to integrate network services

- Need to accommodate future network growth/enhancement

ATM is a connection-oriented data transmission technology in which user information traverses the network through a pre-established path or link between two ATM network endpoints. A network endpoint is that locus in an ATM network where an ATM connection is either initiated or terminated.

ATM switches incorporate self-routing techniques for all ATM cell relay functions in the network. This means that each ATM cell finds its way through the network switching fabric "on the fly" using routing information carried in the cell header.

In other words, an ATM switch accepts a cell from the transmission medium, performs a validity check on the data in the cell header, reads the address in the header, and forwards the cell accordingly to the next link in the network. The switch immediately accepts another cell—one that may be part of an entirely unrelated message—and repeats the process.

The cell header provides control information to the ATM layer of the ATM architecture (see Figure 1-3). The ATM layer, in combination with the physical layer, provides essential services for communications throughout an ATM network.

Since ATM protocols are not tied to any particular transmission rate or physical medium, a communications application can operate at a rate appropriate to the physical layer technology used for data transport. Furthermore, because ATM cell transmission is asynchronous in nature, delay-tolerant traffic (such as user data) can be freely intermixed with time-sensitive traffic (such as voice or video data).

Figure 1-2 illustrates the asynchronous nature of user traffic in an ATM network. Note that there is no predictable or discernible pattern in the way users are allocated cells in the ATM communications channel for data transmission.

Figure 1-2   User Assignments on ATM Communications Channel
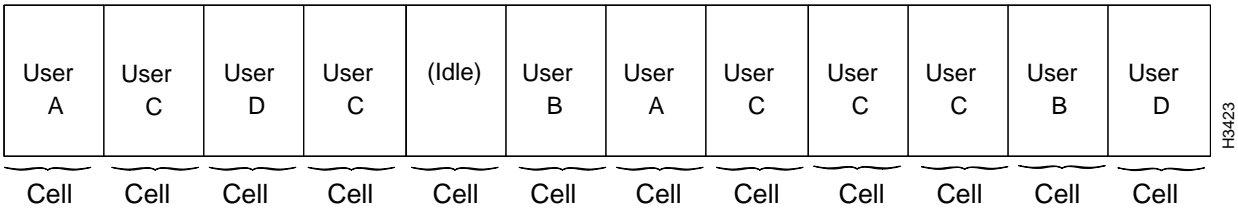
The fixed-size format of ATM cells enables the cells to be switched (routed) through the network by means of high-speed hardware without incurring the overhead ordinarily associated with software or firmware in traditional packet-switching devices.

In ATM communications, access to the communications channel is much more flexible than with TDM communications. Any ATM user needing a communications channel can gain access to that channel whenever it is available. Also, ATM imposes no regular pattern on the way users are granted access to the channel. Thuys, ATM provides transmission bandwidth to users *on demand.*

In the packet-handling technologies discussed earlier, any user can gain access to the communications channel, but a user sending a long message can prevent other users from gaining access to the channel until the entire message is sent. However, with ATM, every message is segmented into small, fixed-length cells that can be transported through the network as needed. Thus, no single user can monopolize the ATM communications channel to the exclusion of other users with pending message traffic.

ATM Benefits

ATM technology offers the following primary benefits:

- **Bandwidth efficiency**—ATM efficiently supports the aggregate transmission requirements of a network by allocating bandwidth on demand, based on actual user needs. Bandwidth allocation is accomplished without administrative intervention. Furthermore, network bandwidth is scalable to meet future user needs for higher transmission rates.

- **Scalability** —ATM is highly flexible, accommodating a wide range of traffic types, traffic rates, and communications applications. ATM interface standards exist for data rates as low as 1.544 Mbps (DS1) and as high as 2.4 Gbps (SONET).

- **Application transparency**—The fixed-length size of an ATM cell is an effective compromise between the typically lengthy packets of data communications applications and the short, repetitive frames of telecommunications (voice) applications.

  The asynchronous nature of ATM data transmission allows a wide range of ATM devices to support traffic at rates and degrees of burstiness compatible with the user's applications, rather than at rates and degrees of burstiness convenient to the network.

  In other words, ATM allows the network to be tailored to the user's needs, rather than forcing the user's applications to fit the network's characteristics.

  ATM affords the following user benefits:

    - Provides timely access to network resources

    - Supports message traffic of variable length

    - Provides higher transmission speeds

    - Provides self-routing capabilities for multiple traffic types

    - Supports new data communications and telecommuncations applications

    - Offers guaranteed network access for voice and video applications

    - Enables users to request a desired level and quality of service

    - Provides protection mechanisms against network congestion conditions

- **Networking advantages**—ATM is a simple, fast, cell-switching technology that derives its cell routing capabilities from information carried within each cell. Thus, no data processing occurs above the cell level in an ATM network; this results in increased message-handling speed and data transport efficiency.

  Furthermore, the self-routing capabilities of ATM allow you to easily incorporate any number of ATM switching devices in your network. Thus, your network can grow in size, speed, and functionality to incorporate new ATM technologies and applications as they become available.

Classes of ATM Applications

From a network point of view, two main types of broadband services are supported by ATM cell relay technology:

- Interactive broadband services

- Distributive broadband services

These types of services are described in Table 1-1.

Table 1-1   **Broadband Services Supported by ATM Cell Relay Technology**

| Service Type	Service Description
Interactive	This type of service takes three forms: conversational services, messaging services, and retrieval services.
	Conversational services provide the means for bidirectional communication with real-time, end-to-end information transfer between users or between users and servers. Examples of this type of service include high-speed data transmission, image transmission, video telephony, and video conferencing.
	Messaging services provide user-to-user communication between individual users by means of storage units with store-and-forward, mailbox, and/or message handling (information editing, processing, and conversion) functions. Examples of this type of service include voicemail and e-mail for transporting audio information and pictures and store-and-forward images.
	Retrieval services allow users to retrieve information on demand that has been stored in information repositories. The time at which the information retrieval sequence begins is under user control. Examples of this type of service include retrieval of film, high-resolution images, information on CD-ROMs, and audio information.
Distributive	Distribution services *without user individual presentation control* provide a continuous flow of information that is distributed from a central source to an unlimited number of authorized receivers connected to the network.
	The user can access this flow of information without having to determine at which instant the distribution of a string of information will be started. The user cannot control the start and order of presentation of the broadcast information. Hence, depending on the time of user access, the information will not be presented from the beginning. Examples of this type of service include the broadcasting of television and audio programs.
	Distribution services *with user individual presentation control* provide information distribution from a central source to a large number of users. Information is rendered as a sequence of information entities with cyclical repetition. The user has individual access to the cyclically distributed information and can control the start and order of the presentation. An example of this type of service is broadcast videography.

ATM Protocol Reference Model

ATM standards define protocols that operate at the layer 2 level (the data link layer) of the International Standards Organization (ISO) 7-layer Open Systems Interconnection (OSI) reference model. These standards define processes that occur in the ATM adaptation layer (AAL) and the ATM layer of the ATM protocol reference model (see Figure 1-3).

The AAL performs two fundamental, and complementary, tasks:

- **In source node**—Translates user data received from higher layer protocols into ATM cell payloads for delivery through the network to a destination node.

- **In destination node**—Translates ATM cells received from a source node and arranges the data in a format suitable for presentation to higher layer protocols.

The ATM layer is that part of the ATM protocol that operates in conjunction with the physical layer to relay cells from one ATM connection in the network to another.

Figure 1-3   ATM Protocol Reference Model
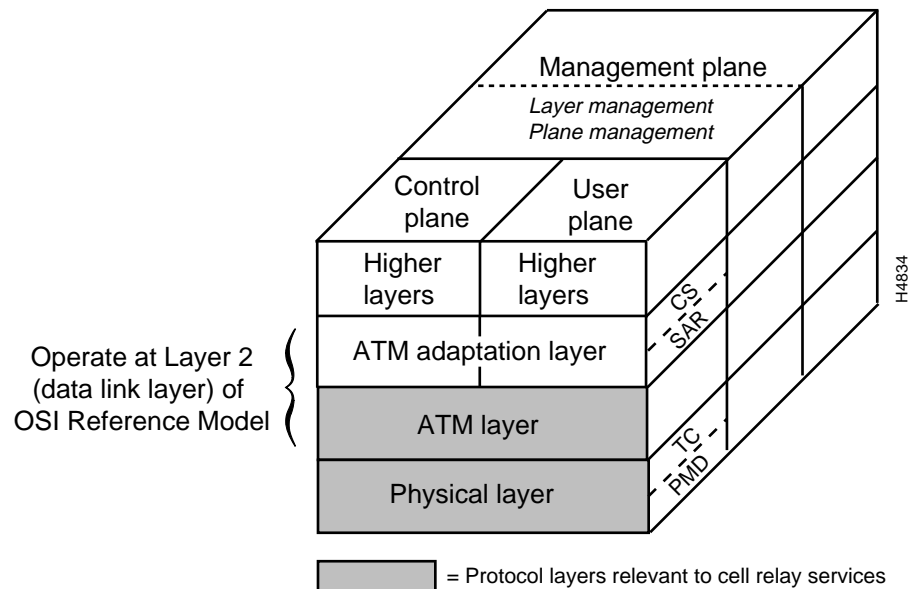
The ATM protocol reference model is patterned after the OSI reference model. However, the former differs from the latter in that it consists of three planes: the control plane, the user plane, and the management plane. The functions of these planes, which operate across all four layers of the ATM architecture, are summarized briefly below:

- **User plane**—Provides for the transfer of end-user information through the network. This plane is concerned primarily with the ATM layer and the physical layer—the layers most relevant to accomplishing cell relay services in an ATM network.

  The user plane also relates to the ATM adaptation layer (AAL) and the higher layer protocols and end-user applications. However, since the AAL layer and the higher layers are specific to the end-user application in use, they are not regarded as an integral part of a network's ATM cell relay services.

- **Control plane**—Provides for the exchange of signaling information between ATM endpoints (the senders and receivers of ATM data) in order to accomplish connection setup. The control plane also provides control functions essential to ATM switched services.

  The control plane deals with the signaling and routing processes necessary to set up, manage, and release switched virtual connections (SVCs) between communicating peers in the network. The control plane also shares the ATM layer and physical layer facilities with the user plane.

- **Management plane**—Provides for operations and management functions, as well as the capability to exchange information between the user plane and the control plane.

  The management plane performs two primary functions: *layer management,* for layer-specific functions, such as detecting failures and protocol abnormalities; and *plane management,* for managing and coordinating functions related to the overall ATM architecture.

The interactions within and between the four layers comprising the ATM architecture in accomplishing ATM communications are summarized briefly below. Referring to Figure 1-3 will be helpful as you read this material.

- **Higher layer applications and protocols**—The layers above the ATM adaptation layer (AAL) relate to the specific communications application(s) that the user chooses to deploy in the ATM networking environment, such as TCP/IP, OSI, Advanced Peer to Peer Networking (APPN), etc.

- **ATM adaptation layer (AAL)**—This layer arranges ("maps") higher-layer user data into ATM cells, making the data suitable for transport though the ATM network. The AAL also insulates the higher layer protocols of the user's communications applications from the intricacies of ATM.

  Two service-specific layers within the AAL, the convergence sublayer (CS) and the segmentation and reassembly (SAR) sublayer, perform application-dependent traffic processing. The processes in these sublayers, which arrange user data into ATM cells, are described in detail in a later section entitled "Functions of ATM Adaptation Layer."

- **ATM layer**—This layer provides native ATM cell relay services for the network. Essentially, the ATM layer delivers ATM cells to the physical layer for transport through the network to destinations. This layer is described in detail in a later section entitled "Functions of ATM Layer."

- **Physical layer**—This layer passes ATM cells received from the ATM layer to the actual physical transmission medium, and vice versa, depending on the direction of cell flow between the senders and receivers of ATM data. This layer is described in detail in a later section entitled "Functions of Physical Layer."

  ATM cells are transported to destinations by means of virtual connections established between communicating network endpoints. Such connections are set up through the exchange of appropriate messaging and routing protocols. Once a connection is established, ATM cells are routed through the network in the same sequence as generated by or received from the user's data origination or termination equipment.

  The physical layer provides the ATM layer with access to the network's physical transmission media, such as a fiber-optic cable or coaxial cable. The process of placing ATM cells onto the physical transmission media takes place in two sublayers of the physical layer: the transmission convergence (TC) sublayer and the physical medium dependent (PMD) sublayer.

  The TC sublayer "maps" the ATM cell stream to the underlying framing mechanism of the physical transmission medium and generates the required ATM protocol information for the physical layer.

The PMD sublayer adapts the ATM cell stream to the specific electrical or optical characteristics of the physical transmission medium. These characteristics include such factors as timing, power, and jitter. (Jitter is line distortion in analog communications caused by a variation of a signal from its timing reference. Such distortion often causes data loss, particularly at high transmission speeds).

Each PMD is tailored to the particular physical medium being used and includes definitions of proper cabling and bit timing for the physical interface.

ATM Cell Format

An ATM cell is a fixed-length, standard unit of data transmission for all cell relay services in an ATM network (see Figure 1-4). The first five bytes of the ATM cell serve as the cell header. The cell header contains information essential to routing the cell through the network and ensuring that the cell reaches its destination.

Figure 1-4   Format of UNI ATM Cell
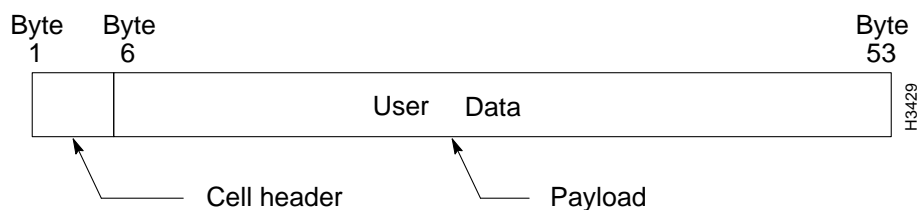
This 5-byte header is divided into fields that contain identification, control, priority, and cell routing information (see Figure 1-5). The remaining 48 bytes constitute the cell payload—the informational substance of the ATM cell. ATM cells are transmitted serially through the network, beginning with bit 8 in the first byte of the cell header.

Figure 1-5   Format of UNI/NNI ATM Cell Header
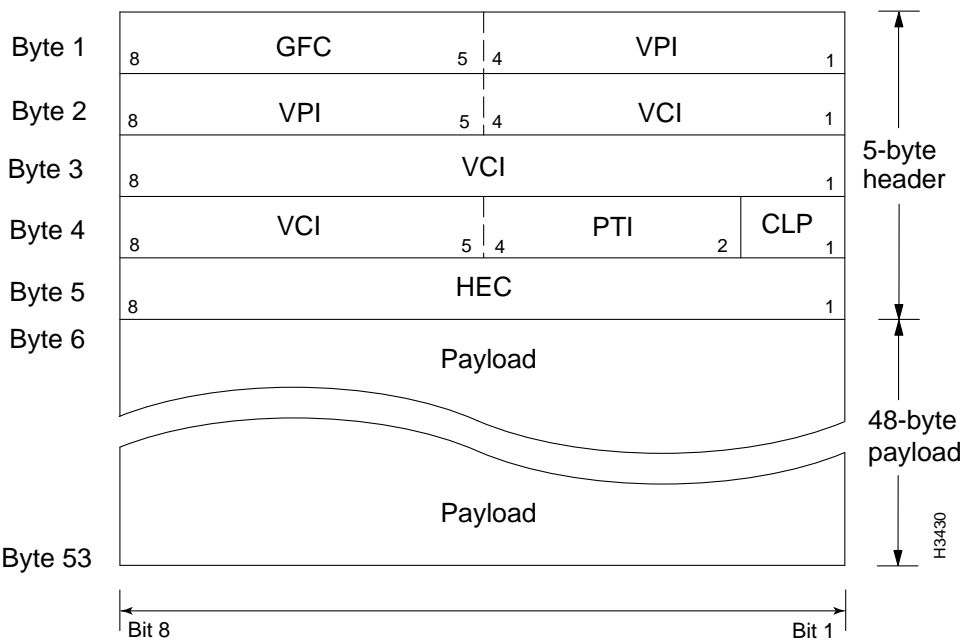
Arranging data into fixed-length cells makes effective use of high-speed transmission media (such as T3, E3, and OC3 trunks), because fixed-length cells can be processed by hardware at electronic speeds while incurring a minimum of software overhead. Hence, transit delays for cells flowing through an ATM network are reduced or eliminated altogether.

An overriding advantage of handling data as fixed-length cells is that this format enables the network to accommodate not only rapid changes in the quantity of network traffic, but also in the pattern of that traffic. Consequently, an ATM network can simultaneously handle a mixture of bursty traffic and delay-sensitive traffic, while at the same time providing services essential to other traffic types.

The structure of an ATM cell is the same everywhere in the network, with the exception of a small (but important) variation in the cell header that differentiates an ATM UNI cell header from an ATM NNI cell header.

Specifically, part of the VPI field in the ATM UNI header (bits 5 through 8 of byte 1 in Figure 1-5) is reserved as a generic flow control (GFC) field, while the ATM NNI header provides for a larger range of VPI values (through bits 5 through 8 of byte 2, in addition to bits 1 through 4 of byte 1). This larger range of VPI values that can be defined in an ATM NNI cell header reflects the greater use of virtual paths (VPs) in the network for trunking purposes between ATM inter-switch and ATM inter-network interfaces.

All traffic to or from an ATM network is prefaced with a virtual path identifier (VPI) and a virtual channel identifier (VCI). A VPI/VCI pair identifies a single virtual circuit (VC) in an ATM network. Each VC constitutes a private connection to another node in an ATM network and is treated as a point-to-point mechanism for supporting bidirectional traffic. Thus, each VC is considered to be a separate and complete link to a destination node.

Table 1-2 describes the fields of the ATM UNI/NNI cell header in detail.

Table 1-2   Fields in ATM UNI/NNI Cell Header

Header Field Name	Location in Header	Description
GFC (generic flow control)[1]	Last four bits of Byte 1	The GFC field is used when passing ATM traffic through a user-to-network (UNI) interface to alleviate short-term overload conditions. A network-to-network (NNI) interface does not use this field for GFC purposes; rather, an NNI uses this field to define a larger VPI value for trunking purposes.
VPI (virtual path identifier)	First four bits of Byte 1 and last four bits of Byte 2	Identifies virtual paths (VPs). In an idle or null cell, the VPI field is set to all zeros. (A cell containing no information in the payload field is either "idle" or "null"). A virtual path connection (VPC) is a group of virtual connections between two points in the network. Each virtual connection may involve several ATM links. VPIs provide a way to bundle ATM traffic being sent to the same destination.
VCI (virtual channel identifier)	First four bits of Byte 2, all of Byte 3, and last four bits of Byte 4	Identifies a particular virtual channel connection (VCC). In an idle or null cell (one containing no payload information), the VCI field is set to all zeros. Other non-zero values in this field are reserved for special purposes. For example, the values VPI=0 and VCI=5 are used exclusively for ATM signaling purposes when requesting an ATM connection. A VCC is a connection between two communicating ATM entities; the connection may consist of a concatenation of many ATM links.
PTI (payload type identifier)	Second, third, and fourth bits of Byte 4	This 3-bit descriptor identifies the type of payload the cell contains: either user data or special network management cells for performing certain network operation, administration, and maintenance (OAM) functions in the network. ATM cells can carry different types of information that may require different handling by the network or the user's terminating equipment.
CLP (cell loss priority)	First bit of Byte 4	This 1-bit descriptor in the ATM cell header is set by the AAL to indicate the relative importance of a cell. This bit is set to 1 to indicate that a cell can be discarded, if necessary, such as when an ATM switch is experiencing traffic congestion. If a cell should not be discarded, such as when supporting a specified or guaranteed quality of service (QoS), this bit is set to 0. This bit may also be set by the ATM layer if an ATM connection exceeds the QoS parameters established during connection setup.
HEC (header error check)	Byte 5	The HEC field is an 8-bit cyclic redundancy check (CRC) computed on all fields in an ATM UNI/NNI cell header. The HEC is capable of detecting all single-bit errors and certain multiple-bit errors. This field provides protection against incorrect message delivery caused by addressing errors. However, it provides no error protection for the ATM cell payload proper. The physical layer uses this field for cell delineation functions during data transport.

1. For a network-to-node (NNI) interface, the GFC field serves as part of the VPI field for trunking purposes.

ATM Data Processing

The processes that map user information (data, voice, and video) into an ATM format, and vice versa, occur at Layer 2, the data link layer, of the OSI reference model. For ATM purposes, Layer 2 consists of the following elements:

- ATM adaptation layer (AAL)

- ATM layer

Figure 1-6 illustrates the relationship of these ATM elements to the physical layer.

Once user data is mapped into ATM cells in Layer 2, the cells are conveyed to Layer 1, the physical layer, for transport through the network to destinations by means of physical media and ATM switches.

An ATM endpoint, as illustrated in Figure 1-6, can be either the point of origin (the source) of an ATM cell or the destination of a cell. Hence, each ATM endpoint represents one end of a connection between communicating peers in the network.

Figure 1-6   Functional Elements in ATM Data Processing and Transport
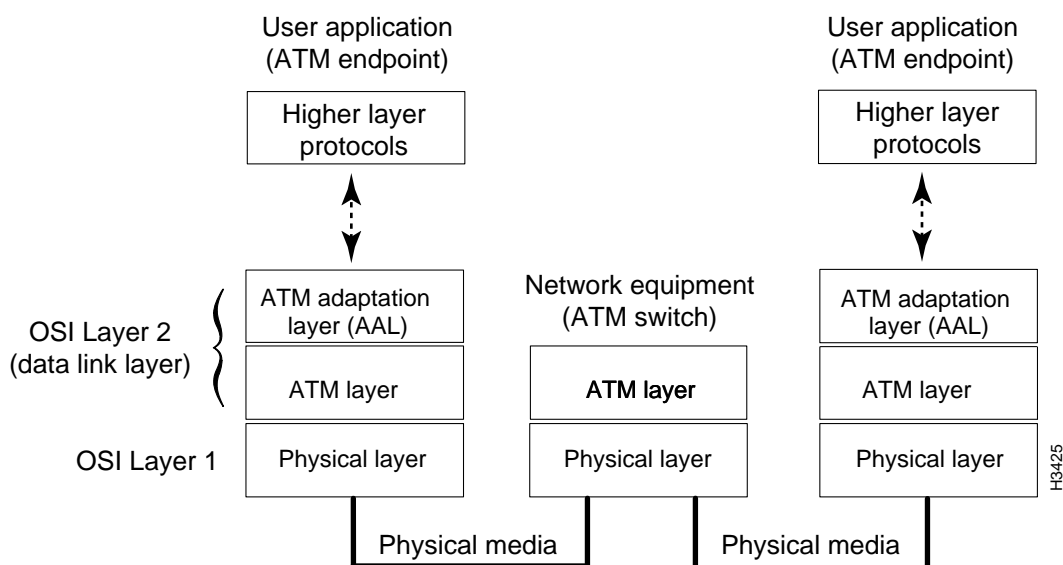
Subsequent sections describe the types of traffic handled by ATM networks and the specific attributes that distinguish one traffic type from another. Finally, the functions and interactions of the active ATM elements depicted in Figure 1-6 are described in detail.

Network Traffic Classes Defined

During the early development phase of Broadband Integrated Services Digital Network (BISDN) technology, several traffic classes were defined that permit networks to carry multiple traffic types for high-bandwidth applications such as data, voice, and video.

BISDN refers to a set of standards under development by the ITU-T for services based on ATM switching and Synchronous Optical Network (SONET) transmission. SONET is an ATM UNI specification and an American National Standards Institute (ANSI) standard (T1.105-1988) for optical transmission at hierarchical rates ranging from 51.84 Mbps to 2.5 Gbps and greater.

The following traffic classes for BISDN networks are supportable by ATM:

- Class A—Used in ATM adaptation layer 1 (AAL1)

- Class B—Used in ATM adaptation layer 2 (AAL2)

- Class C—Used in ATM adaptation layer 3/4 (AAL3/4)

- Class D—Used in ATM adaptation layer 5 (AAL5)

The ATM adaptation layers associated with the four traffic classes listed above provide required services to the higher layer protocols and user applications. Five different, service-specific AAL categories have been defined (specifically, AAL1 through AAL5) to handle one or more of the four BISDN traffic classes supportable by ATM networks.

The operation of each AAL varies according to the type of traffic that the AAL is optimized to handle. In other words, each traffic class imposes certain data processing and handling requirements on the AAL.

However, there is no stipulation in ATM standards that prevents an AAL designed to service one traffic class from being used to service another class. For example, it is common for AAL5 to handle Class B traffic and for AAL1 to handle Class C traffic.

Attributes of Traffic Classes

Traffic classes are categorized according to the following attributes:

- **Timing relationships between communicating entities**—Certain ATM traffic requires a clear timing relationship between the communicating entities.

  For example, in a 64-Kbps pulse code modulation (PCM) voice transmission, a clear timing relationship exists between the source of the traffic and its intended destination(s). Such transmission services occur instantaneously (in "real time"). In contrast, the mere transfer of data files between two network hosts requires no specific timing relationship.

- **Bit rate**—Some traffic service classes exhibit a constant bit rate. Other service classes exhibit a variable bit rate.

  In either case, the bit rate imposes specific processing requirements on the AAL.

- **Connection mode**—Service classes are either connection-oriented or connectionless.

Given these traffic attributes, the ITU-T has categorized network traffic classes and AAL types as outlined in Table 1-3.

Although Table 1-3 describes all four traffic classes, discussions in later sections focus particularly on ATM traffic processing in AAL1 and AAL5, since these two AALs are most pertinent to ATM technology as presently implemented for the LS2020 switch.

Table 1-3   **Traffic Classes Supported by ATM Adaptation Layer**

Traffic Class	Timing Relationship	Connection Mode	Bit Rate	Traffic Description
Class A (AAL1)	Synchronous	Connection-oriented	Constant	This type of traffic typically consists of constant bit rate (CBR) analog signals. Hence, synchronous timing relationships exist between the senders and receivers of such traffic. This type of traffic over an ATM network is often referred to as circuit emulation service, an example of which is fixed bit rate, uncompressed voice or video data.
Class B (AAL2)	Synchronous	Connection-oriented	Variable	As with Class A traffic, synchronous timing relationships exist between the senders and receivers of Class B traffic. However, Class B relates to variable bit rate (VBR) traffic, typical examples of which are compressed voice and video traffic. Such traffic is typically "bursty" in nature.
Class C (AAL3/4)	Asynchronous	Connection-oriented	Variable	In this class, no timing relationships exist between the senders and receivers of data. Hence, such traffic is asynchronous. This class handles VBR, connection-oriented traffic, such as that found in TCP/IP, IPX, X.25, and Frame Relay applications. This class provides point-to-point or point-to-multipoint ATM cell relay services over connections established "on the fly" through signaling and routing messages exchanged between data senders and receivers. This service handles multiple traffic types (data, voice, and video) in which user data is arranged into ATM cells for efficient transport through the network. This type of traffic is sensitive to cell loss, but not to cell transport delay (or latency). Latency is the delay between the time a device receives a cell on its input port and the time the cell is forwarded through its output port.
Class D (AAL5)	Asynchronous	Connectionless	Variable	This class handles VBR traffic in a connectionless, asynchronous manner. An example of this traffic class is switched multimegabit data services (SMDS), which is a high-speed, packet-switched networking service typically offered by telephone companies. In this class, packets or frames contain sufficient addressing information for delivery to destinations without first establishing a connection between data senders and receivers.

Functions of ATM Adaptation Layer

The ATM adaptation layer (AAL) segments upper-layer user information into ATM cells at the transmitting end of a virtual connection and reassembles the cells into a user-compatible format at the receiving end of the connection. Thus, these complimentary functions occur between communicating peers in the network at the same level of the ATM architectural model.

The AAL can be regarded as the single most important element of the ATM architecture. It is the AAL that provides the versatility to handle different types of traffic, ranging from the continuous voice traffic generated by video conferencing applications to the highly bursty messages typically generated by LANs—and to do so with the same data format, namely the ATM cell.

Note, however, that the AAL is not a network process. Rather, AAL functions are performed by the user's network terminating equipment on the user side of the UNI. Consequently, the AAL frees the network from concerns about different traffic types.

How AAL processes are carried out depends on the type of traffic to be transmitted. Different types of AALs handle different types of traffic, but all traffic is ultimately packaged by the AAL into 48-byte segments for placement into ATM cell payloads.

Consequently, several different AALs have been defined for services such as data transport, voice propagation, video conferencing, etc., as described in Table 1-3. The AAL is concerned with the end-to-end processes used by the communicating peers in the network to insert and remove data from the ATM layer.

The ATM layer is designed to make ATM networks more reliable, flexible, and user-friendly than other types of networks; it is the AAL that provides the ability to support many different traffic types and user applications. Also, the AAL isolates higher layer protocols and user applications from the intricacies of ATM.

The AAL performs two main functions in service-specific sublayers of the AAL (see Figure 1-3):

- A convergence function in the convergence sublayer (CS)

- A cell segmentation and reassembly function in the segmentation and reassembly (SAR) sublayer.

The purpose of these two sublayers is to convert user data into 48-byte cell payloads while maintaining the integrity and identity of user data. These AAL sublayers are described briefly below:

- **Convergence sublayer (CS)**—The CS provides appropriate traffic services to higher layer protocols.

  Once a connection is established between communicating ATM entities with an appropriate quality of service (QoS), the CS accepts higher layer traffic for transmission through the network. Depending on the traffic type, certain header and/or trailer fields are added to the user data payload and formed into information packets called convergence sublayer protocol data units (CS-PDUs).

  A protocol data unit (PDU) is a packet of data consisting of control information and user information that is to be exchanged between communicating peers in an ATM network. These packets, illustrated in Figure 1-7, are passed to the segmentation and reassembly sublayer (SAR) of the AAL for further processing.

  In general, a PDU is a segment of data generated by a specific layer of a protocol stack, usually containing information from the next higher layer, encapsulated together with header and trailer information generated by the layer in question (which, for purposes of this discussion, is the AAL).

Figure 1-7   Data Processing in ATM Adaptation Layer
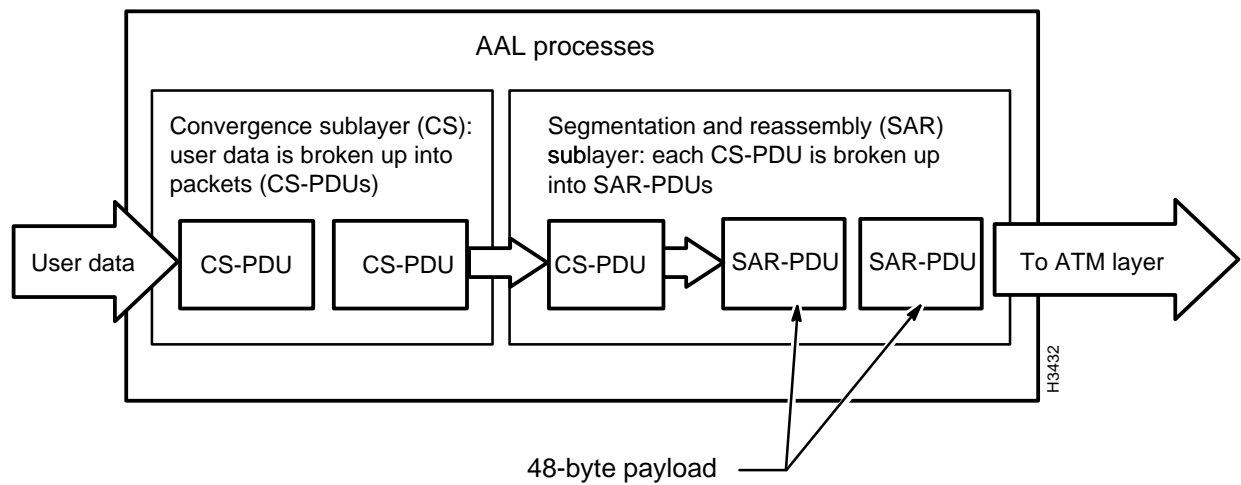
48-byte payload

- **Segmentation and reassembly (SAR) sublayer** —The SAR segments each CS-PDU received from the CS into smaller units and adds a header and/or trailer field, depending on the traffic type, to form 48-byte payloads called segmentation and reassembly sublayer protocol data units (SAR-PDUs).

The generalized processes through which the user data stream is transformed into appropriate ATM data units are illustrated in Figure 1-8.

Once the user data is arranged into SAR-PDUs by the AAL layer, they are passed to the ATM layer, which packages the data into 53-byte ATM cells, making them suitable for transport as out-going ATM cells by the physical layer, as indicated in Figure 1-9.

Thus, the ATM layer serves effectively as an interface between the AAL and the physical layer. The ATM layer is described in detail in a later section entitled "Functions of ATM Layer."

Conversely, upon receipt of incoming ATM cells from the physical layer (that is, cells delivered from a peer physical layer elsewhere in the network), the AAL removes any AAL-specific information from each cell payload and reassembles the packet for presentation to higher layer protocols in a form expected by the user application.

When an ATM cell is transported through the network, it is processed in isolation from all other cells, and all routing decisions for the cell are based on information carried within its header. Note also that no processing of any kind occurs with respect to an ATM cell payload proper, thereby ensuring the integrity of user data.

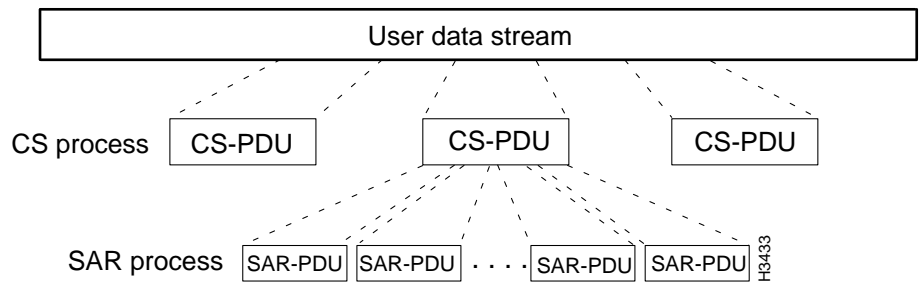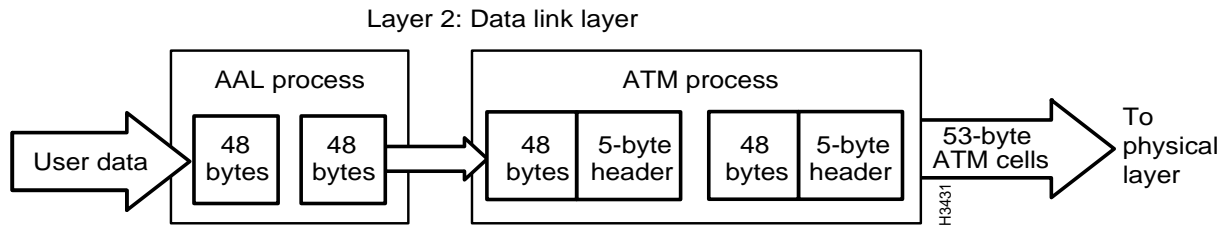**Figure 1-8   Data Processing Relationships in ATM Adaptation Layer**

Figure 1-9   Arranging ATM Data for Transport by Physical Layer

Layer 2: Data link layer

Simplified Example of AAL Data Processing in ATM Network

Figure 1-10 shows an example of ATM network topology and the instances in which AAL data processing is or is not performed by a particular node in the network.

Hosts A and C are connected directly to the network by means of DS3 and OC3 ATM trunk interfaces, respectively. Hence, these interfaces perform all AAL processing functions internally for hosts A and C; the network performs no AAL processing functions for these particular hosts.

In contrast, hosts B and D are connected to native Ethernet interfaces on nodes 1 and 2, respectively. Therefore, node 1 performs all AAL processing functions for host B; similarly, node 2 performs all AAL processing functions for host D. However, given the network topology shown, Node 3 is not required to perform any AAL processing functions whatever.

Figure 1-10   Example of AAL Data Processing in ATM Network
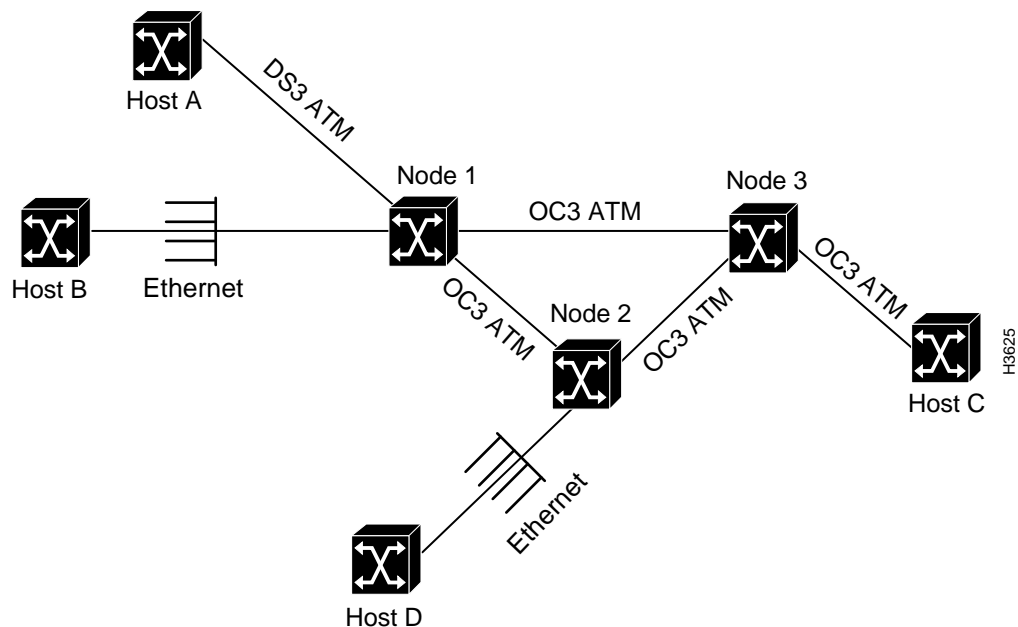
AAL1 Traffic Processing

AAL1 is designed to process Class A, constant bit rate (CBR) traffic from a higher layer application or protocol and to deliver that traffic to its destination at the same rate and at equal intervals. A prime example of this type of service is a connection that supports voice traffic or telephony circuits.

In this type of service, misordering of cells is considered more problematical than losing cells. Hence, a 3-bit sequence number (SN) is added when forming the basic unit of information transfer (the SAR-PDU) for AAL1 processing (see Figure 1-11). The sequence number embodied therein assists in detecting and correcting lost or misinserted cells.

In AAL1 traffic processing, user data is transferred between communicating peers at a constant bit rate after an appropriate connection has been established. AAL1 traffic services include the following:

- Transferring service data units (SDUs) with a constant source bit rate to their destination at the same bit rate

- Transferring timing information between the source and destination endpoints

- Transferring data structure information

- Indicating lost information or information containing errors that cannot be recovered by AAL processes

AAL1 Convergence Sublayer (CS) Functions

The functions of the CS sublayer depend on the particular AAL1 traffic services required and may involve some combination of the following:

- Handling cell delay variation (CDV)

- Handling cell payload assembly delay

- Source clock recovery at the receiver

- Source data recovery at the receiver

- Monitoring of lost and misinserted cells and possible corrective actions

- Monitoring of the AAL protocol for bit errors and possible corrective actions

- Monitoring of the user information field (payload) for bit errors and possible corrective actions

- Reporting the performance status of the end-to-end connection

AAL1 Segmentation and Reassembly (SAR) Sublayer Functions

In processing AAL1 data at the source, the SAR sublayer receives the 3-bit sequence number (SN) from the CS that has been inserted into the segmentation and reassembly protocol data unit (SAR-PDU) header (see Figure 1-11). At the receiving end of the connection, the SN is passed to the communicating peer CS to detect the loss or misinsertion of cell payloads during transmission.

Also, the SAR sublayer accepts a 47-byte block of data from the CS and adds a 1-byte SAR-PDU header to form a 48-byte payload. At the destination end of the connection, the peer SAR sublayer accepts the 48-byte payload from the ATM layer, strips off the 1-byte SAR-PDU header, and passes the remaining 47 bytes of data to the CS.

Figure 1-11 shows the data format for processing AAL1 traffic.

Figure 1-11   SAR-PDU Data Format for AAL1 Processing
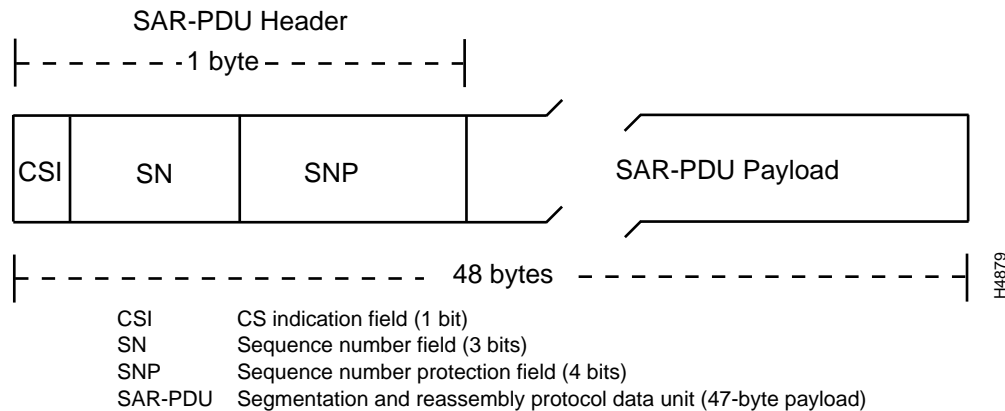
The SAR sublayer also has the optional capability to indicate the existence of the CS sublayer. The SAR receives this indication through a 1-bit field called the CS indicator (CSI) carried in the SAR-PDU header (see Figure 1-11). This CSI field is conveyed to the peer CS at the other end of the virtual connection.

Both the SN and CSI fields are protected against bit errors through a 4-bit sequence number protection (SNP) field also carried in the SAR-PDU header. This field enables both single-bit and multiple-bit error detection to be performed. If the SN and the CSI fields are corrupted and cannot be corrected, the peer CS is so informed.

AAL5 Traffic Processing

AAL5 has been designed to process traffic typical of today's LANs. Originally, AAL3/4 was designed to process this kind of traffic. However, the inefficiency of AAL3/4 for handling LAN traffic led to the use of AAL5 for such traffic.

AAL5 provides a streamlined data transport service that functions with less overhead and affords better error detection and correction capabilities than AAL3/4. AAL5 is typically associated with variable bit rate (VBR) traffic and the emerging available bit rate (ABR) traffic type.

Another AAL5 attribute contributing to its efficiency is the use of the payload type indicator (PTI) field in the ATM cell header (see Figure 1-5) to indicate that the cell is supporting AAL5 traffic, rather than using space in the cell payload to so indicate. Also, AAL5 calculates a 32-bit cyclic redundancy check (CRC) over the entire AAL5 protocol data unit in order to detect cell loss and the misordering or misinsertion of cells.

AAL5 Convergence Sublayer (CS) Functions

For purposes of AAL5 traffic processing, the CS is divided into two parts:

- **Common part convergence sublayer (CPCS)**—This part of the CS provides the capability to transfer the common part convergence sublayer protocol data units (the CPCS-PDU payloads) from one AAL5 user to another AAL5 peer in the network. The AAL5 traffic type supports both a message-mode service and a streaming mode service.

  In message-mode service (see Figure 1-12), the service data unit (SDU) is passed across the AAL5 interface as an interface data unit (IDU), corresponding exactly to one protocol data unit (PDU). In other words, a one-for-one correspondence exists between the user data packets conveyed across the AAL5 interface for transmission to an AAL5 peer in the network. The message-mode service provides for transport of either fixed-size or variable-length data units.

In streaming-mode service (see Figure 1-13), the SDU is passed across the AAL5 interface in one or more IDUs. The transfer of these IDUs across the interface may occur separated in time. In other words, the streaming-mode service can "pipeline" the SDUs, meaning that it can initiate the transfer of information to an AAL 5 peer before the entire SDU is completely available for transmission. In effect, all the IDUs belonging to a single SDU are transferred over the network as one or more AAL5 PDU payloads.

- **Service-specific convergence sublayer (SSCS)**— Different SSCS protocols can be defined to support specific AAL user services or groups of services. The SSCS may also be null in the sense that it provides only for the mapping of equivalent AAL primitives to the CPCS, and vice versa.

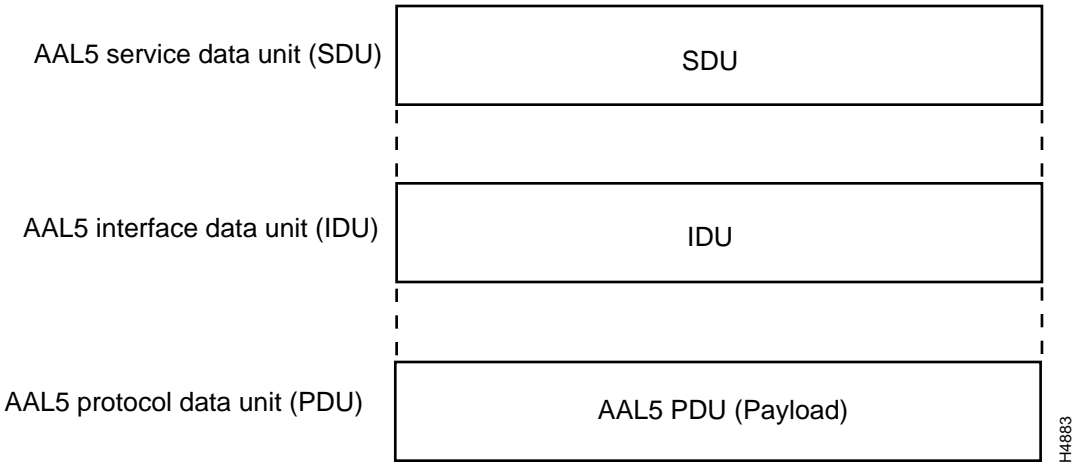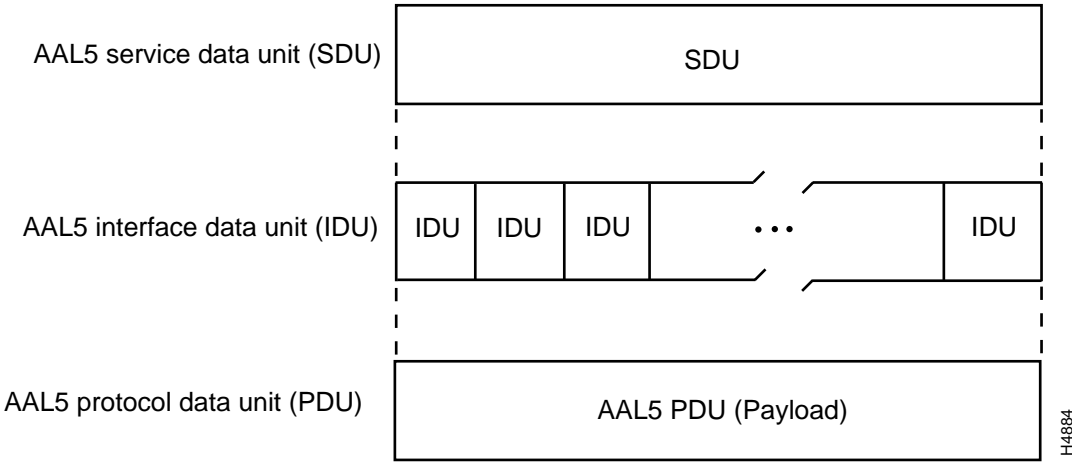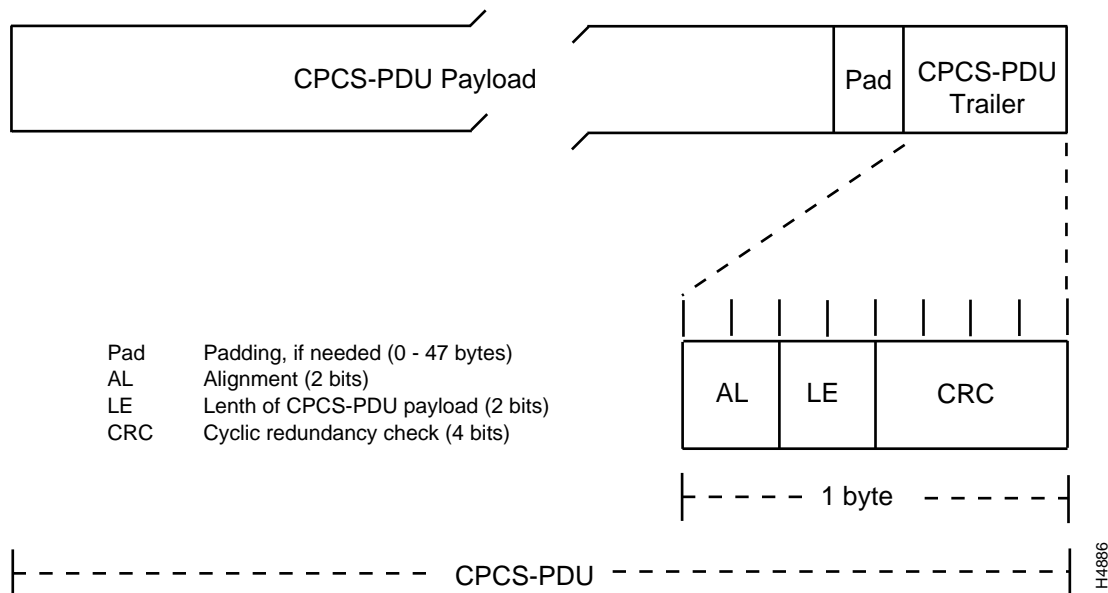**Figure 1-12   AAL5 Message-Mode Transport Service**

Figure 1-13   AAL5 Streaming-Mode Transport Service

AAL5 Segmentation and Reassembly (SAR) Sublayer Functions

The basic unit of information transfer for AAL5 processing is the common part convergence sub-layer protocol data unit (CPCS-PDU). AAL5 enables the transport of variable-length CPCS-PDUs that contain from 1 to 65,535 bytes between communicating peers in an ATM network. The format of these variable-length frames is shown in Figure 1-14.

Figure 1-14   CPCS-PDU Data Format for AAL5 Processing

Pad	Padding, if needed (0 - 47 bytes)
AL	Alignment (2 bits)
LE	Lenth of CPCS-PDU payload (2 bits)
CRC	Cyclic redundancy check (4 bits)

If needed, the CPCS-PDU payload is padded to align the resulting frame with an integral number of ATM cells. The padding field is used strictly for filler purposes and does not convey any useful information.

During AAL5 processing, the CPCS-PDU trailer is appended to the payload to perform the following functions:

- **Alignment (AL) field**—Used to transfer user-to-user information between CPCS peers in the network.

- **Length (LE) field**—Used to encode the length of the CPCS-PDU payload field.

- **Cyclic redundancy check (CRC) field**—Used to detect errors in the CPCS-PDU payload.

Functions of ATM Layer

The ATM layer is concerned with data transmission between two adjacent nodes—nodes that usually are not ATM endpoints. Thus, the ATM layer operates on a link-by-link basis, rather than on an end-to-end connection basis, and cell addressing is of local significance only between adjacent nodes. Also, the ATM layer provides for the basic 53-byte ATM cell format and defines the contents of the ATM cell header.

The ATM layer performs two primary functions:

- Passing outgoing ATM cells from the AAL to the physical layer for subsequent transport through the network to a destination ATM endpoint

- Passing incoming ATM cells from the physical layer to the AAL upon receipt of cells from an ATM source endpoint

The ATM layer performs cell multiplexing, cell header generation and removal, and VPI/VCI translation. Although ATM layer operations are relatively uniform across the network, such operations depend on whether the ATM layer is inside an ATM endpoint or inside an ATM switch. In other words, the ATM layer operates differently in network endpoints and ATM switches.

For example, the ATM layer must generate and remove ATM cell headers in a network endstation (a source or destination endpoint). In a network switching device, however, the ATM layer must simultaneously multiplex/demultiplex ATM cells belonging to several different connections. Additionally, it must translate the VPI/VCI values in the header of each received cell to determine where each cell should be sent next (that is, it must determine the next transmission link in the network). In so doing, it communicates with the peer ATM layer of other switching devices through the VPI/VCI mechanisms provided in each cell's 5-byte header.

In an ATM source endpoint, the ATM layer exchanges a cell stream with the physical layer, inserting idle cells if no higher layer information is waiting to be transmitted, or inserting empty cells if such cells are needed to comply with established quality of service (QoS) parameters. Upon receiving cells from the physical layer, the 48-byte cell payload is passed to the AAL, along with other parameters, such as the payload type indicator (PTI) value or the cell loss priority (CLP) value (see Figure 1-5).

Upon receipt of an ATM cell at a port of an ATM switch, the ATM layer determines from the cell's VPI/VCI values the port to which the cell should be relayed and changes the VPI/VCI values accordingly to this new (outgoing) port. The ATM layer then forwards the cell to the new port, changes the VPI/VCI values to indicate the next link in the transmission path, and then passes the cell down to the physical layer of the outgoing port for transmission to that link.

The ATM layer may also set a bit in the PTI field if traffic congestion is experienced; it may also change the CLP field when enforcing appropriate traffic shaping and policing algorithms, such as the leaky bucket algorithm described in the chapter entitled "Traffic Management" and illustrated in Figure 4-3.

In an ATM switch, the ATM layer also ensures that cells from the same virtual connection are not misordered and that system requirements, such as maximum end-to-end latencies, are met. The ATM layer must also provide adequate buffering and congestion control mechanisms for ATM traffic.

Figure 1-15 illustrates the processes performed by the ATM layer for outbound ATM cells. The ATM layer accepts the 48-byte SAR-PDUs from the segmentation and reassembly (SAR) sublayer of the AAL, builds a 5-byte header for each SAR-PDU, and produces 53-byte ATM cells for delivery to the physical layer for transport to an ATM destination endpoint.

Figure 1-15   ATM Layer Data Handling Processes
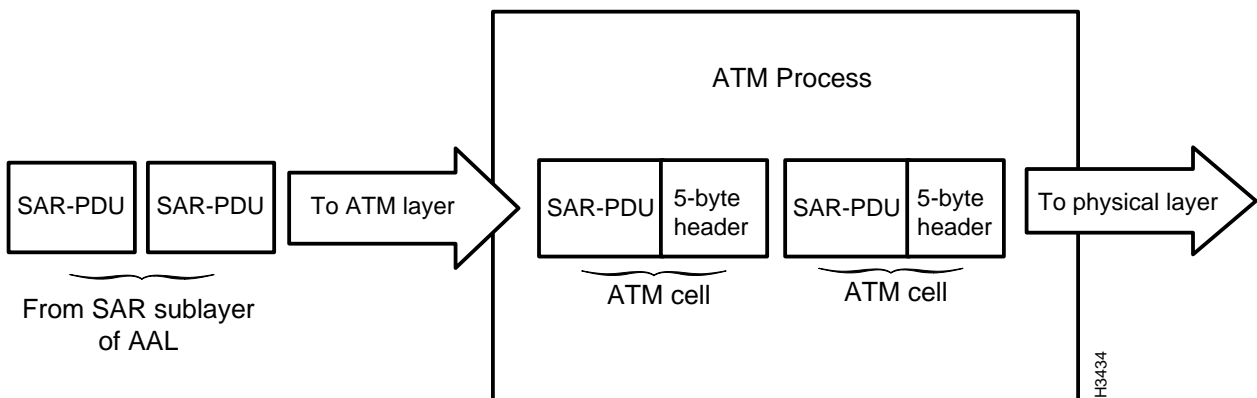
Functions of Physical Layer

After user data is conveyed to the physical layer from the ATM layer, the next step is to place the cells onto a physical transport medium, such as fiber optic cable (for long distance transmission) or coaxial cable (for local transmission). The processes that accomplish this important function occur in two sublayers of the physical layer: the transmission convergence (TC) sublayer, and the physical medium dependent (PMD) sublayer. These sublayers are described in the section below entitled "Physical Layer Elements."

For transport of ATM cells through a network, the cells require an interface to one of the existing physical layers defined in current ATM networking protocols. Accordingly, the physical layer provides the ATM layer with access to the network's physical data transmission medium, and the physical layer proper transports ATM cells between peer entities in the network that support the same transmission medium.

However, since ATM technology does not necessarily depend on any particular physical medium for data transport, ATM networks can be designed and built using a variety of physical device interfaces and media types, the most prominent of which is the fiber-based transmission medium defined by the Synchronous Optical Network (SONET) standard.

SONET - A High-Speed, Fiber-Based Transmission Medium

SONET, a high-speed synchronous network specification developed by Bellcore and approved as an international standard in 1988, defined a fiber-based optical medium that has come into widespread use for data transport in BISDN networks. This standard established a set of data rate and framing standards for data transmission using optical signals over fiber-optic cables.

The SONET data rate and framing standards are designated as Synchronous Transport Signal (STS-n) levels; the related SONET optical signal standards are designated as Optical Carrier (OC-n) levels.

For the STS level, "n" represents the level at which the respective data rate is exactly "n" times the first level. For example, STS-1 has a defined data rate of 51.84 Mbps; therefore, STS-3 is three times the data rate of STS-1, or 3 x 51.84 = 155.52 Mbps. Similarly, STS-12 is 12 x 51.84 = 622.08 Mbps, and so on.

Corresponding to each data rate and framing standard is an equivalent optical fiber standard. For example, the OC-1 fiber standard corresponds to STS-1, OC-3 corresponds to STS-3, and so on. The OC-n standard defines such items as fiber types and optical power levels.

Higher data rates in an ATM network can be achieved in a number of ways. STS-12, for example, can be implemented as 12 multiplexed STS-1 circuits, as four multiplexed STS-3 circuits, or as one single STS-12 circuit. If the STS level is being implemented as a single circuit, it is called a concatenated (or clear) channel connection and is so indicated with a "c" appended to the level designator (as in STS-3c, OC-3c, or STS-12c).

Carrying ATM cells as SONET frames enables both LAN and WAN networks to use the same data rates and framing standards, thereby ensuring easier integration of and internetworking between geographically disparate LAN and WAN domains which, historically, have been implemented with different transmission rates.

LANs typically interconnect workstations, peripherals, terminals, and other devices in a single building or a relatively small geographic locale. LAN standards specify the cabling and signaling requirements at the physical and data link layer of the OSI reference model, embracing such communications technologies as FDDI, Ethernet, and Token Ring.

WANs typically serve users over a much broader geographic area than LANs and often use data transmission devices and services provided by common carriers, embracing such communications technologies as Frame Relay, SMDS, and X.25.

Physical Layer Interfaces

Due to the layered architecture of the BISDN protocol stack, ATM is totally media independent. Many physical layer types can be implemented to serve a variety of data rate and physical interconnection requirements. Table 1-4 shows the specifications for the asynchronous digital hierachy of physical interfaces, while Table 1-5 shows the specifications for the SONET STS-*n* Synchronous Transport Signal hierarchy.

Table 1-4 **Asynchronous Physical Interfaces**

Signal Type	Bit Rate	Description
DS0	64 Kbps	One voice channel
DS1	1.544 Mbps	24 DS0s
DS1C[1]	3.152 Mbps	2 DS1s
DS2	6.312 Mbps	4 DS1s
DS3	44.736 Mbps	28 DS1s

[1]The "C" in DS1C does not imply concatenation, as does the "c" in STS-3c.

Table 1-5 **Synchronous (SONET) Physical Interfaces**

Signal Type	Bit Rate	Description
STS-1/OC-1	51.84 Mbps	28 DS1s or one DS3
STS-3/OC-3	155.52 Mbps	3 STS-1s byte interlaced
STS-3c/OC-3c	155.52 Mbps	Concatenated, indivisible payload
STS-12/OC-12	622.08 Mbps	12 STS-1s, 4 STS-3cs, or any mixture
STS-12c/OC-12c	622.08 Mbps	Concatenated, indivisible payload
STS-48/OC-48	2488.32Mbps	48 STS-1s, 16 STS-3cs, or any mixture

Physical Layer Elements

Interfacing ATM traffic to a wide range of physical transmission media occurs by means of two function-specific sublayers in the physical layer: the transmission convergence (TC) sublayer, and the physical medium-dependent (PMD) sublayer (see Figure 1-3). The functions of these two sublayers are described briefly below.

- **TC sublayer**—This sublayer performs a convergence function by transforming a flow of ATM cells into a flow of information (bits) that can be transmitted or received over the network's physical medium. The following TC functions are common to all the physical layers in an ATM network:

  — Transmission frame generation and recovery—This process, which adds protocol information to ATM cells, generates and recovers transmission frames.

  — Transmission frame adaptation—This process performs the actions necessary to structure the cell flow according to the payload structure of the transmission frame (in the transmit direction) and to extract this cell flow from the transmission frame (in the receive direction).

  — Cell delineation—This process prepares the cell flow in such a way that the receiving entity in the network can determine (recover) the boundaries of transmitted ATM cells.

The TC sublayer determines where each cell starts and ends by calculating a header error control (HEC) value for every received cell and checking this value against what it expects as the cell's HEC value.

The HEC mechanism parses the first five bytes of the cell on the fly until a 5-byte boundary is found. Once found, the rest of the cell boundary is established by counting 48 additional bytes (for the cell payload). This process takes into account the entire cell header, which is available to the TC sublayer by the time the cell is passed to it from the ATM layer.

— Header error control (HEC) sequence generation and cell header verification— The correction code used for this function is capable of either single-bit or multiple-bit error correction. The transmitting side of the virtual connection computes the HEC field value.

— Cell rate decoupling—This process adapts the speed of the ATM layer cell stream to the actual cell rate of the physical interface and includes the insertion or suppression of idle cells to adapt the rate of valid ATM cells to the payload capacity of the transmission system.

— Various operation, administration, and maintenance (OAM) functions—The ATM Forum defined a specification for special cells that are used in an ATM network to monitor virtual circuits. These cells are called OAM cells.

Various operational and maintenance procedures in a network often require the exchange of specific information among nodes in a network by means of these OAM cells. Such cells flowing through an ATM network are identified by the payload type indicator (PTI) field in the ATM cell header (see Figure 1-5 and Table 1-2).

OAM cells contain bit-oriented, overhead management information pertaining to peer-to-peer physical layers and ATM layer termination points in the network. Note, however, that such cells do not form part of the user information stream transferred to or from higher layer protocols or user applications.

Generically, the term OAM refers to preventive maintenance principles and functions recommended by the ITU-T for BISDN networks, such as network supervision, testing, and performance monitoring.

- **PMD sublayer**—This sublayer is responsible for the actual transmission of data between communicating peers in an ATM network. Thus, PMD functions depend on the physical medium being used for data transport.

The PMD is concerned only with physical, medium-dependent functions and specifications, such as the following:

— Line coding, bit alignment, and electrical-optical conversion—These functions relate to the processes through which bits are encoded into appropriate electrical or optical signals and prepared for propagation through the network.

— Physical media characteristics—The PMD sublayer specifies the characteristics of the physical transport medium, such as the type of optical fiber, the transmitter/receiver wavelength, the receiver sensitivity, and power budget parameters (for signal attenuation and dispersion).

The optical connector type and its performance characteristics are also specified in the PMD sublayer.

LS2020 ATM Internal Routing Mechanisms

Internal routing is a mechanism that provides a path for setting up ATM virtual channel connections (VCCs) in an LS2020 network. Routing is an essential function in setting up any of the following types of connections in an LS2020 network:

- ATM UNI permanent virtual connections (PVCs)

- Frame Relay/Frame Forwarding PVCs

- Circuit emulation PVCs

- Ethernet/FDDI LAN switched virtual connections (SVCs)

The LS2020 internal routing architecture is shown in Figure 1-16. The major elements of this architecture are described in the following sections.

Figure 1-16   LS2020 Routing Architecture


```
= Internal routing module
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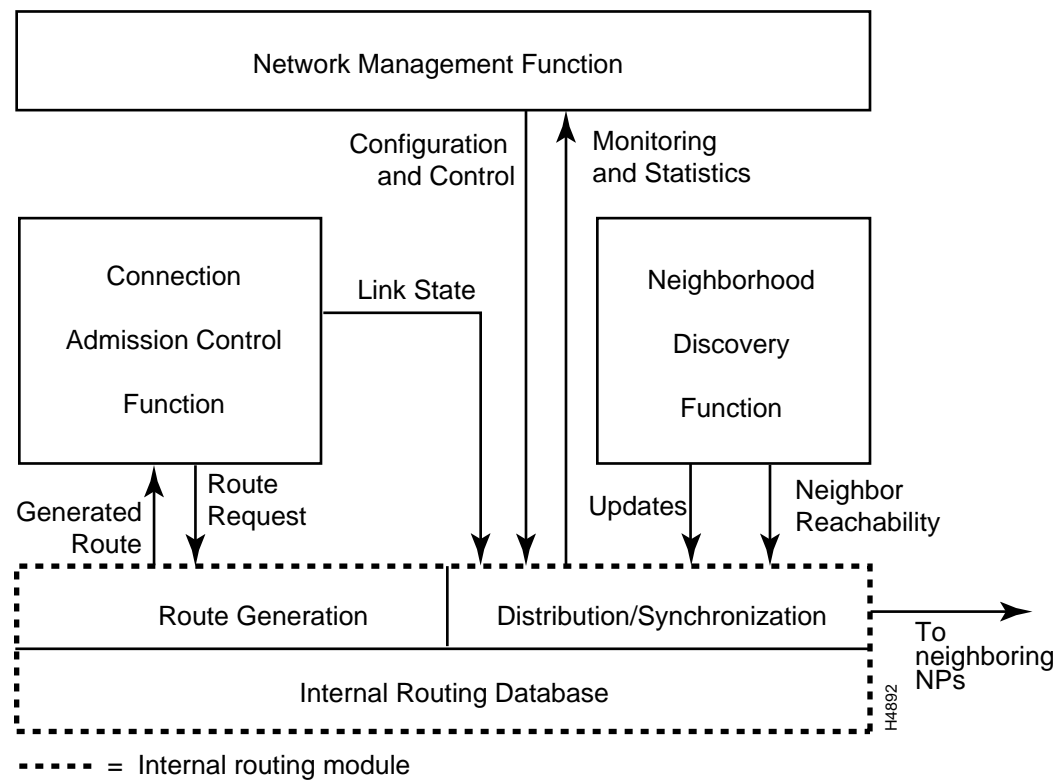
The functions that provide a route for ATM VCCs in an LS2020 network are described briefly below:

- **Neighborhood discovery function**—Provides the means for "discovering" all neighboring nodes in the network, enabling them to be accounted for in the internal routing database. The neighborhood discovery function is used by the internal routing distribution function.

  The neighborhood discovery process runs on every network processor (NP) in an LS2020 network. This process performs three primary tasks:

  — Continuously gathers information about network topology.

  — Keeps track of the interface modules added to or removed from service, in either planned or unplanned ways. Whenever you add a new interface module, the neighborhood discovery function automatically starts up an appropriate process on the NP. Whenever you remove an interface module, the neighborhood discovery process terminates the associated process on the NP.

  — Determines which NP controls each interface module.

  Whenever you add or remove a local resource, the neighborhood discovery process informs the global information distribution (GID) system, which floods information about the change from NP module to NP module throughout the network. The neighborhood discovery process also keeps the local GID process informed about who its neighbors are so it can flood information properly through the network.

  The neighborhood discovery function simplifies the network configuration process and eliminates the need to manually configure some of the attributes of interface modules in each LS2020 switch, as well as the connections to other switches in the network.

- **Connection admission control (CAC) function**—Uses the route generation function of the internal routing module to provide a directed set of links from a source node to a destination node over which a VCC is to be established. It also provides the means to make link state and bandwidth allocation information available to the internal routing distribution function.

  The connection admission control function is described in greater detail in the "Traffic Management" chapter (see the section entitled "Connection Admission Control").

- **Network management function**—Provides SNMP-based configuration and control services, as well as monitoring and statistics services, to the various LS2020 internal routing functions.

- **Internal routing module**—Incorporated into each LS2020 switch, this module contains the following elements:

  — An internal routing database (see the section below entitled "Internal Routing Database").

  — A distribution/synchronization function for updating and maintaining the internal routing database. This function is called the global information distribution (GID) service (see the section below entitled "Global Routing Information Distribution").

  — A route generation function (see the section below entitled "Route Generation Process").

These three elements of the internal routing module are described in separate sections below.

Internal Routing Database

To enable PVCs and SVCs to be set up between any two endpoints in an LS2020 network, an internal routing database must first be established in all the LS2020 switches in the network.

This database is established primarily at network configuration time by downloading configuration information to each LS2020 switch in the network. The database is then kept up to date by an internal routing module (see Figure 1-16) as LS2020 switches are added to or deleted from the network, or as the cards in the LS2020 chassis are changed, or as individual port assignments are changed.

Software processes in the internal routing module are invoked at frequent intervals to update the routing database with state information describing every link in the network.

The routing database is replicated in the network processor (NP) of every LS2020 switch in the network. Also, the database is synchronized with all other switches, providing the means for a routing algorithm to determine a routing path at any time for a connection between any two ATM endpoints.

To enable connection set-up, the routing algorithm requires that a background mechanism be functional in every LS2020 switch through which the status of each switch can be made known to every other switch in the network. Using information maintained in the routing database, the routing algorithm can then calculate the best route for setting up a connection.

For LAN SVCs, the routing mechanism is invoked dynamically as traffic flows and ebbs in the LAN. When a LAN network device receives a message intended for a destination for which a connection does not already exist, the device asks for a route to set up an SVC for message delivery.

Regardless of virtual connection type (PVC or SVC), the same LS2020 internal routing mechanisms keep track of network topology, as well as the variables representing the operational state of each LS2020 switch and the amount of bandwidth currently allocated to each network link.

Using such information, the routing algorithm calculates the minimum distance routing path through the network that provides the required bandwidth and sets up the connection. Also, the algorithm has the capability to use alternative metrics to determine the "least cost" route for setting up a virtual connection.

Port Entries

Each physical trunk link is represented in the internal routing database by two port entries, one for each direction of the VCC. The port entry is "owned" and "advertised" by the NP at the transmitting end of the VCC. At the receiving end of the VCC, an edge port is represented by a single entry that describes the VCC between the LS2020 switch and the user's external equipment or media.

Port Entry Elements

The principal elements of each port entry are described briefly below:

- **Link status variable**—Two link status variables are defined: one for control VCCs, and one for data VCCs. In each case, the variable represents the operational state of the link—either *up* or *down*. A VCC cannot be routed over a down link.

- **Local address**—The address of the port "owning" the link. This address contains the local chassis number, the slot number, and the port number.

- **Raw bandwidth**—The physical bandwidth rate of the link, expressed in cells per second. This value takes into account all physical layer overhead for ATM cell framing purposes. For example, the raw bandwidth of an OC-3c link is 353,208 cells per second.

- **Control and data bandwidth**—A virtual pool exists for both control and data bandwidth from which bandwidth over the link is allocated. These bandwidth variables are expressed in cells per second and represent the remaining unallocated bandwidth in the virtual pool.

- **Link value**—This value, representing the minimum hop count, is used to determine the "least cost" route.

Global Routing Information Distribution

The LS2020 mechanisms for collecting routing information, distributing updates, and synchronizing databases are separate from those that provide route generation functions (see the section below entitled "Route Generation Process").

A function called global information distribution (GID) services maintains a consistent network-wide database for tracking overall network topology and the state of LS2020 nodes and links in the network. The GID process runs on every NP in an LS2020 network, maintaining an internal database that keeps nodes in the network apprised of the following types of changes in network topology:

- Ports, cards, and nodes being added to or removed from the network

- Trunks going up or down

All LS2020 switches in the network contribute to the GID database, and all switches extract information from the database. The GID function ensures that every LS2020 switch contains an up-to-date copy of the GID database.

All the NPs in the network use a flooding algorithm to distribute the global routing information to neighboring NPs. An OSPF-like flooding protocol is used to frequently advertise new link state information to the rest of the network. Flooding, however, can occur only between NPs that have established a neighbor relationship and, therefore, a communication path between them. These relationships and communication paths are established, maintained, and removed by the neighborhood discovery function described in conjunction with Figure 1-16.

The GID function issues an update whenever a neighboring node contributes new link state information, as described in the next section. The GID function also has mechanisms for quickly initializing a GID database when a new LS2020 switch is added to the network.

Announcement Scheduling

Each LS2020 node issues an announcement (update) describing all the links on a line card, based on the following rules:

1 **Significant change**—Whenever a port changes state or connection admission control is blocked due to lack of bandwidth, an announcement incorporating this change (plus any other changes for the same card) becomes a candidate for immediate distribution through the network.

   A significant change is also defined as any change that is more than 10% of the initial bandwidth allocation (for both control and data purposes) caused by VCC establishment or removal.

   Announcements for significant changes are sent no more frequently than once per second.

2 **Other change**—Whenever a VCC is established or removed without causing a 10% change in allocated bandwidth, an announcement incorporating this change (plus any other changes for the same card) is sent no later than 70 seconds after such a change occurs, or sooner if triggered by rule 1.

3 **No change**—An announcement containing the current link states for all ports on a line card is sent at least every 30 minutes, even if no changes have occurred since the last announcement.

Announcement Distribution

An announcement flooding protocol ensures that announcements reach all nodes by sending each new announcement out on all links except the one on which it was received. The flooding process is terminated when nodes receive an update they have already seen, in which case, the announcement is discarded.

A reliable announcement protocol between two nodes ensures that the receiver has the announcement before the sender discards it.

Route Generation Process

The route ultimately selected through the route generation function (subject to the requirements specified during connection admission control) is basically a minimum hop path with a tie-breaking provision based on maximum residual bandwidth. The input parameters to the route generation function ensure that both the burstiness of the traffic and the quality of service (QoS) requirements of the VCC can be met.

A bandwidth request consists of two elements:

- Primary rate

- Secondary rate

The sum of the primary rate and the secondary rate is the *maximum* rate. To meet burstiness requirements, it is necessary for the raw bandwidth of every link to be at least as large as the maximum rate, since a VCC can generate bursts at the maximum rate. If this requirement is not met, cells are dropped during all but the shortest bursts of traffic.

Primary and secondary scaling factors are applied to all bandwidth requests to determine the allocated bandwidth needed to meet the requested QoS requirements. A formula is used to determine the minimum allocatable bandwidth that needs to be available from all the virtual bandwidth pools along the route. This amount of bandwidth is removed from the pool when the VCC is set up, and the bandwidth is returned to the pool when the VCC is torn down.

In addition to determining a "least cost" path, the routing algorithm must satisfy two overall bandwidth requirements:

1 The raw bandwidth along the route must be sufficient to meet the maximum rate requirement.

2 The virtual bandwidth pools along the route must be sufficient to meet the allocated rate requirement.

Input Parameters

When a connection admission control module requires a route to be generated, it activates the route generation function and provides it with the following parameters:

- **Source and destination addresses**—The internal addresses used to designate the VCC endpoints in the network. Such an address is a unique identifier for any port in the network.

- **Bandwidth type**—Indicates which pool is to be used for allocation, data, or control purposes. Subscriber VCCs can request bandwidth allocation only for data.

- **Service specification**—Consists of two types of bandwidth requests:

  — Desired bandwidth—Represents a bandwidth level that meets the requirements of the VCC. If this requirement cannot be met, the minimum acceptable bandwidth request is used.

  — Minimum acceptable bandwidth—Represents the level at which the connection admission control (CAC) function rejects the request, based on insufficient resources.

Each type of bandwidth request contains a *primary* rate and a *secondary* rate, expressed in cells per second. The primary rate is usually the same for both types of bandwidth requests.

- **Scaling factors**—Scaling factors allow partial allocation of bandwidth for best effort traffic (for both desired and minimum acceptable bandwidth requests). The primary scaling factor is not user configurable and is always "1." The secondary scaling factor is user configurable, typically ranging from 1 to 2 per cent.

- **Minimum link size**—An edge port has a minimum enforceable rate. The minimum link size parameter is set to the minimum enforceable rate for the VCC at the entry edge port, requiring any chosen intermediate link to have an equal or greater raw bandwidth capacity. This is necessary to prevent the possibility of an output port sending data at a greater rate than an intermediate link can handle, yet without the ability of the input edge port to properly police the incoming traffic.

Route Generation Algorithm

The route generation input parameters described in the preceding section are used in conjunction with the link status variable (see the earlier section entitled "Port Entry Elements") to determine a route. If no possible route exists to satisfy the desired bandwidth request, the algorithm is again executed using the minimum acceptable bandwidth request.

Using the minimum acceptable bandwidth request to satisfy the need for a VCC is referred to as "fallback routing." definition

The following rules provide a a functional overview of the LS2020 routing algorithm:

1 If multiple acceptable routes exist during the first pass of the routing algorithm, it chooses the route with the least number of hops.

2 If multiple routes have the same least number of hops, the algorithm selects the route that includes the link with the most residual bandwidth, that is, the link with the largest unallocated virtual pool.

3 If a tie exists between two or more candidate routes after rule 2, the algorithm uses a decision tree based on the uniqueness of all possible routes. The algorithm makes this determination by comparing the slot numbers, chassis numbers, and port numbers until a difference is found and a lower number is chosen. The search starts at the destination port, and alternative candidates are discarded each time potential routes diverge. This process continues until only one route (the winning one) remains.

When the route generation process is completed, the routing algorithm returns the following parameters:

- **Status**— Indicates either success or failure in setting up a VCC.

- **Route**—Indicates whether the route determination function was able to honor the desired bandwidth request, or whether it was forced to use the minimum acceptable bandwidth request in setting up the VCC.

- **Minimum link bandwidth**—Indicates the raw bandwidth of the slowest link in the VCC.

ATM Connection Types

ATM is a connection-oriented, cell relay data transmission technology that requires a connection to be established between two or more entities in the network before data transmission can occur. There are two fundamental types of connections in an ATM network:

- **Point-to-point**—Connects two ATM endpoints. Such connections are bidirectional in function (see Figure 1-17), requiring the set-up of two virtual channel connections (VCCs) to complete the transmission path between communicating peers.

- **Point-to-multipoint**—Connects a single ATM endpoint to multiple destination endpoints (see Figure 1-17). This type of connection has the following properties:

  — One ATM link, called the root link, serves as the root in a simple tree topology. When the root sends information, all the remaining nodes on the connection, called leaf nodes, receive copies of the information.

  — Each of the leaf nodes on the connection can send information directly to the root node. However, the root node cannot distinguish which leaf node is sending the information without additional, higher layer protocol information.

  — The leaf nodes cannot communicate directly with each other.

  This type of connectivity, which requires only one VCC, is becoming increasingly important in emerging ATM applications.

Figure 1-17   Types of ATM Connections
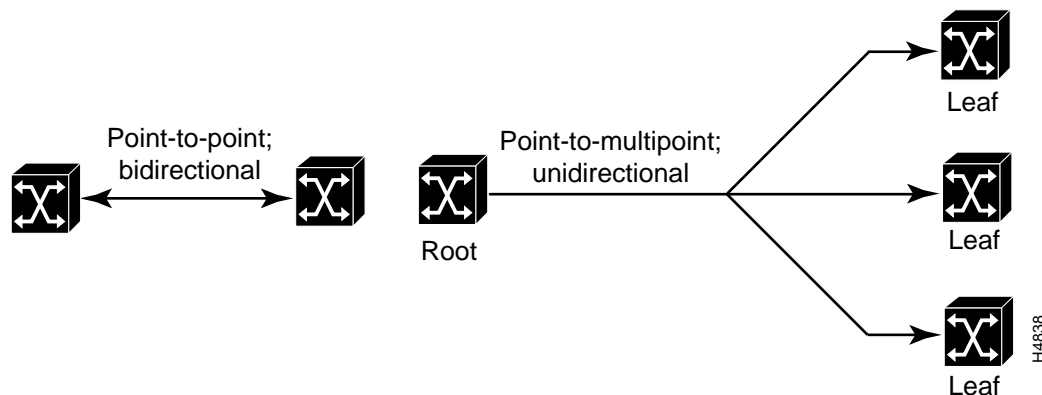
ATM Switching

ATM technology uses a unique cell switching technique for dynamically routing and transporting cells through an ATM network. ATM technology enables you to

- Set up virtual channels and virtual channel connections

- Set up virtual paths and virtual path connections

- Perform virtual channel switching

ATM switching techniques involve the use of two fields in the ATM cell header:

- Virtual path identifier (VPI)

- Virtual channel identifier (VCI)

These fields (shown in Figure 1-5 and described in detail in Table 1-2) provide essential connection setup and routing information for transporting ATM cells through network nodes to their destinations.

Networks that do not use ATM switching techniques for data transport require that each packet (or cell) contain the explicit address of its destination. In contrast, ATM uses a simple, efficient routing and switching technique that enables rapid cell transport along the entire data transmission path.

Basically, ATM cell switching works as described below:

1 An ATM switching device receives an incoming ATM cell from a port of another switching device. The incoming ATM cell contains two routing fields in its header: the VPI and the VCI.

2 The device receiving the cell uses the combination of the input port on which the cell was received and the values in the VPI and VCI routing fields to determine where the cell should be forwarded. To do this, the switch consults an internal routing table that correlates the incoming port and routing fields with the outgoing port and routing fields.

3 The switch replaces the incoming routing fields with the outgoing routing fields and sends the ATM cell through its outgoing port to the next switching device in the network. Thus, on output of an ATM cell from a switch, the VPI and VCI fields are overwritten with new values that direct the cell to the next switching device (link) in the connection.

4 The next switching device receives the incoming ATM cell and, again, correlates the incoming port and routing fields with the outgoing port and routing fields by consulting its internal routing table.

5 This process is repeated across multiple network links until the cell reaches its destination.

For example, suppose that your network includes a switch named "Boston." Suppose further that several data paths traverse the Boston switch. When these data paths were initially created, an internal routing table was set up within the Boston switch that contains an entry for every data path going through that particular switch. Thus, the entries in the routing table map the incoming port and routing fields to the outgoing port and routing fields for each data path (ATM connection) passing through the Boston switch.

Table 1-6 shows a simplified example of how the VPI/VCI values in an ATM cell arriving at an input port of a switch are mapped to the appropriate VPI/VCI values at the output port when the cell is forwarded to the next link in the network.

Table 1-6   Sample Routing Table in Boston Switch

Port In	VPI/VCI Value In	Port Out	VPI/VCI Value Out
1	L	6	Z
1	M	7	X
2	N	7	Y

When the Boston switch receives an incoming cell on port 1 that carries the VPI/VCI value "M" in its header, it consults its internal routing table and finds that the VPI/VCI value M needs to be replaced with the value "X."

It finds further that the cell must be forwarded out of the switch from port 7. Accordingly, the outgoing cell is transmitted to the next switch in the network. This switching and table lookup process is illustrated in Figure 1-18.

Figure 1-18   ATM Cell Passing through Boston Switch
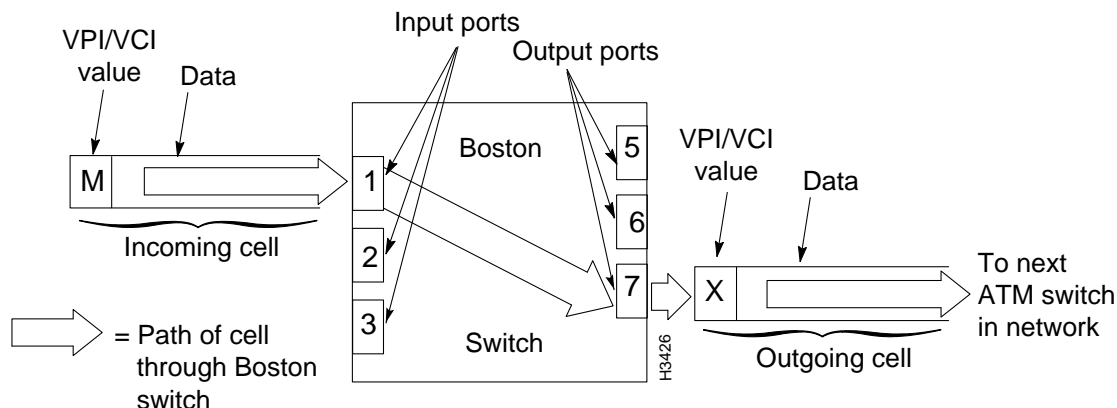
In general, the cell transport process within an ATM network can be summarized as follows:

- An ATM switch receives an ATM cell on an incoming link with known VPI/VCI values.

- The switch looks up the connection value in its own local translation (lookup) table to determine the outgoing port (or ports) of the connection and the new VPI/VCI values of the connection on that outgoing link.

- The switch then retransmits the ATM cell on that outgoing link with the appropriate VPI/VCI values to ensure that the cell is forwarded to the next link in the connection.

This process continues across network links until the ATM cell reaches its destination.

In accomplishing cell transport functions, ATM technology makes use of networking constructs called virtual channel connections (VCCs) and virtual paths (VPs). These constructs are described in the following sections.

Virtual Channels and Virtual Channel Connections

A virtual channel (VC) is a logical circuit created to ensure reliable communications between two endpoints in an ATM network. For purposes of ATM cell transmission, a virtual channel connection (VCC) is regarded as an end-to-end connection for a single data flow between two nodes. A virtual channel is defined by the combination of the VPI field and the VCI field in the ATM cell header (see Figure 1-5).

ATM networking requires that you establish a connection between ATM endpoints. Because ATM is a connection-oriented technology, no information can be transferred from one endpoint in the network to another until such a connection is established.

In an LS2020 network, you pre-provision virtual connections (assign them manually beforehand) to meet a predictable, standing need for network bandwidth capacity. This type of connection endures until changed and is referred to as a permanent virtual connection (PVC).

Ordinarily, PVCs are established in a user's network at service subscription time, or at network configuration time, through the manual provisioning process mentioned above. However, these connections can be changed by a subsequent provisioning process or by means of a customer network management application.

In a typical ATM cell switching environment, a VCC consists of a concatenation of virtual channel links (VCLs), each of which serves as a means of bidirectional transport of ATM cells. Figure 1-19 illustrates a simple VCC consisting of two VCLs, although many such VCLs often exist in an actual ATM communications application.

Figure 1-19   VCLs as Elements of VCCs
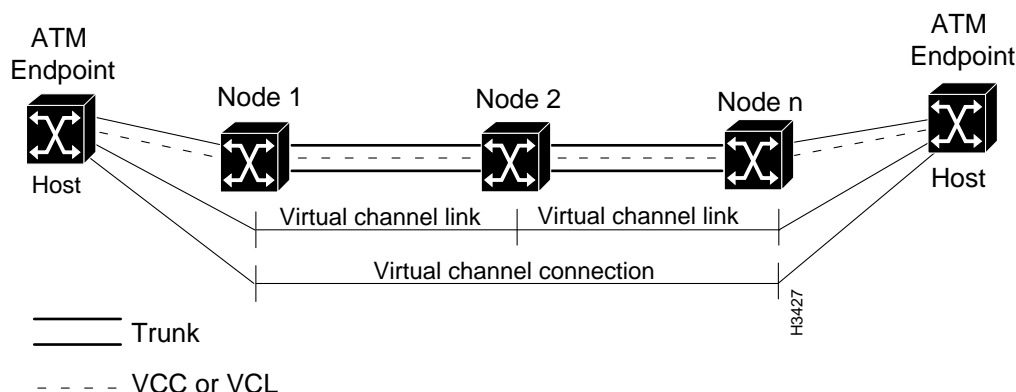
The virtual channel identifier (VCI) in each ATM cell header identifies the VCL through which a cell must pass. Thus, in effect, a concatenation of VCLs sets up a communications path through which ATM cells flow between network endpoints. A connection from a local LS2020 switch to a central office that, in turn, is connected to another LS2020 switch is an example of a simple two-link VCC.

All communications between two network endpoints can occur by means of the same VCC. Such a connection preserves the sequence of ATM cells being transmitted between the endpoints and guarantees a certain level or quality of service. ATM cells may also be transported within virtual paths (VPs), as described in the following section.

Virtual Paths and Virtual Path Connections

The term virtual path (VP) is a generic designation that defines a bundle of virtual channels being directed to the same ATM endpoint. In effect, a VP is a "large pipe" containing a logical grouping of virtual connections between two ATM sites.

A VP is identified solely by the VPI field in the ATM cell header (see Figure 1-5); for VP purposes, the VCI field in the header is ignored.

From the viewpoint of the network, an ATM cell is either a VP cell or a VC cell. If a cell traversing the network is a VP cell, the network pays attention to the VPI field in the cell header; similarly, if a cell traversing the network is a VC cell, the network pays attention to the VCI field.

Two fundamental advantages derive from VPs in a network:

- The network end-user may wish to handle individual ATM cells in some proprietary way that is entirely transparent to the network service provider.

- If the user is directing traffic to the same destination(s) by means of numerous VCs, network overhead can be minimized by treating such traffic as a single, logical transmission entity, rather than as multiple transmission entities. Thus, VPs eliminate the need to switch multiple VCs.

The practical advantage of VPs in an ATM network is that they enable cell streams from multiple users to be bundled together into a higher-rate signal on the same physical link for transport through the network. Figure 1-20 illustrates this principle.

Thus, VPs provide a convenient way of handling traffic being directed to the same destination in the network. VPs are also useful in handling traffic that requires the same quality of service (QoS). For these reasons, VPs are typically used in ATM networks for trunking purposes.

Figure 1-20   Virtual Channels within Virtual Paths

VP = Virtual path
VC = Virtual channel
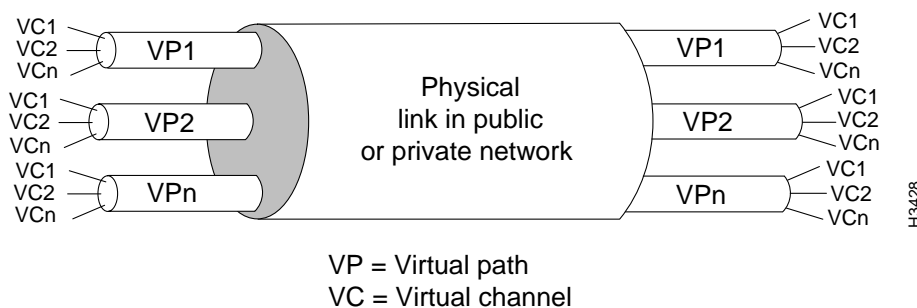
ATM Networking Model

This section describes the ATM UNI interface types and the ATM addressing scheme used in establishing virtual connections in an ATM network.

ATM Network Interfaces

ATM networks often pass information of different types. Furthermore, the types of connections set up between communicating peers can vary according to the network's end-to-end topology and its underlying nature.

For example, an ATM network may encompass a local workgroup, an enterprise network, a public or private network, or some combination of these domains. Accordingly, the interfaces between these domains vary, as described below:

- **User-to-Network Interface (UNI)**—A UNI is an interface defined by the ATM Forum for accessing public and private ATM networks.

  A UNI interface is defined as any connection that directly links a user's device (such as a host node or router) to an ATM network through an ATM switch (see Figure 1-21). An interface of this type is referred to as an "edge" interface.

- **Network-to-Network Interface (NNI)**—Passing information between an end-user device and an ATM switch by means of a UNI is simpler than passing information between two ATM switches. Hence, a slightly different and more complex interface, the NNI, has been defined for

ATM switch-to-switch connections. For example, ATM switches must update each other regarding the status of their respective links, and the switches must also be able to participate in network-wide connection set-up requests.

An NNI interface is defined as any connection between two ATM switching devices in a network or between an ATM switching device and an entire switching system (see Figure 1-21). An ATM connection of this type is commonly referred to as a "trunk" interface.

An NNI is sometimes also referred to as a network-to-node interface or network-node interface.

Originally, the term NNI described the interface between two public ATM switches. Currently, however, the term private NNI, or PNNI, has been adopted to describe an ATM switch-to-switch interface within the user's premises. The term PNNI has also come into use to refer to the interface between two ATM switches in a public network. Hence, the meaning of the term PNNI must often be deduced from the context of its usage.

Figure 1-21 illustrates the interface types common to ATM networks.

Figure 1-21   ATM Network Interface Types
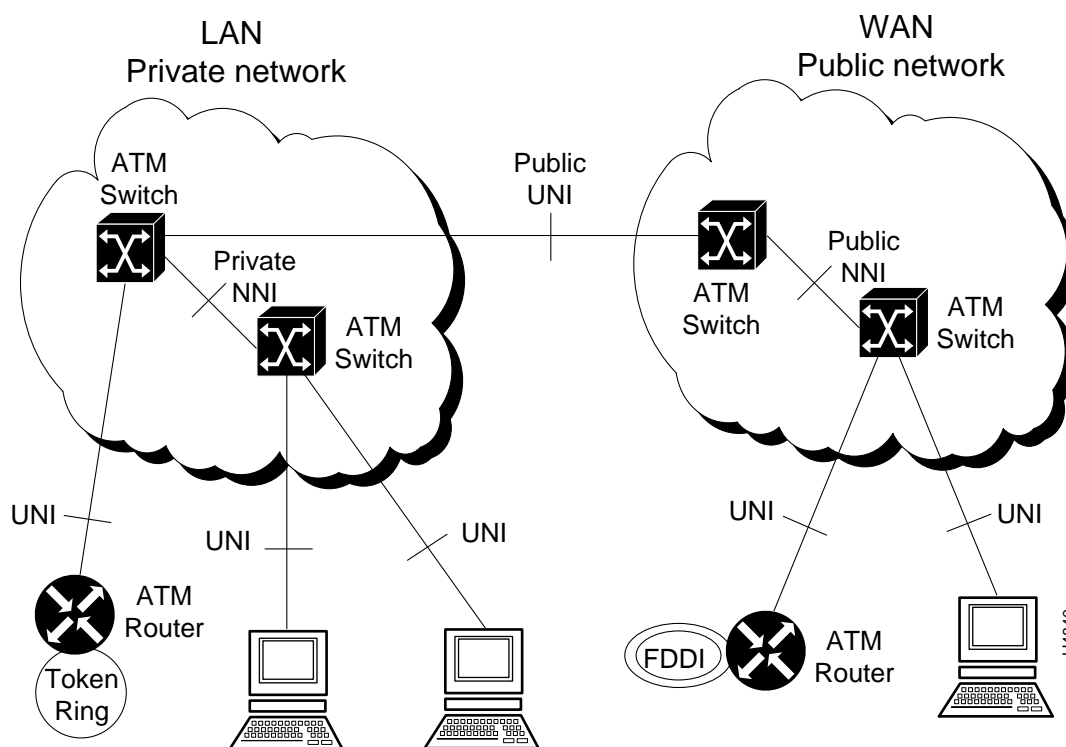
ATM Addressing Scheme

The ATM Forum agreed that all ATM equipment would identify ATM endpoints using what is known as the OSI Network Services Access Point (NSAP) addressing format. An NSAP address represents that point in a network at which OSI network services are provided to a transport layer (layer 4) entity. The ATM private network address formats are described in the following section.

ATM Private Network Address Formats

Several address formats, or ATM endpoint identifiers, have been specified by the ATM Forum for use in private ATM networks. These 20-byte address formats are illustrated in Figure 1-22.

All NSAP format ATM addresses consist of three components:

- Authority and Format Identifier (AFI)—Identifies the type and format of the Initial Domain Identifier (IDI)

- IDI—Identifies the address allocation and administration authority

- Domain Specific Part (DSP)—Contains actual routing information

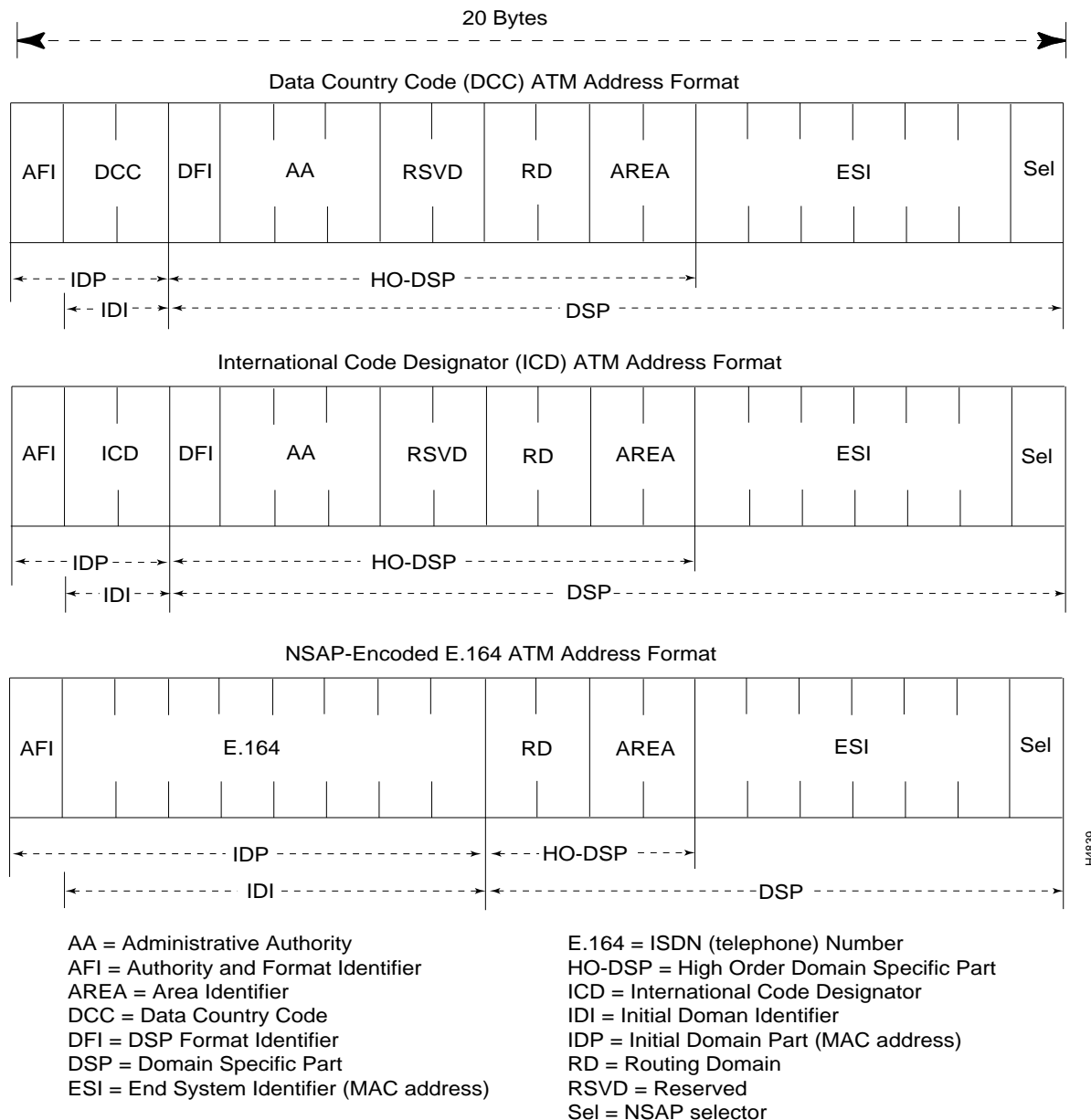The three private network address formats are described briefly below:

- **Data Country Code (DCC) ATM format**—In this format, the Initial Domain Identifier (IDI) is a Data Country Code (DCC). A DCC identifies a particular country, as specified in ISO 3166. DCCs are administered by the ISO National Member Body in each country.

- **International Code Designator (ICD) ATM format**—In this format, the IDI is an International Code Identifier (ICD). An ICD identifies a particular international organization. ICDs are allocated by the ISO 6523 registration authority (the British Standards Institute).

- **NSAP-Encoded E.164 Format**—In this format, the IDI is an E.164 number, which functions much like a conventional telephone number.

These three private network addresses can be specific to a local country or they can be globally unique.

In ATM LANs, an ATM endpoint's IEEE MAC (media access control) address will most likely be used as the End System Identifier (ESI). See Figure 1-22. Therefore, when an ATM endstation connects to a network for the first time, it must register its MAC address with an address registration service provided by the ATM network. The address registration service then responds to the endstation with its assigned NSAP address and stores its MAC-to-ATM address pairs with the respective switch and port number.

Note A MAC address is a standardized data link layer address required for every port or device connected to a LAN. Other devices in the network use these addresses to locate specific ports in the network and to create and update internal routing tables and data structures. These 6-byte MAC addresses are controlled by the IEEE.

The address registration service is accessed and maintained by means of the Interim Local Management Interface (ILMI), which facilitates auto-configuration of an ATM endpoint's NSAP address.

Figure 1-22   ATM Private Network Addressing Formats

AA = Administrative Authority
AFI = Authority and Format Identifier
AREA = Area Identifier
DCC = Data Country Code
DFI = DSP Format Identifier
DSP = Domain Specific Part
ESI = End System Identifier (MAC address)

E.164 = ISDN (telephone) Number
HO-DSP = High Order Domain Specific Part
ICD = International Code Designator
IDI = Initial Doman Identifier
IDP = Initial Domain Part (MAC address)
RD = Routing Domain
RSVD = Reserved
Sel = NSAP selector

ATM Public Network Address Format

Public ATM networks use a telephone number-like E.164 address that is formatted as specified by the ITU-T. This format is typically used in today's public telephony networks. E.164 addresses, being a public (and expensive) resource, are ordinarily not used in private ATM networks.

Note, however, that public ATM networks can use an NSAP-encoded addressing format that incorporates an E.164-like address, as shown in Figure 1-22. This format is ordinarily used for encoding E.164 addresses in private networks, but it may also be used in public networks.