CHAPTER 18

Virtual-Circuit Networks: Frame Relay andATM

In Chapter 8, we discussed switching techniques. We said that there are three types of switching: circuit switching, packet switching, and message switching. We also mentioned that packet switching can use two approaches: the virtual-circuit approach and the datagram approach.

In this chapter, we show how the virtual-circuit approach can be used in wide-area networks. Two common WAN technologies use virtual-circuit switching. Frame Relay is a relatively high-speed protocol that can provide some services not available in other WAN technologies such as DSL, cable TV, and T lines. ATM, as a high-speed protocol, can be the superhighway of communication when it deploys physical layer carriers such as SONET.

We first discuss Frame Relay. We then discuss ATM in greater detaiL Finally, we show how ATM technology, which was originally designed as a WAN technology, can also be used in LAN technology, ATM LANs.

18.1 FRAME RELAY

Frame Relay is a virtual-circuit wide-area network that was designed in response to demands for a new type of WAN in the late 1980s and early 1990s.

1. Prior to Frame Relay, some organizations were using a virtual-circuit switching network called X.25 that performed switching at the network layer. For example, the Internet, which needs wide-area networks to carry its packets from one place to another, used X.25. And X.25 is still being used by the Internet, but it is being replaced by other WANs. However, X.25 has several drawbacks:
   a. X.25 has a low 64-kbps data rate. By the 1990s, there was a need for higher-data-rate WANs.
   b. X.25 has extensive flow and error control at both the data link layer and the network layer. This was so because X.25 was designed in the 1970s, when the available transmission media were more prone to errors. Flow and error control at both layers create a large overhead and slow down transmissions. X.25 requires acknowledgments for both data link layer frames and network layer packets that are sent between nodes and between source and destination.

c. Originally X.25 was designed for private lise, not for the Internet. X.25 has its own network layer. This means that the user's data are encapsulated in the network layer packets of X.25. The Internet, however, has its own network layer, which means if the Internet wants to use X.25, the Internet must deliver its network layer packet, called a datagram, to X.25 for encapsulation in the X.25 packet. This doubles the overhead.

2. Disappointed with X.25, some organizations started their own private WAN by leasing T-l or T-3 lines from public service providers. This approach also has some drawbacks.
   a. If an organization has n branches spread over an area, it needs $n(n-1)/2$ T-I or T-3 lines. The organization pays for all these lines although it may use the lines only 10 percent of the time. This can be very costly:
   b. The services provided by T-I and T-3 lines assume that the user has fixed-rate data all the time. For example, a T-l line is designed for a user who wants to use the line at a consistent 1.544 Mbps. This type of service is not suitable for the many users today that need to send **bursty data.** For example, a user may want to send data at 6 Mbps for 2 s, 0 Mbps (nothing) for 7 s, and 3.44 Mbps for 1 s for a total of 15.44 Mbits during a period of 10 s. Although the average data rate is still 1.544 Mbps, the T-I line cannot accept this type of demand because it is designed for fixed-rate data, not bursty data. Bursty data require what is called **bandwidth on demand.** The user needs different bandwidth allocations at different times.

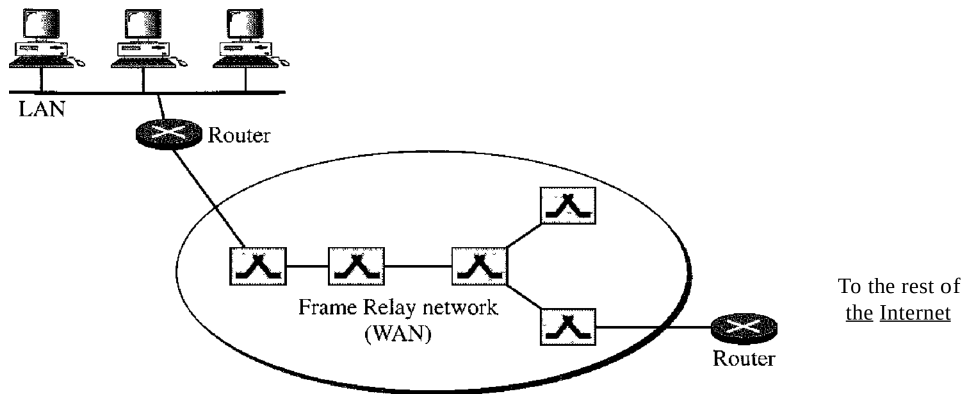
In response to the above drawbacks, Frame Relay was designed. Frame Relay is a wide-area network with the following features:

1. Frame Relay operates at a higher speed (1.544 Mbps and recently 44.376 Mbps). This means that it can easily be used instead of a mesh of T-I or T-3 lines.
2. Frame Relay operates in just the physical and data link layers. This means it can easily be used as a backbone network to provide services to protocols that already have a network layer protocol, such as the Internet.
3. Frame Relay allows bursty data.
4. Frame Relay allows a frame size of 9000 bytes, which can accommodate all local-area network frame sizes.
5. Frame Relay is less expensive than other traditional WANs.
6. Frame Relay has error detection at the data link layer only. There is no flow control or error control. There is not even a retransmission policy if a frame is damaged; it is silently dropped. Frame Relay was designed in this way to provide fast transmission capability for more reliable media and for those protocols that have flow and error control at the higher layers.

Architecture

Frame Relay provides permanent virtual circuits and switched virtual circuits. Figure 18.1 shows an example of a Frame Relay network connected to the Internet. The routers are used, as we will see in Chapter 22, to connect LANs and WANs in the Internet. In the figure, the Frame Relay WAN is used as one link in the global Internet.

Figure 18.1 *Frame Relay network*



Virtual Circuits

Frame Relay is a virtual circuit network. A virtual circuit in Frame Relay is identified by a number called a data link connection identifier (DLCI).

VCIs in Frame Relay are called DLCIs.

Permanent Versus Switched Virtual Circuits

A source and a destination may choose to have a permanent virtual circuit (PVC). In this case, the connection setup is simple. The corresponding table entry is recorded for all switches by the administrator (remotely and electronically, of course). An outgoing DLCI is given to the source, and an incoming DLCI is given to the destination.

PVC connections have two drawbacks. First, they are costly because two parties pay for the connection all the time even when it is not in use. Second, a connection is created from one source to one single destination. If a source needs connections with several destinations, it needs a PVC for each connection. An alternate approach is the switched virtual circuit (SVC). The SVC creates a temporary, short connection that exists only when data are being transferred between source and destination. An SVC requires establishing and terminating phases as discussed in Chapter 8.

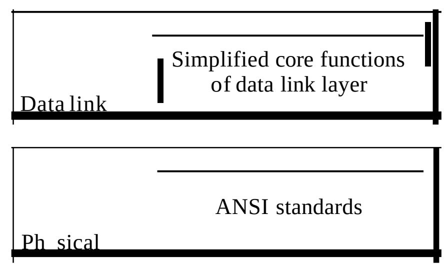
Switches

Each switch in a Frame Relay network has a table to route frames. The table matches an incoming port-DLCI combination with an outgoing port-DLCI combination as we described for general virtual-circuit networks in Chapter 8. The only difference is that VCIs are replaced by DLCIs.

Frame Relay Layers

Figure 18.2 shows the Frame Relay layers. Frame Relay has only physical and data link layers.

Figure 18.2 *Frame Relay layers*



Frame Relay operates only at the physical and data link layers.

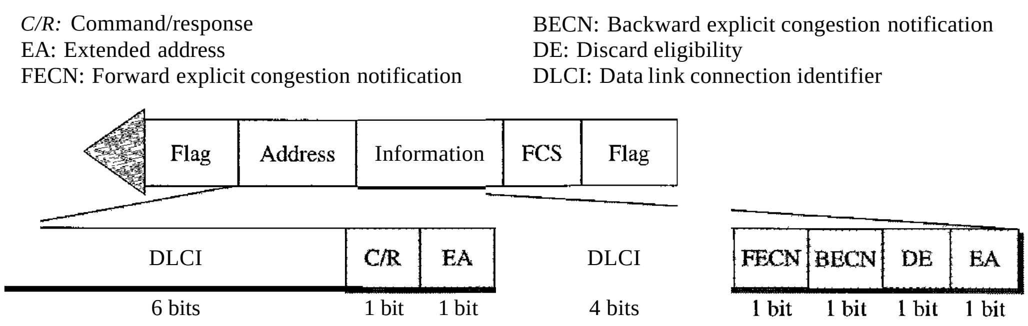
Physical Layer

No specific protocol is defined for the physical layer in Frame Relay. Instead, it is left to the implementer to use whatever is available. Frame Relay supports any of the protocols recognized by ANSI.

Data Link Layer

At the data link layer, Frame Relay uses a simple protocol that does not support flow or error control. It only has an error detection mechanism. Figure 18.3 shows the format of a Frame Relay frame. The address field defines the DLCI as well as some bits used to control congestion.

Figure 18.3 *Frame Relay frame*



The descriptions of the fields are as follows:

- Address (DLCI) field. The first 6 bits of the first byte makes up the first part of the DLCI. The second part of the DLCI uses the first 4 bits of the second byte. These bits are part of the lO-bit data link connection identifier defined by the standard. We will discuss extended addressing at the end of this section.

- Command/response (CIR). The command/response (C/R) bit is provided to allow upper layers to identify a frame as either a command or a response. It is not used by the Frame Relay protocol.
- Extended address (EA). The extended address (EA) bit indicates whether the current byte is the final byte of the address. An EA of 0 means that another address byte is to follow (extended addressing is discussed later). An EA of 1 means that the current byte is the final one.
- Forward explicit congestion notification (FECN). The forward explicit congestion notification (FECN) bit can be set by any switch to indicate that traffic is congested. This bit informs the destination that congestion has occurred. In this way, the destination knows that it should expect delay or a loss of packets. We will discuss the use of this bit when we discuss congestion control in Chapter 24.
- Backward explicit congestion notification (BECN). The backward explicit congestion notification (BECN) bit is set (in frames that travel in the other direction) to indicate a congestion problem in the network. This bit informs the sender that congestion has occurred. In this way, the source knows it needs to slow down to prevent the loss of packets. We will discuss the use of this bit when we discuss congestion control in Chapter 24.
- Discard eligibility (DE). The discard eligibility (DE) bit indicates the priority level of the frame. In emergency situations, switches may have to discard frames to relieve bottlenecks and keep the network from collapsing due to overload. When set (DE 1), this bit tells the network to discard this frame if there is congestion. This bit can be set either by the sender of the frames (user) or by any switch in the network.

Frame Relay does not provide flow or error control;
they must be provided by the upper-layer protocols.

Extended Address

To increase the range of DLCIs, the Frame Relay address has been extended from the original 2-byte address to 3- or 4-byte addresses. Figure 18.4 shows the different addresses. Note that the EA field defines the number of bytes; it is 1 in the last byte of the address, and it is a in the other bytes. Note that in the 3- and 4-byte formats, the bit before the last bit is set to 0.

Figure 18.4 *Three address formats*

DLCI			C/R	EA = 0
DLCI	FECN	BECN	DE	EA = 1

a. Two-byte address (lO-bit DLCI)

DLCI			CIR	EA=O
OLCI	FECN	BECN	DE	EA=O
DLCI			0	EA= I

b. Three-byte address (16-bit DLCI)

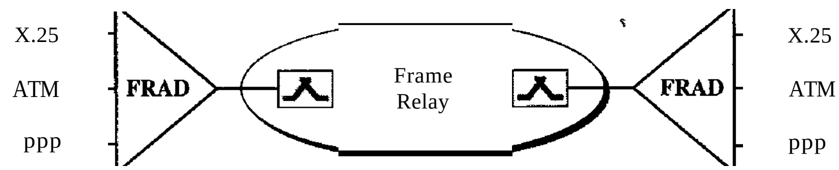
OLCI			CIR	EA=O
OLCI	PECN	BECN	OE	EA=O
DLCI				EA=O
DLCI			0	EA= 1

c. Four-byte address (23-bit DLCI)

FRADs

To handle frames arriving from other protocols, Frame Relay uses a device called a Frame Relay assembler/disassembler (FRAD). A FRAD assembles and disassembles frames coming from other protocols to allow them to be carried by Frame Relay frames. A FRAD can be implemented as a separate device or as part of a switch. Figure 18.5 shows two FRADs connected to a Frame Relay network.

Figure 18.5 *FRAD*



VOFR

Frame Relay networks offer an option called Voice Over Frame Relay (VOFR) that sends voice through the network. Voice is digitized using PCM and then compressed. The result is sent as data frames over the network. This feature allows the inexpensive sending of voice over long distances. However, note that the quality of voice is not as good as voice over a circuit-switched network such as the telephone network. Also, the varying delay mentioned earlier sometimes corrupts real-time voice.

LMI

Frame Relay was originally designed to provide PVC connections. There was not, therefore, a provision for controlling or managing interfaces. Local Management Information (LMI) is a protocol added recently to the Frame Relay protocol to provide more management features. In particular, LMI can provide

- A keep-alive mechanism to check if data are flowing.
- A multicast mechanism to allow a local end system to send frames to more than one remote end system.
- A mechanism to allow an end system to check the status of a switch (e.g., to see if the switch is congested).

Congestion Control and Quality of Service

One of the nice features of Frame Relay is that it provides congestion control and quality of service (QoS). We have not discussed these features yet. In Chapter 24, we introduce these two important aspects of networking and discuss how they are implemented in Frame Relay and some other networks.

18.2 ATM

Asynchronous Transfer Mode (ATM) is the cell relay protocol designed by the ATM Forum and adopted by the ITU-T. The combination of ATM and SONET will allow high-speed interconnection of all the world's networks. In fact, ATM can be thought of as the "highway" of the information superhighway.

Design Goals

Among the challenges faced by the designers of ATM, six stand out.

1. Foremost is the need for a transmission system to optimize the use of high-data-rate transmission media, in particular optical fiber. In addition to offering large bandwidths, newer transmission media and equipment are dramatically less susceptible to noise degradation. A technology is needed to take advantage of both factors and thereby maximize data rates.
2. The system must interface with existing systems and provide wide-area interconnectivity between them without lowering their effectiveness or requiring their replacement.
3. The design must be implemented inexpensively so that cost would not be a barrier to adoption. If ATM is to become the backbone of international communications, as intended, it must be available at low cost to every user who wants it.
4. The new system must be able to work with and support the existing telecommunications hierarchies (local loops, local providers, long-distance carriers, and so on).
5. The new system must be connection-oriented to ensure accurate and predictable delivery.
6. Last but not least, one objective is to move as many of the functions to hardware as possible (for speed) and eliminate as many software functions as possible (again for speed).

Problems

Before we discuss the solutions to these design requirements, it is useful to examine some of the problems associated with existing systems.

Frame Networks

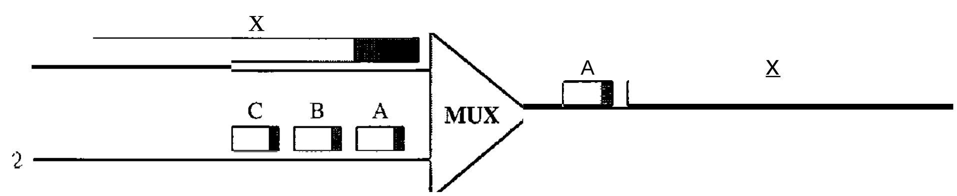
Before ATM, data communications at the data link layer had been based on frame switching and frame networks. Different protocols use frames of varying size and intricacy. As networks become more complex, the information that must be carried in the header becomes more extensive. The result is larger and larger headers relative to the size of the data unit. In response, some protocols have enlarged the size of the data unit to make header use more efficient (sending more data with the same size header). Unfortunately, large data fields create waste. If there is not much information to transmit, much of the field goes unused. To improve utilization, some protocols provide variable frame sizes to users.

Mixed Network Traffic

As you can imagine, the variety of frame sizes makes traffic unpredictable. Switches, multiplexers, and routers must incorporate elaborate software systems to manage the various sizes of frames. A great deal of header information must be read, and each bit counted and evaluated to ensure the integrity of every frame. Internetworking among the different frame networks is slow and expensive at best, and impossible at worst.

Another problem is that of providing consistent data rate delivery when frame sizes are unpredictable and can vary so dramatically. To get the most out of broadband technology, traffic must be time-division multiplexed onto shared paths. Imagine the results of multiplexing frames from two networks with different requirements (and frame designs) onto one link (see Figure 18.6). What happens when line 1 uses large frames (usually data frames) while line 2 uses very small frames (the norm for audio and video information)?

Figure 18.6 *Multiplexing using different frame sizes*



If line 1's gigantic frame X arrives at the multiplexer even a moment earlier than line 2's frames, the multiplexer puts frame X onto the new path first. After all, even if line 2's frames have priority, the multiplexer has no way of knowing to wait for them and so processes the frame that has arrived. Frame A must therefore wait for the entire X bit stream to move into place before it can follow. The sheer size of X creates an unfair delay for frame A. The same imbalance can affect all the frames from line 2.

Because audio and video frames ordinarily are small, mixing them with conventional data traffic often creates unacceptable delays of this type and makes shared frame links unusable for audio and video information. Traffic must travel over different paths, in much the same way that automobile and train traffic does. But to fully utilize broad bandwidth links, we need to be able to send all kinds of traffic over the same links.

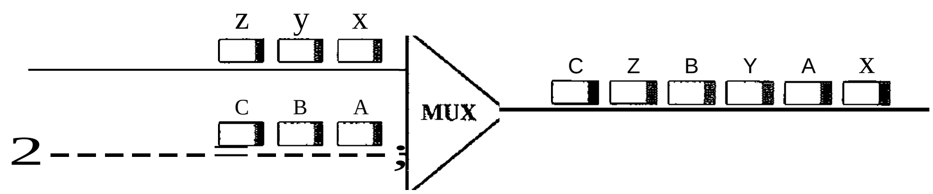
Cell Networks

Many of the problems associated with frame internetworking are solved by adopting a concept called cell networking. A cell is a small data unit of fixed size. In a **cell** network, which uses the **cell** as the basic unit of data exchange, all data are loaded into identical cells that can be transmitted with complete predictability and uniformity. As frames of different sizes and formats reach the cell network from a tributary network, they are split into multiple small data units of equal length and are loaded into cells. The cells are then multiplexed with other cells and routed through the cell network. Because each cell is the same size and all are small, the problems associated with multiplexing different-sized frames are avoided.

A cell network uses the cell as the basic unit of data exchange.
A cell is defined as a small, fixed-size block of information.

Figure 18.7 shows the multiplexer from Figure 18.6 with the two lines sending cells instead of frames. Frame X has been segmented into three cells: X, Y, and Z. Only the first cell from line 1 gets put on the link before the first cell from line 2. The cells from the two lines are interleaved so that none suffers a long delay.

Figure 18.7 *Multiplexing using cells*



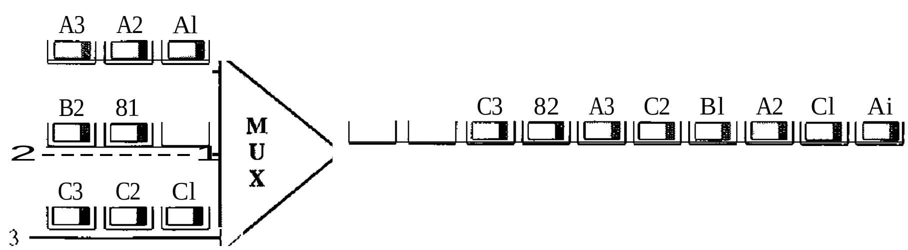
A second point in this same scenario is that the high speed of the links coupled with the small size of the cells means that, despite interleaving, cells from each line arrive at their respective destinations in an approximation of a continuous stream (much as a movie appears to your brain to be continuous action when in fact it is really a series of separate, still photographs). In this way, a cell network can handle real-time transmissions, such as a phone call, without the parties being aware of the segmentation or multiplexing at all.

Asynchronous TDM

ATM uses asynchronous time-division multiplexing-that is why it is called Asynchronous Transfer Mode-to multiplex cells corning from different channels. It uses fixed-size slots (size of a cell). ATM multiplexers fill a slot with a cell from any input channel that has a cell; the slot is empty if none of the channels has a cell to send.

Figure 18.8 shows how cells from three inputs are multiplexed. At the first tick of the clock: channel 2 has no cell (empty input slot), so the multiplexer fills the slot with a cell from the third channel. When all the cells from all the channels are multiplexed, the output slots are empty.

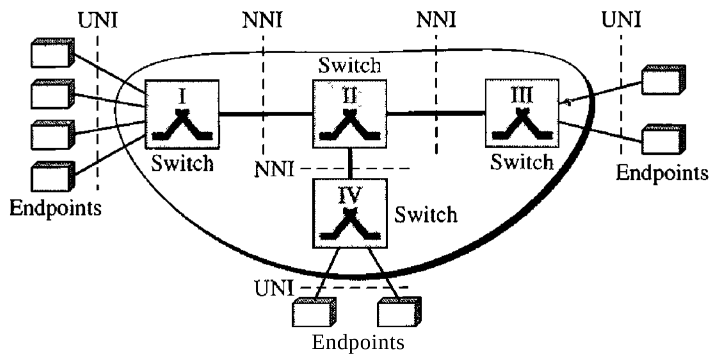
Figure 18.8 *ATM multiplexing*



Architecture

ATM is a cell-switched network. The user access devices, called the endpoints, are connected through a user-to-network interface (UNI) to the switches inside the network. The switches are connected through network-to-network interfaces (NNIs). Figure 18.9 shows an example of an ATM network.

Figure 18.9 *Architecture of an ATM network*



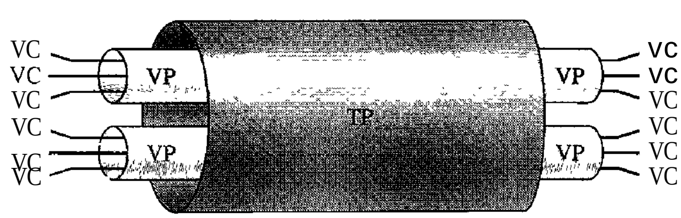
Virtual Connection

Connection between two endpoints is accomplished through transmission paths (TPs), virtual paths (YPs), and virtual circuits (YCs). A transmission path (TP) is the physical connection (wire, cable, satellite, and so on) between an endpoint and a switch or between two switches. Think of two switches as two cities. A transmission path is the set of all highways that directly connect the two cities.

A transmission path is divided into several virtual paths. A virtual path (VP) provides a connection or a set of connections between two switches. Think of a virtual path as a highway that connects two cities. Each highway is a virtual path; the set of all highways is the transmission path.

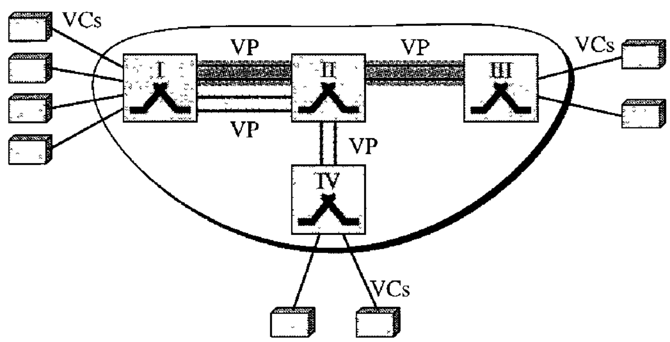
Cell networks are based on virtual circuits (VCs). All cells belonging to a single message follow the same virtual circuit and remain in their original order until they reach their destination. Think of a virtual circuit as the lanes of a highway (virtual path). Figure 18.10 shows the relationship between a transmission path (a physical connection), virtual paths (a combination of virtual circuits that are bundled together because parts of their paths are the same), and virtual circuits that logically connect two points.

Figure 18.10 *Tp, VPs, and VCs*



To better understand the concept of VPs and VCs, look at Figure 18.11. In this figure, eight endpoints are communicating using four VCs. However, the first two VCs seem to share the same virtual path from switch I to switch III, so it is reasonable to bundle these two VCs together to form one VP. On the other hand, it is clear that the other two VCs share the same path from switch I to switch IV, so it is also reasonable to combine them to form one VP.

Figure 18.11 *Example ofVPs and VCs*



Identifiers In a virtual circuit network, to route data from one endpoint to another, the virtual connections need to be identified. For this purpose, the designers of ATM created a hierarchical identifier with two levels: a virtual path identifier (VPI) and a virtual-circuit identifier (Vel). The VPI defines the specific VP, and the Vel defines a particular VC inside the VP. The VPI is the same for all virtual connections that are bundled (logically) into one VP.

Note that a virtual connection is defined by a pair of numbers: the VPI and the vel.

Figure 18.12 shows the VPIs and VCls for a transmission path. The rationale for dividing an identifier into two parts will become clear when we discuss routing in an ATM network.

The lengths of the VPIs for UNIs and NNIs are different. In a UNI, the VPI is 8 bits, whereas in an NNI, the VPI is 12 bits. The length of the VCI is the same in both interfaces (16 bits). We therefore can say that a virtual connection is identified by 24 bits in a UNI and by 28 bits in an NNI (see Figure 18.13).

The whole idea behind dividing a virtual circuit identifier into two parts is to allow hierarchical routing. Most of the switches in a typical ATM network are routed using VPIs. The switches at the boundaries of the network, those that interact directly with the endpoint devices, use both VPIs and VCIs.

Cells

The basic data unit in an ATM network is called a cell. A cell is only 53 bytes long with 5 bytes allocated to the header and 48 bytes carrying the payload (user data may be less

Figure 18.12 *Connection identifiers*

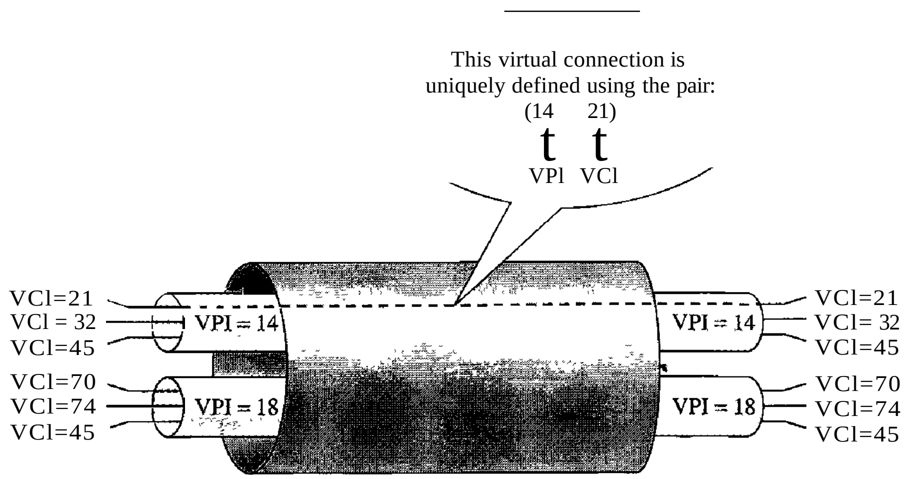
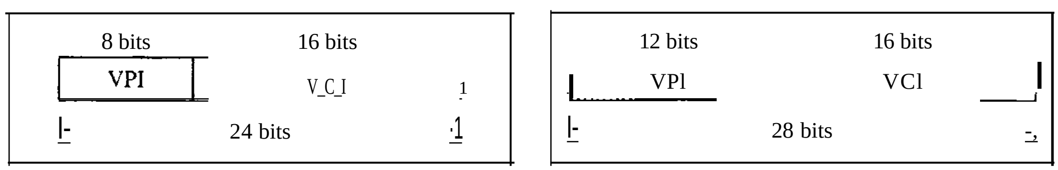


Figure 18.13 *Virtual connection identifiers in UNIs and NNIs*

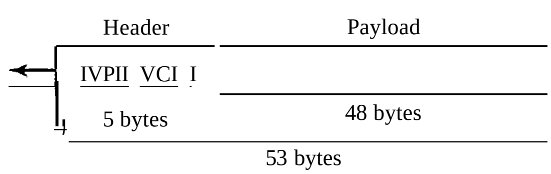


a. VPI and VCI in a UNI

b. VPI and VCI in an NNI

than 48 bytes). We will study in detail the fields of a cell, but for the moment it suffices to say that most of the header is occupied by the VPI and VCI that define the virtual connection through which a cell should travel from an endpoint to a switch or from a switch to another switch. Figure 18.14 shows the cell structure.

Figure 18.14 *An ATM cell*



Connection Establishment and Release

Like Frame Relay, ATM uses two types of connections: PVC and SVc.

PVC A permanent virtual-circuit connection is established between two endpoints by the network provider. The VPls and vcrs are defined for the permanent connections, and the values are entered for the tables of each switch.

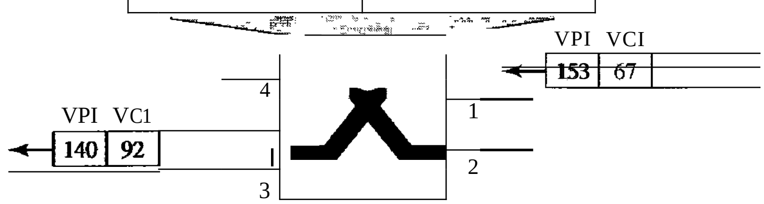
SVC In a switched virtual-circuit connection, each time an endpoint wants to make a connection with another endpoint, a new virtual circuit must be established. ATM cannot do the job by itself, but needs the network layer addresses and the services of another protocol (such as IP). The signaling mechanism of this other protocol makes a connection request by using the network layer addresses of the two endpoints. The actual mechanism depends on the network layer protocol.

Switching

ATM uses switches to route the cell from a source endpoint to the destination endpoint. A switch routes the cell using both the VPls and the VCls. The routing requires the whole identifier. Figure 18.15 shows how a VPC switch routes the cell. A cell with a VPI of 153 and VCI of 67 arrives at switch interface (port) 1. The switch checks its switching table, which stores six pieces of information per row: arrival interface number, incoming VPI, incoming VCI, corresponding outgoing interface number, the new VPI, and the new VCL The switch finds the entry with the interface 1, VPI 153, and VCI 67 and discovers that the combination corresponds to output interface 3, VPI 140, and VCI 92. It changes the VPI and VCI in the header to 140 and 92, respectively, and sends the cell out through interface 3.

Figure 18.15 *Routing with a switch*

Input			Output		
Interface	VPI	VCI	Interface	VPI	VCI
1	153	67	3	140	92
.....	.....	.....	.....	...	.....



Switching Fabric

The switching technology has created many interesting features to increase the speed of switches to handle data. We discussed switching fabrics in Chapter 8.

ATM Layers

The ATM standard defines three layers. They are, from top to bottom, the application adaptation layer, the ATM layer, and the physical layer (see Figure 18.16).

The endpoints use all three layers while the switches use only the two bottom layers (see Figure 18.17).

Physical Layer

Like Ethernet and wireless LANs, ATM cells can be carried by any physical layer carrier.

Figure 18.16 *ATM layers*

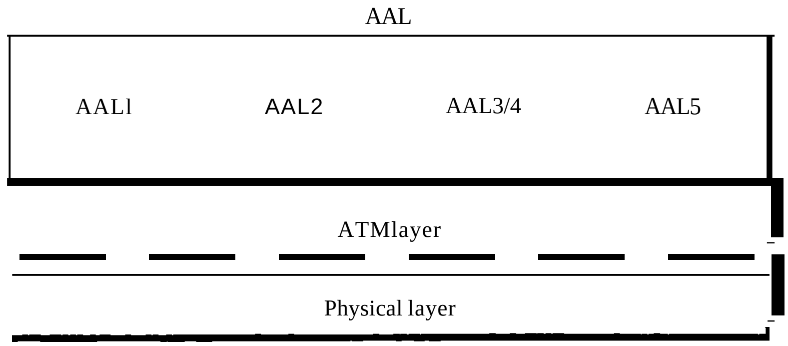
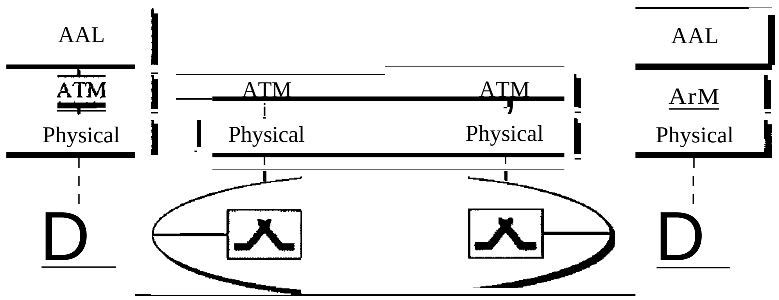


Figure 18.17 *ATM layers in endpoint devices and switches*



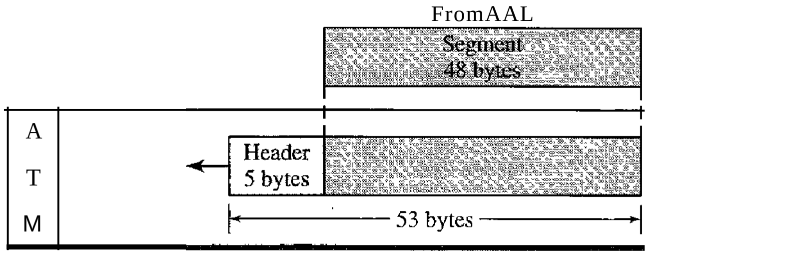
SONET The original design of ATM was based on *SONET* (see Chapter 17) as the physical layer carrier. SONET is preferred for two reasons. First, the high data rate of SONET's carrier reflects the design and philosophy of ATM. Second, in using SONET, the boundaries of cells can be clearly defined. As we saw in Chapter 17, SONET specifies the use of a pointer to define the beginning of a payload. If the beginning of the first ATM cell is defined, the rest of the cells in the same payload can easily be identified because there are no gaps between cells. Just count 53 bytes ahead to find the next cell.

Other Physical Technologies ATM does not limit the physical layer to SONET. Other technologies, even wireless, may be used. However, the problem of cell boundaries must be solved. One solution is for the receiver to guess the end of the cell and apply the CRC to the 5-byte header. If there is no error, the end of the cell1s found, with a high probability, correctly. Count 52 bytes back to find the beginning of the cell.

ATM Layer

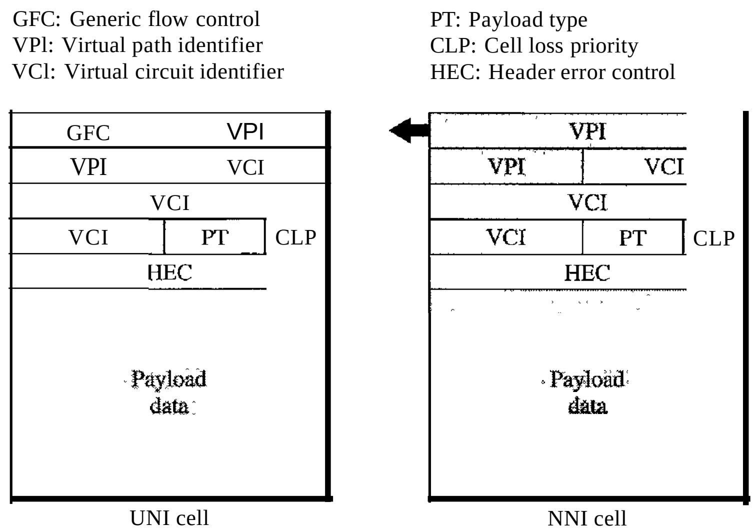
The ATM layer provides routing, traffic management, switching, and multiplexing services. It processes outgoing traffic by accepting 48-byte segments from the AAL sublayers and transforming them into 53-byte cells by the addition of a 5-byte header (see Figure 18.18).

Figure 18.18 *ATM layer*



Header Format ATM uses two fonnats for this header, one for user-to-network interface (UNI) cells and another for network-to-network interface (NNI) cells. Figure 18.19 shows these headers in the byte-by-byte format preferred by the ITU-T (each row represents a byte).

Figure 18.19 *ATM headers*



- Generic flow control (GFC). The 4-bit GFC field provides flow control at the UNI level. The ITU-T has determined that this level of flow control is not necessary at the NNI level. In the NNI header, therefore, these bits are added to the VPI. The longer VPI allows more virtual paths to be defined at the NNI level. The format for this additional VPI has not yet been determined.
- Virtual path identifier (VPI). The VPI is an 8-bit field in a UNI cell and a 12-bit field in an NNI cell (see above).
- Virtual circuit identifier (VCI). The VCI is a 16-bit field in both frames.
- Payload type (PT). In the 3-bit PT field, the first bit defines the payload as user data or managerial information. The interpretation of the last 2 bits depends on the first bit.

- Cell loss priority (CLP). The I-bit CLP field is provided for congestion control. A cell with its CLP bit set to I must be retained as long as there are cells with a CLP of 0. We discuss congestion control and quality of service in an ATM network in Chapter 24.
- Header error correction (HEC). The HEC is a code computed for the first 4 bytes of the header. It is a CRC with the divisor $x^8 + x^2 + x + 1$ that is used to correct single-bit errors and a large class of multiple-bit errors.

Application Adaptation Layer

The application adaptation layer (AAL) was designed to enable two ATM concepts. First, ATM must accept any type of payload, both data frames and streams of bits. A data frame can come from an upper-layer protocol that creates a clearly defined frame to be sent to a carrier network such as ATM. A good exampre is the Internet. ATM must also carry multimedia payload. It can accept continuous bit streams and break them into chunks to be encapsulated into a cell at the ATM layer. AAL uses two sublayers to accomplish these tasks.

Whether the data are a data frame or a stream of bits, the payload must be segmented into 48-byte segments to be carried by a cell. At the destination, these segments need to be reassembled to recreate the original payload. The AAL defines a sublayer, called a segmentation and reassembly (SAR) sublayer, to do so. Segmentation is at the source; reassembly, at the destination.

Before data are segmented by SAR, they must be prepared to guarantee the integrity of the data. This is done by a sublayer called the convergence sublayer (CS).

ATM defines four versions of the AAL: AALl, AAL2, *AAL3/4,* and AAL5. Although we discuss all these versions, we need to inform the reader that the common versions today are AAL I and AAL5. The first is used in streaming audio and video communication; the second, in data communications.

AALI AALI supports applications that transfer information at constant bit rates, such as video and voice. It allows ATM to connect existing digital telephone networks such as voice channels and T lines. Figure 18.20 shows how a bit stream of data is chopped into 47-byte chunks and encapsulated in cells.

The CS sublayer divides the bit stream into 47-byte segments and passes them to the SAR sublayer below. Note that the CS sublayer does not add a header.

The SAR sublayer adds 1 byte of header and passes the 48-byte segment to the ATM layer. The header has two fields:

- Sequence number (SN). This 4-bit field defines a sequence number to order the bits. The first bit is sometimes used for timing, which leaves 3 bits for sequencing (modulo 8).
- Sequence number protection (SNP). The second 4-bit field protects the first field. The first 3 bits automatically correct the SN field. The last bit is a parity bit that detects error over all 8 bits.

AAL2 Originally AAL2 was intended to support a variable-data-rate bit stream, but it has been redesigned. It is now used for low-bit-rate traffic and short-frame traffic such as audio (compressed or uncompressed), video, or fax. A good example of AAL2 use is in mobile telephony. AAL2 allows the multiplexing of short frames into one cell.

Figure 18.20 *AAL1*

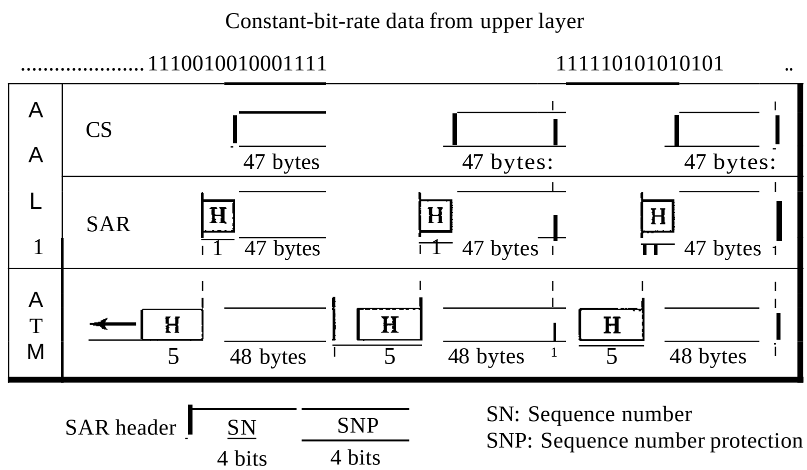
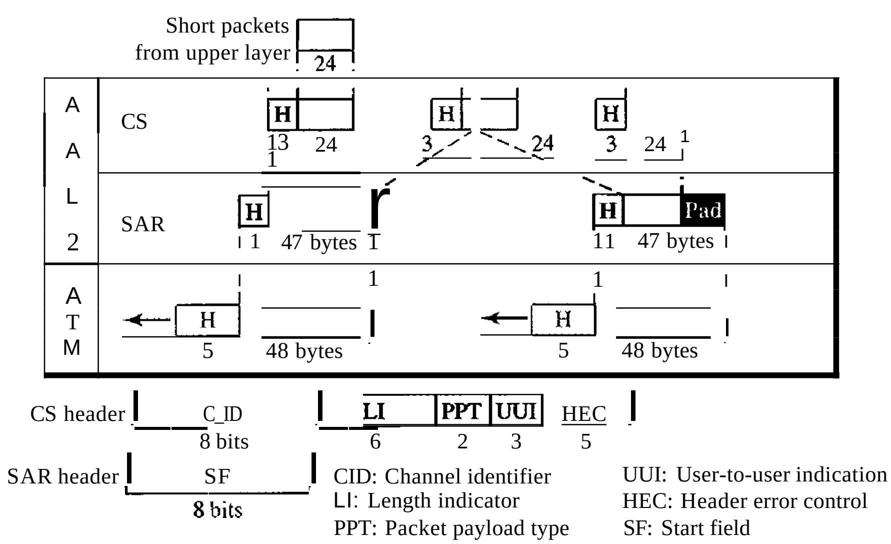


Figure 18.21 shows the process of encapsulating a short frame from the same source (the same user of a mobile phone) or from several sources (several users of mobile telephones) into one cell.

Figure 18.21 *AAL2*



The CS layer overhead consists of five fields:

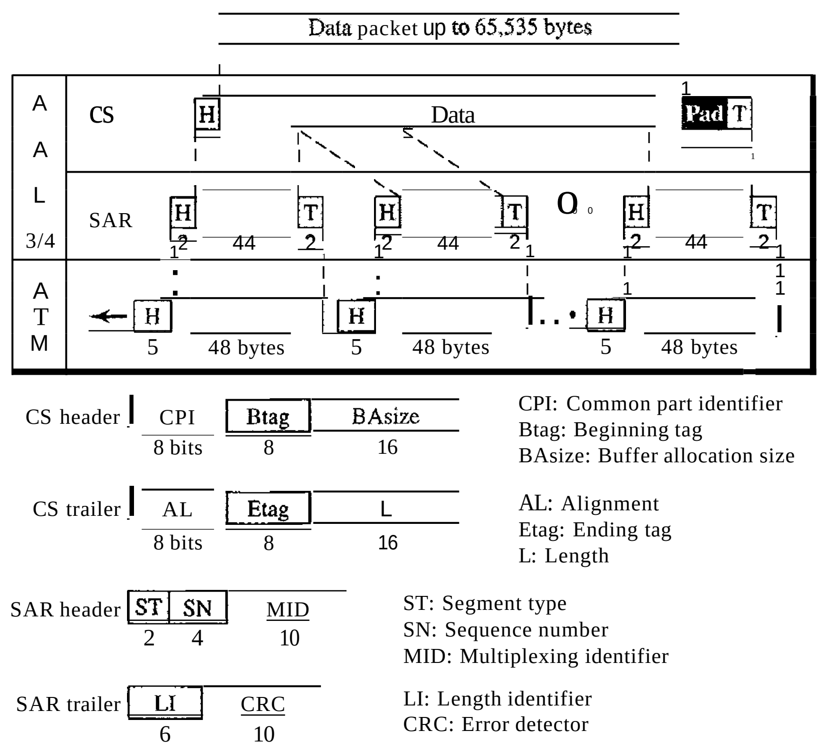
- Channel identifier (CID). The 8-bit CID field defines the channel (user) of the short packet.
- Length indicator (LI). The 6-bit LI field indicates how much of the final packet is data.
- Packet payload type (PPT). The PPT field defines the type of packet.

- User-to-user indicator (UUI). The UUI field can be used by end-to-end users.
- Header error control (HEC). The last 5 bits is used to correct errors in the header.

The only overhead at the SAR layer is the start field (SF) that defines the offset from the beginning of the packet.

AAL3/4 Initially, AAL3 was intended to support connection-oriented data services and AAL4 to support connectionless services. As they evolved, however, it became evident that the fundamental issues of the two protocols were the same. They have therefore been combined into a single format called AAL3/4. Figure 18.22 shows the AAL3/4 sublayer.

Figure 18.22 *AAL3/4*



The CS layer header and trailer consist of six fields:

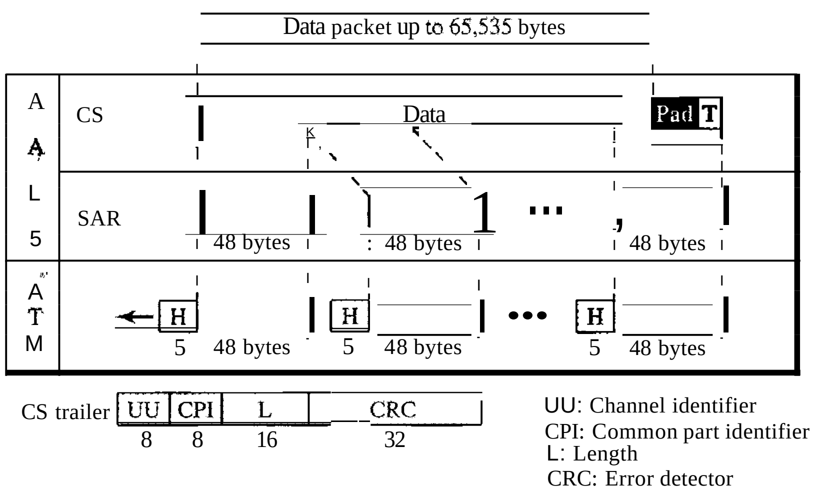
- Common part identifier (CPI). The CPI defines how the subsequent fields are to be interpreted. The value at present is 0.
- Begin tag (Btag). The value of this field is repeated in each ceU to identify all the cells belonging to the same packet. The value is the same as the Etag (see below).
- Buffer allocation size (BAsize). The 2-byte BA field tells the receiver what size buffer is needed for the coming data.
- Alignment (AL). The I-byte AL field is included to make the rest of the trailer 4 bytes long.
- Ending tag (Etag). The I-byte ET field serves as an ending flag. Its value is the same as that of the beginning tag.
- Length (L). The 2-byte L field indicates the length of the data unit.

The SAR header and trailer consist of five fields:

- Segment type (ST). The 2-bit ST identifier specifies the position of the segment in the message: beginning (00), middle (01), or end (10). A single-segment message has an STof 11.
- Sequence number (SN). This field is the same as defined previously.
- Multiplexing identifier (MID). The 10-bit MID field identifies cells coming from different data flows and multiplexed on the same virtual connection.
- Length indicator (LI). This field defines how much of the packet is data, not padding.
- CRC. The last 10 bits of the trailer is a CRC for the entire data unit.

AALS AAL3/4 provides comprehensive sequencing and error control mechanisms that are not necessary for every application. For these applications, the designers of ATM have provided a fifth AAL sublayer, called the simple and efficient adaptation layer (SEAL). AALS assumes that all cells belonging to a single message travel sequentially and that control functions are included in the upper layers of the sending application. Figure 18.23 shows the AAL5 sublayer.

Figure 18.23 *AAL5*



The four trailer fields in the CS layer are

- User-to-user (UU). This field is used by end users, as described previously.
- Common part identifier (CPI). This field is the same as defined previously.
- Length (L). The 2-byte L field indicates the length of the original data.
- CRC. The last 4 bytes is for error control on the entire data unit.

Congestion Control and Quality of Service

ATM has a very developed congestion control and quality of service that we discuss in Chapter 24.

18.3 ATM LANs

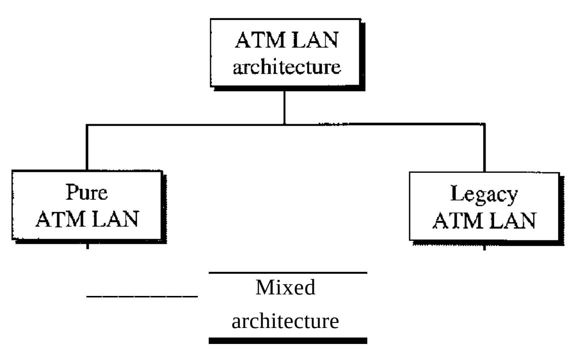
ATM is mainly a wide-area network (WAN ATM); however, the technology can be adapted to local-area networks (ATM LANs). The high data rate of the technology (155 and 622 Mbps) has attracted the attention of designers who are looking for greater and greater speeds in LANs. In addition, ATM technology has several advantages that make it an ideal LAN:

- ATM technology supports different types of connections between two end users. It supports permanent and temporary connections.
- ATM technology supports multimedia communication with a variety of bandwidths for different applications. It can guarantee a bandwidth of several megabits per second for real-time video. It can also provide support for text transfer during off-peak hours.
- An ATM LAN can be easily adapted for expansion in an organization.

ATM LAN Architecture

Today, we have two ways to incorporate ATM technology in a LAN architecture: creating a pure ATM LAN or making a legacy ATM LAN. Figure 18.24 shows the taxonomy.

Figure 18.24 *ATM LANs*



Pure ATM Architecture

In a pure ATM LAN, an ATM switch is used to connect the stations in a LAN, in exactly the same way stations are connected to an Ethernet switch. Figure 18.25 shows the situation.

In this way, stations can exchange data at one of two standard rates of ATM technology (155 and 652 Mbps). However, the station uses a virtual path identifier (VPI) and a virtual circuit identifier (Vel), instead of a source and destination address.

This approach has a major drawback. The system needs to be built from the ground up; existing LANs cannot be upgraded into pure ATM LANs.

Legacy LAN Architecture

A second approach is to use ATM technology as a backbone to connect traditional LANs. Figure 18.26 shows this architecture, a legacy ATM LAN.

Figure 18.25 *Pure ATM LAN*

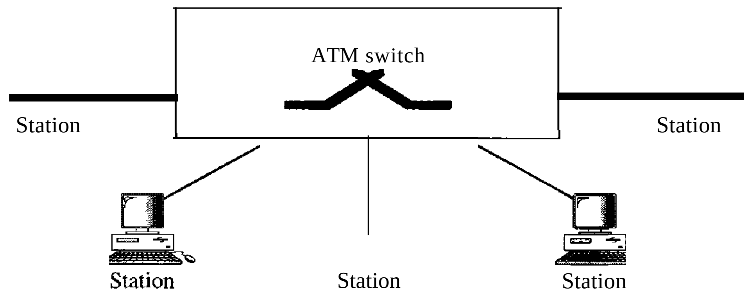
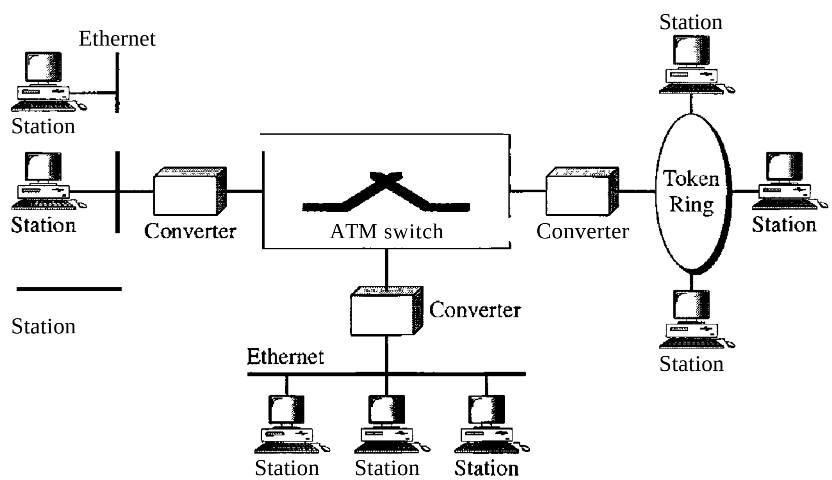


Figure 18.26 *Legacy ATM LAN*



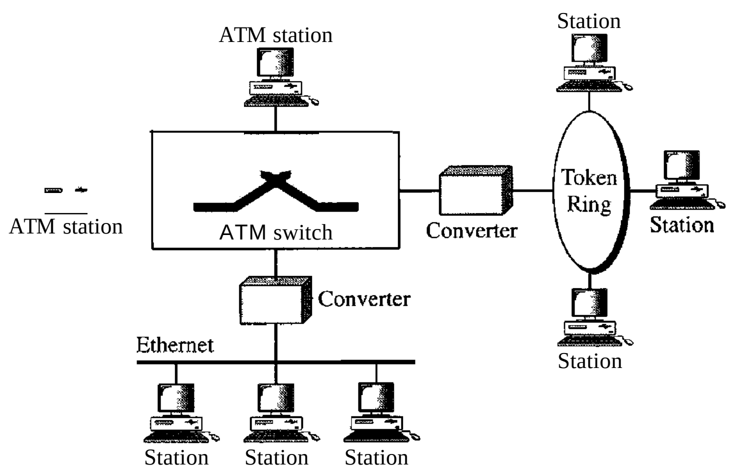
In this way, stations on the same LAN can exchange data at the rate and format of traditional LANs (Ethernet, Token Ring, etc.). But when two stations on two different LANs need to exchange data, they can go through a converting device that changes the frame format. The advantage here is that output from several LANs can be multiplexed together to create a high-data-rate input to the ATM switch. There are several issues that must be resolved first.

Mixed Architecture

Probably the best solution is to mix the two previous architectures. This means keeping the existing LANs and, at the same time, allowing new stations to be directly connected to an ATM switch. The mixed architecture LAN allows the gradual migration of legacy LANs onto ATM LANs by adding more and more directly connected stations to the switch. Figure 18.27 shows this architecture.

Again, the stations in one specific LAN can exchange data using the format and data rate of that particular LAN. The stations directly connected to the ATM switch can use an ATM frame to exchange data. However, the problem is, How can a station in a

Figure 18.27 *Mixed architecture ATM LAN*



traditional LAN communicate with a station directly connected to the ATM switch or vice versa? We see how the problem is resolved now.

LAN Emulation (LANE)

At the surface level, the use of ATM technology in LANs seems like a good idea. However, many issues need to be resolved, as summarized below:

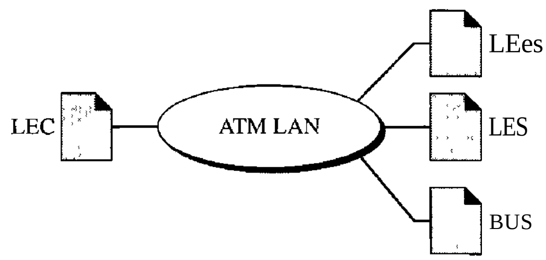
- Connectionless versus connection-oriented. Traditional LANs, such as Ethernet, are *connectionless protocols.* A station sends data packets to another station whenever the packets are ready. There is no *connection establishment* or *connection termination* phase. On the other hand, ATM is a *connection-oriented protocol;* a station that wishes to send cells to another station must first establish a connection and, after all the cells are sent, terminate the connection.
- Physical addresses versus virtual-circuit identifiers. Closely related to the first issue is the difference in addressing. A connectionless protocol, such as Ethernet, defines the route of a packet through *source* and *destination addresses.* However, a connection-oriented protocol, such as ATM, defines the route of a cell through virtual connection identifiers (VPIs and VCIs).
- Multicasting and broadcasting delivery. Traditional LANs, such as Ethernet, can both *multicast* and *broadcast* packets; a station can send packets to a group of stations or to all stations. There is no easy way to multicast or broadcast on an ATM network although point-to-multipoint connections are available.
- Interoperability. In a mixed architecture, a station connected to a legacy LAN must be able to communicate with a station directly connected to an ATM switch.

An approach called local-area network emulation (LANE) solves the above-mentioned problems and allows stations in a mixed architecture to communicate with one another. The approach uses emulation. Stations can use a connectionless service that emulates a connection-oriented service. Stations use the source and destination addresses for initial connection and then use VPI and VCI addressing. The approach allows stations to use unicast, multicast, and broadcast addresses. Finally, the approach converts frames using a legacy format to ATM cells before they are sent through the switch.

Client/Server Model

LANE is designed as a client/server model to handle the four previously discussed problems. The protocol uses one type of client and three types of servers, as shown in Figure 18.28.

Figure 18.28 *Client and servers in a LANE*



LAN Emulation Client

All ATM stations have LAN emulation client (LEC) software installed on top of the three ATM protocols. The upper-layer protocols are unaware of the existence of the ATM technology. These protocols send their requests to LEC for a LAN service such as connectionless delivery using MAC unicast, multicast, or broadcast addresses. The LEC, however, just interprets the request and passes the result on to the servers.

LAN Emulation Configuration Server

The LAN emulation configuration server (LECS) is used for the initial connection between the client and LANE. This server is always waiting to receive the initial contact. It has a well-known ATM address that is known to every client in the system.

LAN Emulation Server

LAN emulation server (LES) software is installed on the LES. When a station receives a frame to be sent to another station using a physical address, LEC sends a special frame to the LES. The server creates a virtual circuit between the source and the destination station. The source station can now use this virtual circuit (and the corresponding identifier) to send the frame or frames to the destination.

Broadcast/Unknown Server

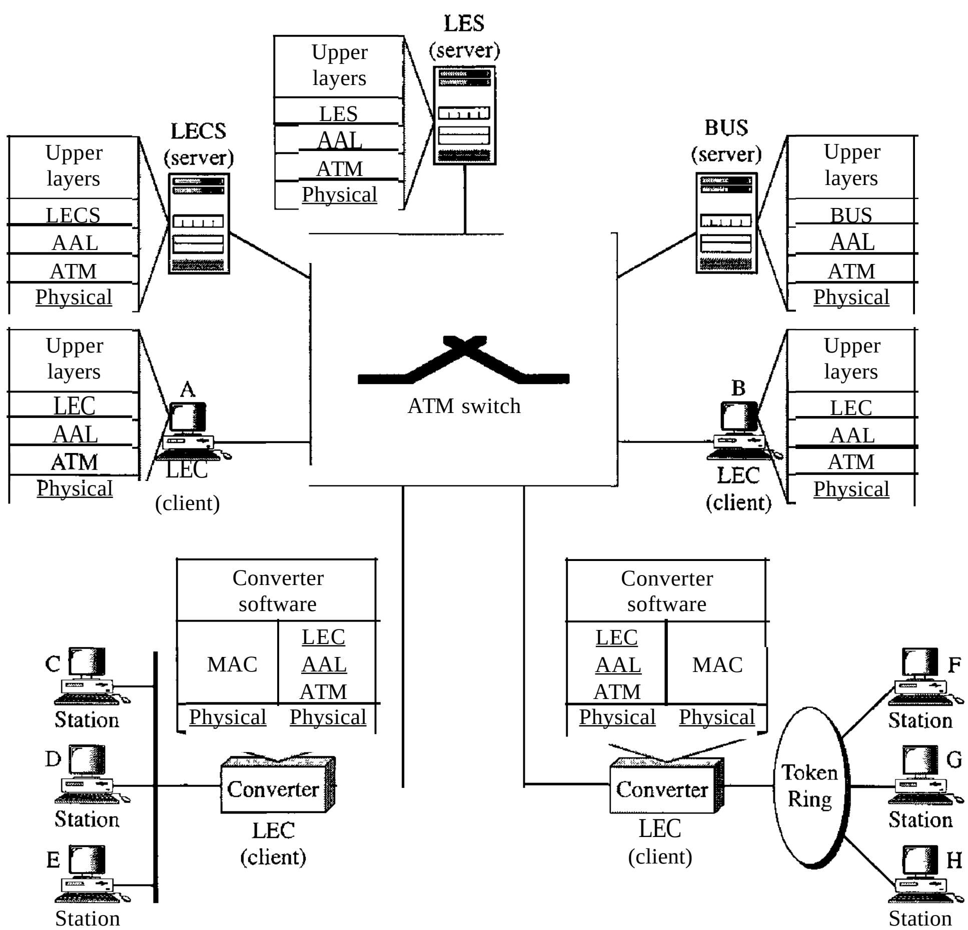
Multicasting and broadcasting require the use of another server called the broadcast! unknown server (BUS). If a station needs to send a frame to a group of stations or to every station, the frame first goes to the BUS; this server has permanent virtual connections to every station. The server creates copies of the received frame and sends a copy to a group of stations or to all stations, simulating a multicasting or broadcasting process.

The server can also deliver a unicast frame by sending the frame to every station. In this case the destination address is unknown. This is sometimes more efficient than getting the connection identifier from the LES.

Mixed Architecture with Client/Server

Figure 18.29 shows clients and servers in a mixed architecture ATM LAN. In the figure, three types of servers are connected to the ATM switch (they can actually be part of the switch). Also we show two types of clients. Stations A and B, designed to send and receive LANE communication, are directly connected to the ATM switch. Stations C, D, E, F, G, and H in traditional legacy LANs are connected to the switch via a converter. These converters act as LEC clients and communicate on behalf of their connected stations.

Figure 18.29 *A mixed architecture ATM IAN using IANE*



18.4 RECOMMENDED READING

For more details about subjects discussed in this chapter, we recommend the following books. The items in brackets [...] refer to the reference list at the end of the text.

Books

Frame Relay and ATM are discussed in Chapter 3 of [Sta98]. ATM LAN is discussed in Chapter 14 of [For03]. Chapter 7 of [Kei02] also has a good discussion of ATM LANs.

18.5 KEY TERMS

AALI
AAL2
AAL3/4
AAL5
application adaptation layer (AAL)
Asynchronous Transfer Mode (ATM)
ATMlayer
ATM switch
backward explicit congestion notification (BECN)
bandwidth on demand
broadcast/unknown server (BUS)
bursty data
cell
cell network
cell relay
client/server model
congestion control
conyergence sublayer (CS)
data link connection identifier (DLCI)
discard eligibility (DE)
forward explicit congestion notification (FECN)
Frame Relay
Frame Relay assembler/disassembler (FRAD)
LAN emulation client (LEC)
LAN emulation configuration server (LECS)
LAN emulation server (LES)
legacy ATM LAN
local-area network emulation (LANE)
Local Management Information (LMI)
mixed architecture LAN
network-to-network interface (NNI)
permanent virtual circuit (PVC)
pureATMLAN
quality of service (QoS)
segmentation and reassembly (SAR)
simple and efficient adaptation layer (SEAL)
switched virtual circuit (SVC)
transmission path (TP)
user-to-network interface (UNI)
virtual circuit (VC)
virtual-circuit identifier (VCl)
virtual path (VP)
virtual path identifier (VPI)
Voice Over Frame Relay (VOFR)
X.25

18.6 SUMMARY

- Virtual-circuit switching is a data link layer technology in which links are shared.
- A virtual-circuit identifier (VCI) identifies a frame between two switches.
- Frame Relay is a relatively high-speed, cost-effective technology that can handle bursty data.

- Both PVC and SVC connections are used in Frame Relay.
- The data link connection identifier (DLCI) identifies a virtual circuit in Frame Relay.
- Asynchronous Transfer Mode (ATM) is a cell relay protocol that, in combination with SONET, allows high-speed connections.
- A cell is a small, fixed-size block of information.
- The ATM data packet is a cell composed of 53 bytes (5 bytes of header and 48 bytes of payload).
- ATM eliminates the varying delay times associated with different-size packets.
- ATM can handle real-time transmission.
- A user-to-network interface (UNI) is the interface between a user and an ATM switch.
- A network-to-network interface (NNI) is the interface between two ATM switches.
- In ATM, connection between two endpoints is accomplished through transmission paths (TPs), virtual paths (VPs), and virtual circuits (VCs).
- In ATM, a combination of a virtual path identifier (VPI) and a virtual-circuit identifier identifies a virtual connection.
- The ATM standard defines three layers:
  a. Application adaptation layer (AAL) accepts transmissions from upper-layer services and maps them into ATM cells.
  b. ATM layer provides routing, traffic management, switching, and multiplexing serVIces.
  c. Physical layer defines the transmission medium, bit transmission, encoding, and electrical-to-optical transformation.
- The AAL is divided into two sublayers: convergence sublayer (CS) and segmentation and reassembly (SAR).
- There are four different AALs, each for a specific data type:
  a. AALI for constant-bit-rate stream.
  b. AAL2 for short packets.
  c. AAL3/4 for conventional packet switching (virtual-circuit approach or datagram approach).
  d. AAL5 for packets requiring no sequencing and no error control mechanism.
- ATM technology can be adopted for use in a LAN (ATM LAN).
- In a pure ATM LAN, an ATM switch connects stations.
- In a legacy ATM LAN, the backbone that connects traditional LANs uses ATM technology.
- A mixed architecture ATM LAN combines features of a pure ATM LAN and a legacy ATM LAN.
- Local-area network emulation (LANE) is a client/server model that allows the use of ATM technology in LANs.
- LANE software includes LAN emulation client (LECS), LAN emulation configuration server (LECS), LAN emulation server (LES), and broadcast/unknown server (BUS) modules.

18.7 PRACTICE SET

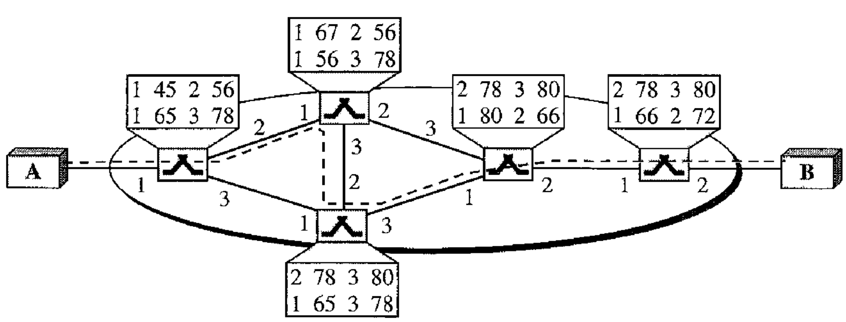
Review Questions

1. There are no sequence numbers in Frame Relay. Why?
2. Can two devices connected to the same Frame Relay network use the same DLCIs?
3. Why is Frame Relay a better solution for connecting LANs than T-llines?
4. Compare an SVC with a PVc.
5. Discuss the Frame Relay physical layer.
6. Why is multiplexing more efficient if all the data units are the same size?
7. How does an NNI differ from a UNI?
8. What is the relationship between TPs, VPs, and VCs?
9. How is an ATM virtual connection identified?
10. Name the ATM layers and their functions.
11. How many virtual connections can be defined in a UNI? How many virtual connections can be defined in an NNI?
12. Briefly describe the issues involved in using ATM technology in LANs.

Exercises

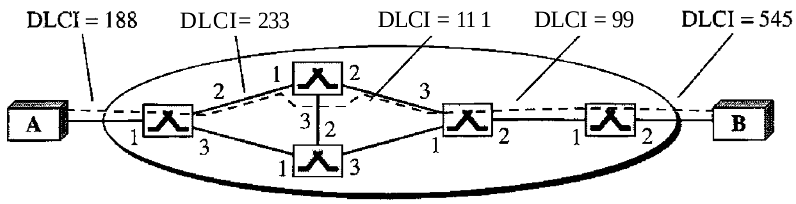
13. The address field of a Frame Relay frame is 1011000000010111. What is the DLCI (in decimal)?
14. The address field of a Frame Relay frame is 101100000101001. Is this valid?
15. Find the DLCI value if the first 3 bytes received is 7C 74 El in hexadecimal.
16. Find the value of the 2-byte address field in hexadecimal if the DLCI is 178. Assume no congestion.
17. **In** Figure 18.30 a virtual connection is established between A and B. Show the DLCI for each link.

Figure 18.30 *Exercise 17*



18. In Figure 18.31 a virtual connection is established between A and B. Show the corresponding entries in the tables of each switch.

Figure 18.31 *Exercise 18*



19. An AAL1 layer receives data at 2 Mbps. How many cells are created per second by the ATM layer?
20. What is the total efficiency of ATM using AAL1 (the ratio of received bits to sent bits)?
21. If an application uses AAL3/4 and there are 47,787 bytes of data coming into the CS, how many padding bytes are necessary? How many data units get passed from the SAR to the ATM layer? How many cells are produced?
22. Assuming no padding, does the efficiency of ATM using AAL3/4 depend on the size of the packet? Explain your answer.
23. What is the minimum number of cells resulting from an input packet in the AAL3/4 layer? What is the maximum number of cells resulting from an input packet?
24. What is the minimum number of cells resulting from an input packet in the AAL5 layer? What is the maximum number of cells resulting from an input packet?
25. Explain why padding is unnecessary in AAL1, but necessary in other AALs.
26. Using AAL3/4, show the situation where we need of padding.
    a. 0 bytes (no padding)
    b. 40 bytes
    c. 43 bytes
27. Using AAL5, show the situation where we need of padding.
    a. 0 bytes (no padding)
    b. 40 bytes
    c. 47 bytes
28. In a 53-byte cell, how many bytes belong to the user in the following (assume no padding)?
    a. AAL1
    b. AAL2
    c. AAL3/4 (not the first or last cell)
    d. AAL5 (not the first or last cell)

Research Activities

29. Find out about 1.150 protocol that provides generic flow control for UNI interface.
30. ATM uses the 8-bit HEe (header error control) field to control errors in the first four bytes (32 bits) of the header. The generating polynomial is $x^8 + x^2 + x + 1$. Find out how this is done.
31. Find the format of the LANE frames and compare it with the format of the Ethernet frame.
32. Find out about different steps involved in the operation of a LANE.

PART 4

Network Layer

Objectives

The network layer is responsible for the source-to-destination delivery of a packet, possibly across multiple networks (links). Whereas the data link layer oversees the delivery of the packet between two systems on the same network (links), the network layer ensures that each packet gets from its point of origin to its final destination.

The network layer is responsible for the delivery of individual packets from the source to the destination host.

The network layer adds a header that includes the logical addresses of the sender and receiver to the packet corning from the upper layer. If a packet travels through the Internet, we need this addressing system to help distinguish the source and destination.

When independent networks or links are connected together to create an internetwork, routers or switches route packets to their final destination. One of the functions of the network layer is to provide a routing mechanism.

In Part 4 of the book, we first discuss logical addressing (referred to as IP addressing in the Internet). We then discuss the main as well as some auxiliary protocols that are responsible for controlling the delivery of a packet from its source to its destination.

Part 4 of the book is devoted to the network layer and the services provided by this layer.

Chapters

This part consists of four chapters: Chapters 19 to 22.

Chapter 19

Chapter 19 discusses logical or IP addressing. We first discuss the historical classful addressing. We then describe the new classless addressing designed to alleviate some problems inherent in classful addressing. The completely new addressing system, IPv6, which may become prevalent in the near future, is also discussed.

Chapter 20

Chapter 20 is devoted to the main protocol at the network layer that supervises and controls the delivery of packets from the source to destination. This protocol is called the Internet Protocol or IP.

Chapter 21

Chapter 21 is devoted to some auxiliary protocols defined at the network layer, that help the IP protocol do its job. These protocols perform address mapping (logical to physical or vice versa), error reporting, and facilitate multicast delivery.

Chapter 22

Delivery and routing of packets in the Internet is a very delicate and important issue. We devote Chapter 22 to this matter. We first discuss the mechanism of delivery and routing. We then briefly discuss some unicast and multicast routing protocols used in the Internet today.