Chapter 2

An Overview of ATM Network

ATM is a form of packet switching technology. That is, ATM networks transmit their information in small, fixed length packets called “cell” each of which contains 48-octets (or bytes) of data and 5-octets of header information. The small, fixed cell size was chosen to facilitate the rapid processing of packet in hardware and to minimize the amount of time required to fill a single packet. This is particularly important for real-time applications such as voice and video that require short packetization delays. ATM is the transfer mode for implementing Broadband Integrated Service Digital Networks (B-ISDN) [21].

The term transfer comprises both transmission and switching aspects, so a transfer mode is a specific way of transmitting and switching information in a network. The term asynchronous, in new transfer mode name refers to the fact that, in the context of multiplexed transmission, cells allocated to the same connection may exhibit an irregular recurrence pattern as they are filled according to the actual demand, this is shown in Figure 2-1(a).

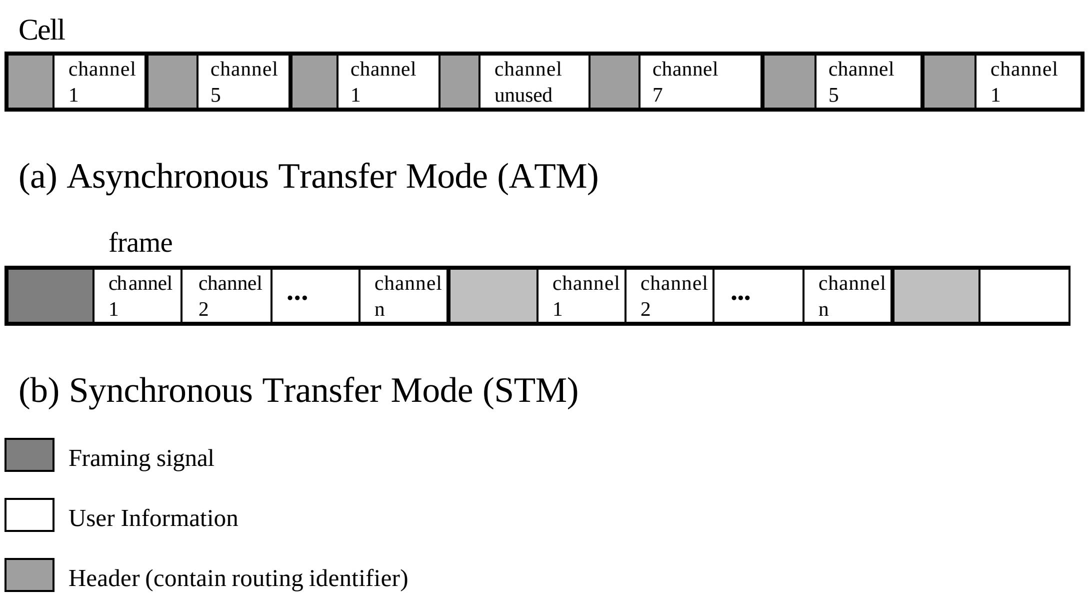


Figure 2-1 Synchronous and Asynchronous Transfer Modes.

Figure 2-1 describes the difference between the Synchronous Transfer Mode (STM), and the Asynchronous Transfer Mode (ATM). As we have mentioned above that ATM is the data transfer interface for B-ISDN, let's give short notes about B-ISDN standards.

2-1 B-ISDN Standards

In 1988, the telecommunication standardization sector of the ITU, the international standards agency commissioned by the United Nations for the global standardization of telecommunications, has developed a number of standards for ATM networks. Other standards bodies and consortia (e.g., the ATM Forum, ANSI) have also contributed to the development of ATM standards. The following subsection presents an overview of the standards, with particular emphasis on the protocol reference model used by ATM [22].

2-1-1 Protocol Reference Model

The B-ISDN protocol reference model, defined in ITU-T recommendation I-321, is shown in Figure 2-2 [23]. The purpose of the protocol reference model is to clarify the functions that ATM networks perform by grouping them into a set of interrelated, function-specific layers and planes. The reference model consists of a user plane, a control plane and a management plane (more details about these planes are in [24, 25, 26]. Within the user and control planes is a hierarchical set of layers. The user plane defines a set of functions for the transfer of user information between communication end-points; the control plane defines control functions such as call establishment, call maintenance, and call release, and the management plane defines the operations necessary to control information flow between planes and layers, and maintain accurate and fault-tolerant network operation.

Within the user and control planes, there are three layers; the physical layer, the ATM layer, and the ATM adaptation layer (AAL).

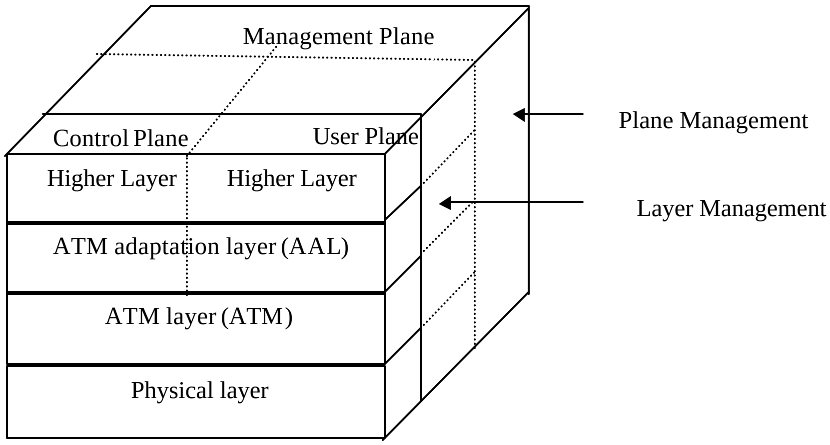


Figure 2-2 Protocol Reference Model for ATM

Table 2-1 summarizes the functions of each layer [23]. The physical layer performs primarily bit level functions, the ATM layer is primarily responsible for the switching of ATM cells, and the ATM adaptation layer is responsible for the conversion of higher layer protocol forms into ATM cells. The function that the physical, ATM, and adaptation layers perform are described in more detail in the following:

Layer management	Higher Layer Functions	Higher Layers		
	.convergence	CS	AAL	
	.segmentation and reassembly	SAR		
	.generic flow control .cell-header generation/extraction .cell VPI/VCI translation .cell multiplex and demultiplex	ATM layer		
	.cell-rate decoupling .HEC, header-sequence generation/verification .cell delineation .transmission-frame adaptation .transmission-frame generation/recovery	TC	physical layer	PHY independent
	bit timing physical medium	PM		PHY dependent

AAL : ATM Adaptation layer.
CS : Convergence Sublayer.
SAR : Segmentation And Reassembly.
VPI : Virtual Path Identifier.
VCI : Virtual Channel Identifier.
HEC : Header Error Control.
TC : Transmission Control.
PM : Physical Medium

Table 2-1 the Functions of B-ISDN in Relation to the B-ISDN PRM.

2-1-2 Physical Layer

The physical layer is divided into two sublayers: the physical medium sublayer, and the transmission convergence sublayer [23].

2-1-2-1 Physical Medium (PM) sublayer

The physical medium sublayer performs medium-dependent functions. For example, it provides bit transmission capabilities including bit alignment, line coding and electrical/optical conversion. The PM sublayer is also responsible for bit timing, i.e., the insertion and extraction of bit timing information. The PM sublayer currently supports two types of interface: optical and electrical.

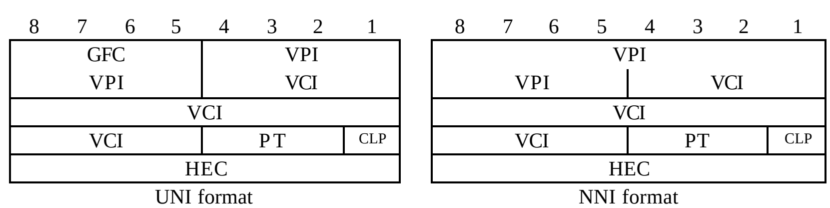
2-1-2-2 Transmission Convergence (TC) sublayer

Above the physical medium sublayer is the transmission convergence sublayer, which is primarily responsible for framing of data transported over the physical medium. The ITU-T recommendation specifies two options for TC sublayer transmission frame structure: cell-based and Synchronous Digital Hierarchy (SDH). In the cell-based case, cells are transported continuously without any regular frame structure. Under SDH, cells are carried in a special frame structure based on the North American SONET (Synchronous Optical Network) protocol [27]. Regardless of which transmission frame structure is used, the TC sublayer is responsible for the following four functions: cell rate decoupling, header error control, cell delineation, and transmission frame adaptation. Cell rate decoupling is the insertion of idle cells at the sending side to adapt the ATM cell stream's rate to the rate of the transmission path. Header error control is the insertion of an 8-bit CRC polynomial in the ATM cell header to protocol the contents of the ATM cell header. Cell delineation is the detection of cell boundaries. Transmission frame adaptation is the encapsulation of departing cells into an appropriate framing structure (either cell-based or SDH-based).

2-1-3 ATM Layer

The ATM layer lies a top the physical layer and specifies the functions required for the switching and flow control of ATM cells [23].

There are two interfaces in an ATM network; the user-network-interface (UNI) between the ATM end-point and the ATM switch, and the network-network interface (NNI) between two ATM switches. Although a 48-octets cell payload is used at both interfaces, the 5-octets cell header differs slightly at these interfaces. Figure 2-3 shows the cell header structures used at the UNI and NNI [23]. At the UNI, the header contains a 4-bits Generic Flow Control (GFC) field, a 24-bits label field containing VPI and VCI subfields (8-bits for the VPI and 16-bits for the VCI), a 2-bits payload type (PT) field, a 1-bit priority (PR) field, and an 8-bit header error check (HEC) field. The cell header for an NNI cell is identical to that for the UNI cell, except that it lacks the GFC field; these four bits are used for an additional 4 VPI bits in the NNI cell header.



GFC : General Flow Control PT: Payload Type. CLP : Cell Loss Priority

Figure 2-3 ATM Cell Header Format

The VCI and VPI fields are identifier values for VC and VP respectively. A virtual channel connects two ATM communication end-points. A virtual path connects two ATM devices, which can be switches or end-points, and several virtual channels may be multiplexed onto the same virtual path. The 2-bit PT field identifiers whether the cell payload contains data or control information. The CLP bit is used by the user for explicit indication of cell loss priority. If the value of the CLP is 1, then the cell is subject to discarding in case of congestion. The HEC field is an 8-bit CRC polynomial that protects the contents of the cell header. The GFC field, which appears only at the UNI, is used to assist the customer premises network in controlling the traffic flow for different qualities of service. At the time of writing, the exact procedures for use of this field have not been agreed upon.

2-1-3-1 ATM Layer Functions

The primary function of the ATM layer is VPI/VCI translation. As ATM cells arrive at ATM switches, the VPI and VCI values contained in their headers are examined by the switch to determine which output port should be used to forward the cell. The process, the switch translates the cell’s original VPI and VCI values into new outgoing VPI and VCI values, which are used in turn by the next ATM switch to send the cell toward its intended destination. The table used to perform this translation is initialized during the establishment of the call.

An ATM switch may either be a VP switch, in which case it only translates the VPI values contained in cell headers, or it may be a VP/VC switch, in which case it translates the incoming VCI value into an outgoing VPI/VCI pair. Since VPI and VCI values do not represent a unique end-to-end virtual connection, they can be reused at different switches through the network. This is important, because the VPI and VCI fields are limited in length and would be quickly exhausted if they were used simply as destination addresses.

The ATM layer supports two types of virtual connections; switched virtual connection (SVC) and permanent, or semi-permanent, virtual connections (PVC). Switched virtual connections are established and torn down dynamically by an ATM signaling procedure. That is, they only exist for the duration of a single call. Permanent virtual connections, on the other hand, are established by network administrators and continue to exist as long as the administrator leaves them up, even if they are not used to transmit data.

Other important functions of the ATM layer include cell multiplexing and demultiplexing, cell header creation and extraction, and generic flow control. Cell multiplexing is the merging of cells from several calls onto a single transmission path. Cell header creation is the attachment of a 5-octets cell header to each 48-octets block of user payload, and generic flow control is used at the UNI to prevent short-term overload condition from occurring within the network.

2-1-3-2 The AAL Functions

AAL functions are organized in two sublayers. The essential functions of the Segmentation And Reassembly (SAR) sublayer are, at the transmitting side, segmentation of higher layer Packet Data Units (PDUs) into a suitable size for the information field of the ATM cell and, at receiving side, Reassembly of the particular information fields into higher layer PDUs. The Convergence Sublayer (CS) is service dependent and provides the AAL service at the AAL-SAP. No Service Access Point (SAP) has yet been defined between these two sublayers.

Figure 2-4 depicts the AAL classes. Not all-possible combinations make sense and therefore only four classes are distinguished [25].

	Class A	Class B	Class C	Class D
Timing relation between source and destination	Required		Not required	
Bit rate	Constant	Variable		
Connection mode	Connection oriented			Connectionless

Figure 2- 4 Service Classification of AAL

AAL Type 1: This service is used by the applications that require a Constant Bit Rate (CBR), such as uncompressed voice and video, and usually referred to as isochronous. This type of application is extremely time-sensitive and therefore end-to-end timing is paramount and must be supported. Isochronous traffic is assigned service class A.

AAL Type 2: again this service is used for compressed voice and video (packetized isochronous traffic), however, it is primarily developed for multimedia applications. The compression allows for a Variable Bit Rate (VBR) service without losing voice and video quality. The compression of voice and video (class B) however, does not negate the need for end-to-end timing. However, timing is still important and is assigned a service class just below that of AAL Type 1.

AAL Type ¾: This adaptation layer supports both connection-oriented and compatibility with IEEE 802.6 that is used by Switched Multimegabit Data Service (SMDS). Connection-oriented AAL Type 3 and AAL Type 4 payloads are provided with a service class C while connectionless-oriented AAL Type 3 and AAL Type 4 payloads are assigned the service class D. The support for IEEE 802.6 significantly increases cell overhead for data transfer when compared with AAL Type 5.

AAL Type 5: For data transport, AAL Type 5 is the preferred AAL to be used by applications. Its connection-oriented mode guarantees delivery of data by the servicing applications and doesn't add any cell overhead.

2-2 The B-ISDN Layers

In ATM, all information to be transferred is packed into fixed-size length called cell, the structure is shown in Figure 2-5, in which the information field (48 octets) is available for the user. The header field carries information that pertains to the ATM layer functionality itself, mainly the identification of cell by means of a label.

Header (5 octets)	**Information field** (48 octets)

Figure 2-5 Cell Structure

Octets are sent in increasing order starting with octet 1. Bits within an octet are sent in decreasing order starting with bit 8. For all fields, the first bit sent is the most significant bit (MSB). The header consists of primarily of virtual path/ channel identifiers (VPI/VCI). The layers in the ATM contain the physical layer, and ATM layer as shown in Figure 2-6.

Higher layer	
ATM Layer	Virtual channel level
	Virtual path level
Physical layer	Transmission path level
	Digital section level
	Regenerator section level

Figure 2-6 ATM Layer Hierarchy

Figure 2-7 demonstrates the relationship between virtual channel, virtual path and transmission path. A transmission path may comprise several virtual paths and each virtual path may carry several virtual channels. Concerning the levels of the ATM layer (virtual channel and virtual path), it is helpful to distinguish between links and connections.

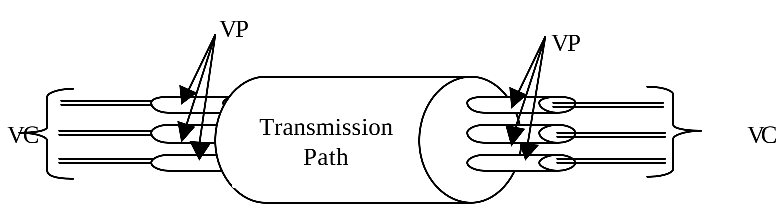


Figure 2-7 Relationships between Virtual Channel, Virtual Path, and Transmission Path

A Virtual Channel Link: means unidirectional transport of ATM cells between a point where a VCI value is assigned and the point where that value is translated or removed. Similarly, the points where VPI value is assigned and translated or removed terminate a Virtual Path link. A concatenation of VC links is called a Virtual Channel Connection (VCC) and likewise, a concatenation of VP links is called a Virtual Path Connection (VPC). The relationship between different levels of the ATM transport network is shown in Figure 2-8. A VCC may consist of several concatenations VC links, each of which is embedded, in a VPC. The VPC's usually consists of several concatenations VP links. Each VP link is implemented on a transmission path, which hierarchically comprises digital section and regenerator sections.

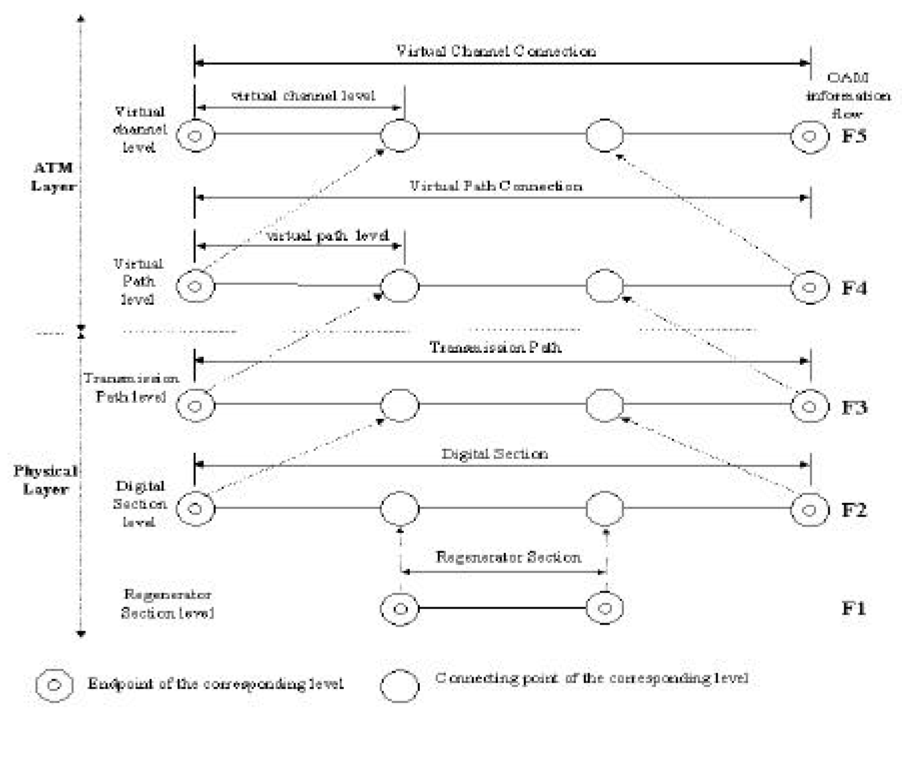


Figure 2-8 Hierarchical Layer-to-Layer Relationship.

2-2-1 The Physical Layer

1- Transmission path level extends between network elements that assemble and disassemble the payload of a transmission system. For end to end communication, the payload is end-user information. For user-to-network communication, the payload may be signaling information. Cell delineation and HEC functions are required at the end-points of each transmission path.

2- Digital section level extends between network elements that assemble and disassemble a continuous bit or byte stream. This refers to the exchange or signal-transfer points in a network that are involved in switching data streams.

3- Regenerator section level, a portion of a digital section. An example of this level is a repeater that is used to simply regenerate the digital signal a long a transmission path that is too long to be used without such regeneration no switching is involved.

2-2-2 The ATM Layer

The logical connection in ATM is referred to as virtual channel connection (VCC). VCC is analogous to a virtual circuit in frame relay logical connection. It is the basic unit of switching in B-ISDN, a VCC is setup between two end users through the network, and a variable rate, and full-duplex flow of fixed-size cells is exchanged over the connection. VCCs are also used for user-network exchange (control signaling) and network-network exchange (management and routing).

The second sublayer of processing has been introduced that deals with the concepts of virtual path. A virtual path connection (VPC) is a bundle of VCCs that has the same end points. Thus, all the cells flowing over all the VCCs in a single VPC are switched together.

2-3 Signaling: Making ATM Connections

Signaling is responsible for setting up the desired connection or virtual circuit and tearing it down when the transmission is completed.

2-3-1 Connection Types

There are two types of connection depending on how the virtual channel established. One is Permanent Virtual Circuit (PVC) and the other is Switched Virtual Circuit (SVC).

2-3-1-1 Permanent Virtual Circuits (PVCs)

PVCs are those data connections that require the circuit to be manually setup. Typically, a VPI/VCI combination is stored into look-up tables on ATM hardware on the network. To set up the connection, the network administrator will specify a set of VPI/VCI source and destination option. The ATM end-station can then be connected to another end-station over the network via a switched path.

2-3-1-2 Switched Virtual Circuits (SVCs)

Switched signaling mechanisms facilitate dynamic links between end-stations. The setup and tear down of a virtual circuit can be accomplished without manual intervention.

2-3-2 Call Types

Now that the mechanisms for signaling have been established, data may be transferred between the calling and the called party. This section covers the various types of desired connections and how they are established.

1. Point-to-Point

Connections made between two end-stations compose a point-to-point link. Point-to-point links may be bidirectional or full duplex. In these cases the sender and receiver both make a data transfer request. Each issues the appropriate connection setup messages. They can then send data on their separately established virtual circuit connections. If the service connections are identical for each end-station (e.g., same bandwidth and other quality of service parameters), then the connection is said to be symmetric. Should the bandwidth requests be different for each end-station, then the connection is said to be asymmetric.

2. Point-to-Multipoint

Point-to-Multipoint works much the same as point-to-point. Here however, one virtual circuit connection established from one end-station specifies many recipients. The initiating end-station is classified as the root station. All called end-stations are classified as leaves. A point-to-point link is established from the root to each leaf, one at a time, until all leaves are connected via the root virtual circuit or connection. While a point-to-point link may be established in a two-way (full-duplex) mode, leaves are not able to initiate a call back to the root.

3. Multipoint-to-Multipoint

The signaling mechanism established so far for ATM VCCs supports the exchange of addresses between end-station only. This precludes the ability of the current signaling mechanism to set up many-to-many users or Multipoint-to-Multipoint connections. The Signaling Working Group (SWG) of the ATM Forum addresses this area.

2-3-3 Call Setup and Tear down

Messages are exchanged between the calling end-station and its nearest neighbor. These messages are passed along the network until the called party is reached and can acknowledge the call. This is illustrated in Figure 2-9.

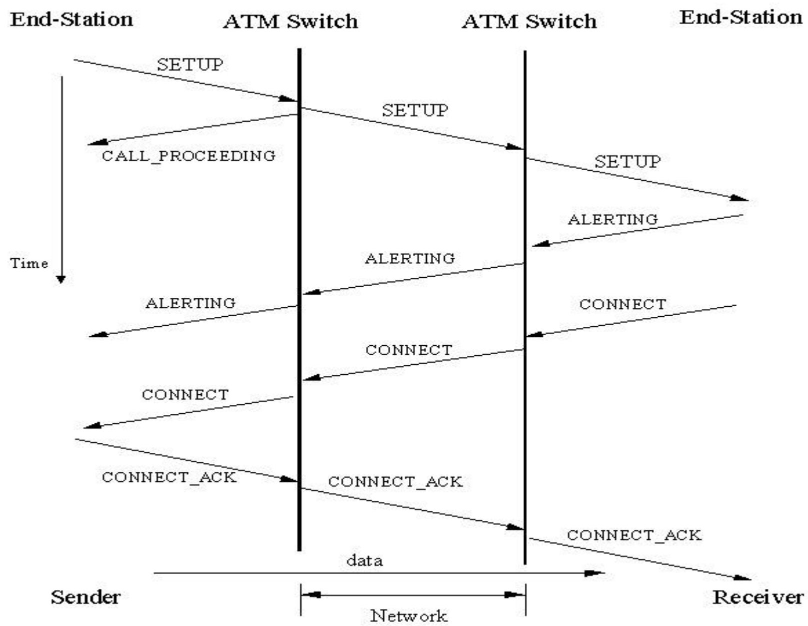


Figure 2-9 Call Setup

Call Completed

Here, we look at an end-station successfully completing a call to another end-station across an ATM network. Initially a call SETUP message is transmitted from the sending end-station. The nearest neighbor, here a switch, return a CALL_PROCEEDING message to the end-station. Meanwhile, the SETUP message is being forwarded to the receiving end-station via the network of switches. Once it reviews the SETUP request message and can accommodate the call, the receiver forwards an ALERTING message through the network that presages a CONNECT message. At this time, or at the time a CALL_PROCEEDING message is received by the sender, a VPI/VCI number is determined and allocated to the sender.

Once the sender receives the CONNECT message, it returns a CONNECT_ACK, or acknowledge message, to the receiver. When the data transmission is completed, a RELEASE_COMPLETE message is transmitted, causing the circuit to tear down. This allows other end-stations access to the network.

Call Refused

If a call cannot be completed, the situation is such that a ELEASE_COMPLETE is transmitted back to the sender instead of an ALERT, followed by a CONNECT message.

2-4 SONET/SDH Specifications

Signal Hierarchy:

The SONET (Synchronous Optical Network) specification defines a hierarchy of standardized digital data rates, as shown in Table 2-2 [28].

SONET Designation	CCITT Designation	Data Rate (Mbps)	Payload Rate
STS-1/OC-1	-	51.84	50.112
STS-3/OC-3	STM-1	155.52	150.336
STS-9/OC-9	STM-3	466.56	451.008
STS-12/OC-12	STM-4	622.08	601.344
STS-18/OC-18	STM-6	933.12	902.016
STS-24/OC-24	STM-8	1,244.16	1202.688
STS-36/OC-36	STM-12	1,866.24	1804.032
STS-48/OC-48	STM-16	2,488.32	2405.376

STS : Synchronous Transport Signal OC : Optical Carrier STM: Synchronous Transport Module.

Table 2-2 SONET/ SDH Signal Hierarchy.

System Hierarchy

SONET capabilities have been mapped into a four-layer hierarchy Figure 2-10, more details in [24]. Figure 2-11 shows the physical realization of the logical layers.

1. **Photonic**: This is the physical layer, it includes a specification of the type of optical fiber-that may be used and details such as the required minimum powers and dispersion characteristics of the transmitting lasers and the required sensitivity of the receivers. This layer is also

responsible for converting STS (electrical) signals to OC (optical) signals.

2. **Section**: This layer creates the basic SONET frames. Transmission functions include framing scrambling, and error monitoring.
3. **Line**: This layer is responsible for synchronization, multiplexing of data onto the SONET frames, and protection switching.
4. **Path**: This layer is responsible for end-to-end transport of data at the appropriate signaling speed.

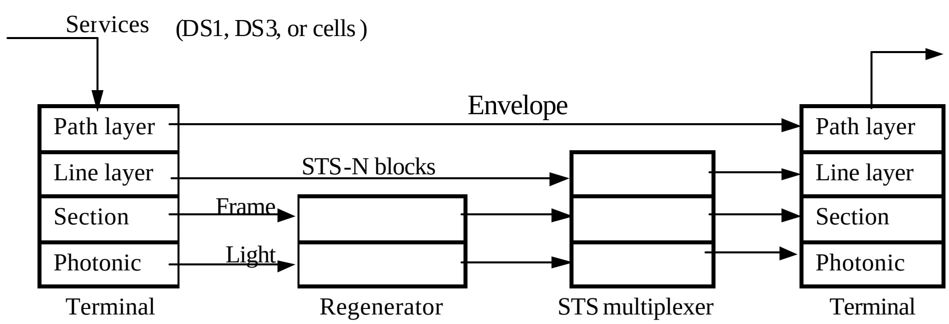


Figure 2-10 Logical Hierarchy of SONET System.

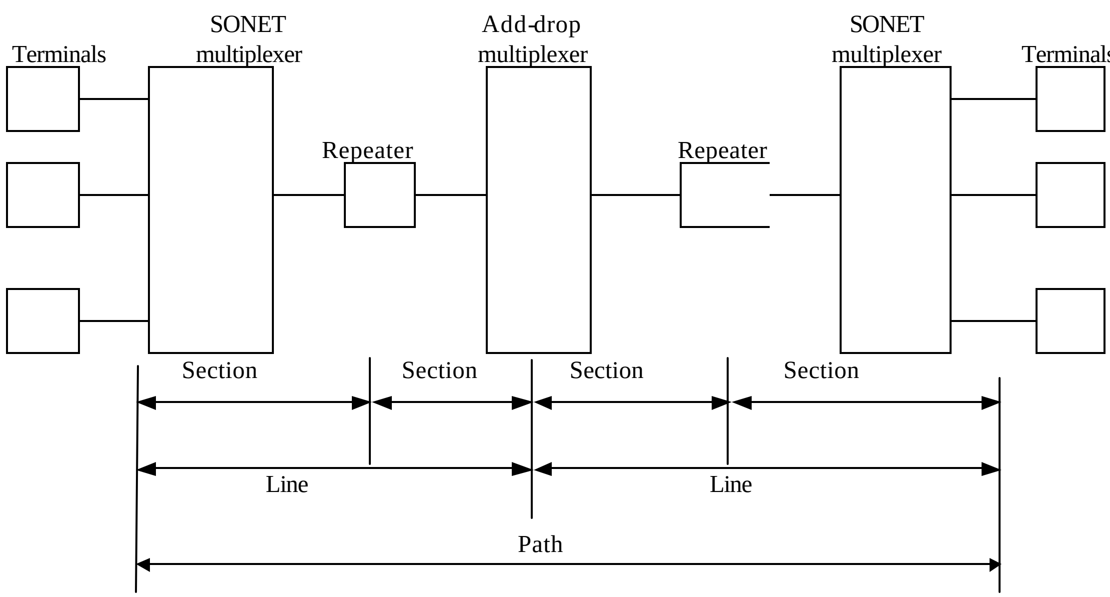


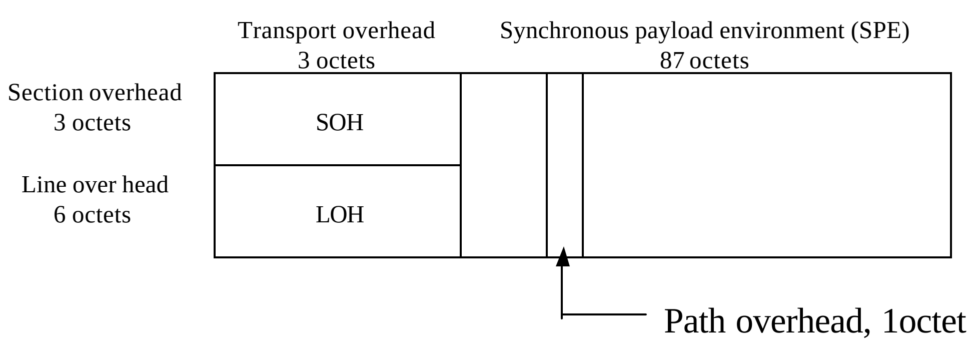
Figure 2-11 Physical Hierarchy of SONET System

***The SONET Frame Format*:**

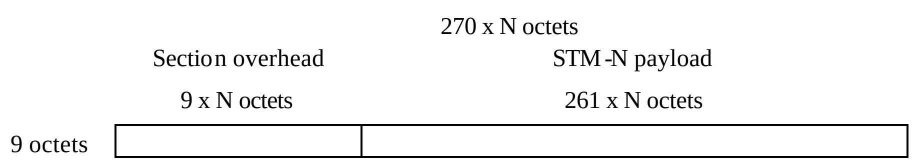
The basic SONET building block is the STS-1 frame, which consists of 810-octets and is transmitted once every 125 µs (micro-second). For an overall data rate of 51.84 Mbps is shown in Figure 2-12 (a). The frame can logically be viewed as a matrix of nine rows of 90 octets each, with transmission being one row at a time, from left to right and top to bottom. Figure 2-12 (b), illustrates the size of the matrix of STM-N frame format.

2-4-1 SDH-Based Interface at 51.84 Mbps (STS-1)

The first three elements (9 x 3 = 27 octets) of the frame are devoted to overhead octets with 9 octets being devoted to section-related overhead and 18 octets to line overhead. Figure 2-13, shows the arrangement of overhead octets, and Table 2-3 defines the various fields. The remainder of the frame is payload, which is provided by the path layer. The payload includes a column of path overhead, which is not necessarily in the first available column position, the line overhead contains a pointer that indicates where the path overhead starts.



(a) STS-1 frame format



(b) STM-N frame format

Figure 2-12 SONET/SDH Frame Format

				Path overhead
Section overhead	Framing A1	Framing A2	STS-ID C1	Trace j1
	BIP-8 B1	Orderwire E1	User F1	BIP B3
	Data com. D1	Data com. D1	Data com. D1	Signal label C2
Line overhead	Pointer H1	Pointer H2	Pointer action H3	Path status G1
	BIP-8 B2	APS K1	APS K2	User F2
	Data com. D4	Data com. D5	Data com. D6	Multiframe H4
	Data com. D7	Data com. D8	Data com. D9	Growth Z3
	Data com. D10	Data com. D11	Data com. D12	Growth Z4
	Growth Z1	Growth Z2	Orderwire E2	Growth Z5
	Section overhead			Path overhead

Figure 2-13 SONET STS-1 Overhead octets.

Section overhead	
A1,A2	Framing bytes =F6, 28hex; used to synchronize the beginning of the frame.
C1	STS-1 ID identifies the STS-1 number (1 to N) for each STS-1 within an STS-n multiplex.
B1	Bit-interleaved Parity byte providing even parity over previous STS-N frame after scrambling; the i^{th} bit of this octet contains the even parity value calculated from the i^{th} bit position of all octets in the previous frame.
E1 F1	Section-level 64-Kbps PCM Orderwire; optional 64-Kbps voice channel to be used between section-terminating equipment, hubs, and remote terminals. 64-Kbps channel set aside for user purposes.
D1-D3	192-Kbps data communications channel for alarms, maintenance, control, and administration between sections.
Line Overhead	
H1-H3	pointer bytes used in frame alignment and frequency adjustment of payload data
B2	Bit-interleaved parity byte for line-level error monitoring.
K1,K2	Two bytes allocated for signaling between line-level automatic-protection switching equipment; uses a bit- oriented protocol that provides for error protection and management of the SONET optical link.
D4-D12	576-Kbps data communication channel for alarms, maintenance, control, monitoring and administration at the line level.
Z1,Z2	Reserved for future use.
E2	64-Kbps PCM voice channel for line-level Orderwire.

Table 2-3 STS-1 Overhead Bits

Path Overhead	
j1	64-Kbps channel used to repetitively send a 64-octet fixed-length string so a receiving terminal can continuously verify the integrity of a path; the contents of the message are user-programmable.
B3	Bit-interleaved parity byte at the path level, calculated over all bits of the previous SPE.
C2	STS path signal label to designate equipped versus unequipped STS signals. Unequipped means that the line connection is complete but there are no path data to send. For equipped signals, the label can indicate the specific STS payload mapping that might be needed in receiving terminals to interpret the payloads.
G1	Status byte sent from path-terminating equipment back to path-originating equipment to convey the status of terminating equipment and path error performance.
F2	64-Kbps channel for path user.
H4	Multiframe indicator for payloads needing frames that are longer than a single STS frame; Multiframe indicators are used when packing lower-rate channels (virtual tributaries) into the SPE.
Z3-Z5	Reserved for future use.

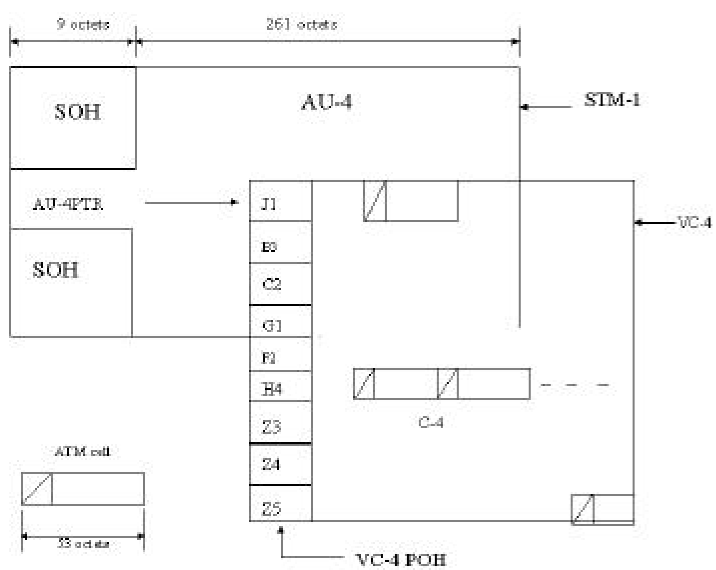
Table 2-3 STS-1 Overhead Bits (continue).

2- 4-2 SDH-Based interface at 155.52 Mbps (STS-3)

At the physical bit level the B-ISDN UNI has a bit rate of 155.520 Mbps or 622.080 Mbps. The interface transfer capability is defined as the bit rate available for user information cells, signaling cells and ATM and higher layer operation and maintenance (OAM) information cells, excluding physical layer frame structure bytes or physical layer cells. Its value of 149.760 Mbps for the 155.52 Mbps interface complies with SDH. The transfer capacity of the 622.08 Mbps interface is 599.04 Mbps (four times 149.76 Mbps). The transmission frame structure for an SDH-based interface at 155.52 Mbps is shown in Figure 2-14.

This frame is byte-structured and consists of 9 rows and 270 columns. The frame repetition frequency is 8 kHz (9 x 270 byte x 8 bit x 8 kHz) = 155.520 Mbps. The first 9 columns comprise section overhead (SOH) and administrative pointer-4 (AU-4). Another 9-byte column is dedicated to the path overhead

(POH). Generation of the SDH-based UNI signal is as follows. First, the ATM cell stream is mapped into Container-4 (C-4) which is a 9 rows x 260 columns container corresponding to the transfer capability of 149.76 Mbps. Next C-4 is packet in Virtual Container-4 (VC-4) along with the VC-4 POH. The ATM cell boundaries are aligned with the byte boundaries of the frame. It should be noted that an ATM cell may cross a C-4 boundary as the C-4 capacity (2340 bytes) is not an integer multiple of the cell length (53 bytes). VC-4 is then mapped into the 9 x 270 byte frame (known as the synchronous transport module 1 (STM-1). The AU-4 pointer is used to find the first byte of VC-4. POH bytes J1, B3, C2, G1 are then activated.



PTR : Pointer
c : Container
VC-4: Virtual Container 4
POH : Path OverHead
AU :Administrative unit
SOH : Section OverHead
STM-1:Synchronous Transport Module 1

Figure 2-14 Frame Structure of the 155.52 Mb/s SDH-Based Interface.