Chapter 15
Computer and Multimedia Networks

15.1 Basics of Computer and Multimedia Networks

- Computer networks are essential to modern computing.
- Multimedia networks share all major issues and technologies of computer networks.
- The ever-growing needs for various multimedia communications have made networks one of the most active areas for research and development.
- Various high-speed networks are becoming a central part of most contemporary multimedia systems.

OSI Network Layers

- **OSI Reference Model has the following network layers:**

  1. **Physical Layer**: Defines electrical and mechanical properties of the physical interface, and specifies the functions and procedural sequences performed by circuits of the physical interface.

  2. **Data Link Layer**: Specifies the ways to establish, maintain and terminate a link, e.g., transmission and synchronization of data frames, error detection and correction, and access protocol to the Physical layer.

  3. **Network Layer**: Defines the routing of data from one end to the other across the network. Provides services such as addressing, internetworking, error handling, congestion control, and sequencing of packets.

OSI Network Layers (Cont'd)

4. **Transport Layer**: Provides end-to-end communication between *end systems* that support end-user applications or services. Supports either *connection-oriented* or *connectionless* protocols. Provides error recovery and flow control.

5. **Session Layer**: Coordinates interaction between user applications on different hosts, manages sessions (connections), e.g., completion of long file transfers.

6. **Presentation Layer**: Deals with the syntax of transmitted data, e.g., conversion of different data formats and codes due to different conventions, compression or encryption.

7. **Application Layer**: Supports various application programs and protocols, e.g., FTP, Telnet, HTTP, SNMP, SMTP/MIME, etc.

TCP/IP Protocols

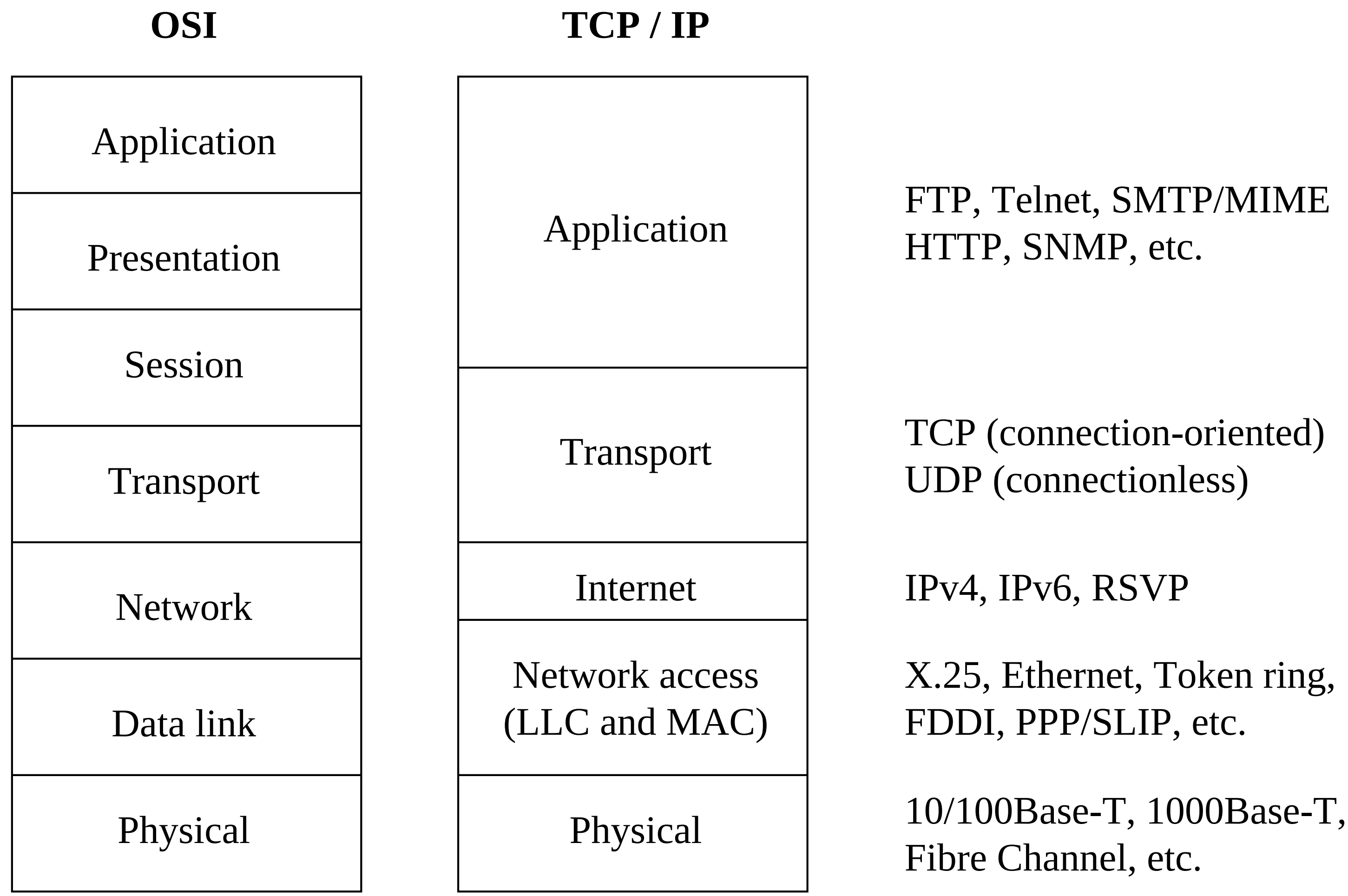


Fig. 15.1: Comparison of OSI and TCP/IP protocol architectures

Transport Layer — TCP and UDP

- **TCP (Transmission Control Protocol)**
  - *Connection-oriented.*
  - Established for packet switched networks only — no circuits and data still have to be packetized.
  - Relies on the IP layer for delivering the message to the destination computer specified by its IP address.
  - Provides message packetizing, error detection, retransmission, packet resequencing and multiplexing.
  - Although reliable, the overhead of retransmission in TCP may be too high for many real-time multimedia applications such as streaming video — UDP can be used instead.

UDP (User Datagram Protocol)

- *Connectionless*: the message to be sent is a single Datagram.
- The only thing UDP provides is multiplexing and error detection through a Checksum.
- The source port number in UDP header is optional since there is no acknowledgment.
- Much faster than TCP, however it is unreliable:
  - In most real-time multimedia applications (e.g., streaming video or audio), packets that arrive late are simply discarded.
  - Flow control, and congestion avoidance, more realistically *error concealment* must be explored for acceptable Quality of Service (QoS).

Network Layer — IP (Internet Protocol)

- Two basic services: **packet addressing** and **packet fragmentation**.
- **Packet addressing**:
  - The IP protocol provides for a global addressing of computers across all interconnected networks.
  - For an IP packet to be transmitted within LANs, either broadcast based on *hubs* or point-to-point transmission based on *switch* is used.
  - For an IP packet to be transmitted across WANs, *Gateways* or *routers* are employed, which use *routing tables* to direct the messages according to destination *IP addresses*.

Network Layer — IP (Internet Protocol) (Cont'd)

- The IP layer also has to:
  - translate the destination IP address of incoming packets to the appropriate network address.
  - identify for each destination IP the next best router IP through which the packet should travel based on routing table.
- Routers have to communicate with each other to determine the best route for groups of IPs. The communication is done using *Internet Control Message Protocol (ICMP)*.
- IP is *connectionless* — provides no end-to-end flow control, packets could be received out of order, and dropped or duplicated.

Network Layer — IP (Internet Protocol) (Cont'd)

- **Packet fragmentation**: performed when a packet travels over a network that only accepts packets of a smaller size.
  - IP packets are split into the required smaller size, sent over the network to the next hop, and reassembled and resequenced.
- IP versions:
  - IPv4 (IP version 4): IP addresses are 32 bit numbers, usually specified using *dotted decimal notation* (e.g. 128.77.149.63) — running out of new IP addresses soon (projected in year 2008).
  - IPv6 (IP version 6): The *next generation IP (IPng)* - adopts 128-bit addresses, allowing $2^{128} \approx 3.4 \times 10^{38}$ addresses.

15.2 Multiplexing Technologies

- **Basics of Multiplexing**

  1. **FDM (Frequency Division Multiplexing)** — Multiple *channels* are arranged according to their frequency:

     – For FDM to work properly, analog signals must be *modulated* so that the signal occupies a bandwidth B_s centered at f_c — *carrier* frequency unique for each channel.

     – The receiver uses a band-pass filter tuned for the particular channel-of-interest to capture the signal, and then uses a demodulator to decode it.

     – Basic modulation techniques: *Amplitude Modulation (AM)*, *Frequency Modulation (FM)*, *Phase Modulation (PM)*, and *Quadrature Amplitude Modulation (QAM)*.

2. **WDM (Wavelength Division Multiplexing)**: A variation of FDM for data transmission in optical fibers:

   – Light beams representing channels of different wavelengths are combined at the source, and split again at the receiver.

   – The capacity of WDM is tremendous — a huge number of channels can be multiplexed (aggregate bit-rate can be up to dozens of terabits per second).

   – Two variations of WDM:

   (a) **DWDM** (Dense WDM): employs densely spaced wavelengths so as to allow a larger number of channels than WDM (e.g., more than 32).

   (b) **WWDM** (Wideband WDM): allows the transmission of color lights with a wider range of wavelengths (e.g., 1310 to 1557 nm for long reach and 850 nm for short reach) to achieve a larger capacity than WDM.

3. **TDM (Time Division Multiplexing)** — A technology for directly multiplexing digital data:

   – If the source data is analog, it must first be digitized and converted into PCM (Pulse Code Modulation).

   – Multiplexing is performed along the time (t) dimension. Multiple buffers are used for m ($m > 1$) channels.

   – Two variations of TDM:

   (a) **Synchronous TDM**: Each of the m buffers is scanned in turn and treated equally. If, at a given time slot, some sources (accordingly buffers) do not have data to transmit the slot is wasted.

   (b) **Asynchronous TDM**: Only assign k ($k < m$) time slots to scan the k buffers that are likely to have data to send (based on statistics) — has the potential of having a higher throughput given the same carrier data rate.

TDM Carrier Standards

- T1 carrier is basically a Synchronous TDM of 24 voice channels (23 for data, and 1 for synchronization).
- Four T1 carriers are multiplexed to yield a T2.

  T3, T4 are further created in a similar fashion.
- ITU-T standard with Level 1 (E1): starting at 2.048 Mbps, in which each frame consists of 32 time slots (30 for data, and 2 for framing and synchronization).

Table 15.1 Comparison of TDM Carrier Standards

Format	Num of channels	Data Rate (Mbps)	Format	Num of channels	Data Rate (Mbps)
T1	24	1.544	E1	32	2.048
T2	96	6.312	E2	128	8.448
T3	672	44.736	E3	512	34.368
T4	4032	274.176	E4	2048	139.264
			E5	8192	565.148

ISDN (Integrated Services Digital Network)

- In 1980s, the ITU-T started to develop **ISDN** (Integrated Services Digital Network) to meet the needs of various digital services.

- By default, ISDN refers to **Narrowband ISDN**. The ITU-T has developed **Broadband ISDN** (B-ISDN). Its default switching technique is **ATM** (Asynchronous Transfer Mode).

- ISDN defined several types of full-duplex channels:

  – **B (Bearer) channel**: 64 kbps each — for data transmission. Mostly circuit-switched, also support Packet Switching.

  – **D (Delta) channel**: 16 kbps or 64 kbps — takes care of call set-up, call control (call forwarding, call waiting, etc.), and network maintenance.

Main specifications of ISDN

- ISDN adopts the technology of Synchronous TDM (Time Division Multiplexing) in which the above channels are multiplexed.
- Two type of interfaces were available:
  - **Basic Rate Interface**: Provides two B-channels and one D-channel (at 16 kbps). The total of 144 kbps ($64 \times 2 + 16$) is multiplexed and transmitted over a 192 kbps link.
  - **Primary Rate Interface**: Provides 23 B-channels and one D-channel (at 64 kbps) in North America and Japan (fit in T1); 30 B-channels and two D-channels (at 64 kbps) in Europe (fit in E1).

SONET (Synchronous Optical NETwork)

- A standard initially developed by Bellcore for optical fibers.
- It uses the technology of circuit switching.
  - SONET adopts the technology of Synchronous TDM (Time Division Multiplexing).
  - An STS-1 (OC-1) frame consists of 810 TDM bytes. It is transmitted in 125 μsec, i.e., 8,000 frames per second. Hence a data rate of $810 \times 8 \times 8,000 = 51.84$ Mbps for STS-1 (OC-1).
  - All other STS-N (OC-N) signals are further multiplexing of STS-1 (OC-1) signals. For example, three STS-1 (OC-1) are multiplexed for each STS-3 (OC-3) at 155.52 Mbps.
- ITU-T developed a similar standard to SONET — **SDH** (Synchronous Digital Hierarchy).

Table 15.2: Equivalency of SONET and SDH

SONET Electrical-Level	SONET Optical-Level	SDH Equivalent	Line Rate (Mbps)	Payload Rate (Mbps)
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	1244.16	1202.688
STS-36	OC-36	STM-12	1866.24	1804.032
STS-48	OC-48	STM-16	2488.32	2405.376
STS-96	OC-96	STM-32	4976.64	4810.752
STS-192	OC-192	STM-64	9953.28	9621.504

- Table 15.2 lists the SONET electrical and optical levels, and their SDH equivalents and data rates.

ADSL (Asymmetric Digital Subscriber Line)

- Adopts a higher data rate downstream and lower data rate upstream, hence *asymmetric*.
- Makes use of existing telephone twisted-pair lines to transmit QAM (Quadrature Amplitude Modulated) digital signals.
- Bandwidth on ADSL lines: 1 MHz or higher.
- ADSL uses FDM to multiplex three channels:
  (a) the high speed (1.5 to 9 Mbps) downstream channel at the high end of the spectrum.
  (b) a medium speed (16 to 640 kbps) duplex channel.
  (c) a POTS (Plain Old Telephone Service) channel at the low end (next to DC, 0-4 kHz) of the spectrum.

ADSL Distance Limitation

- ADSL is known to have the following distance limitation when only using ordinary twisted-pair copper wires:

Table 15.3: Maximum Distance of ADSL Using Twisted-Pair Wire

Data Rate	Wire Size	Distance
1.544 Mbps	0.5 mm	5.5 km
1.544 Mbps	0.4 mm	4.6 km
6.1 Mbps	0.5 mm	3.7 km
6.1 Mbps	0.4 mm	2.7 km

- **Key technology for ADSL**: *Discrete Multi-Tone (DMT)*.
  - For a better transmission in potentially noisy channels, the DMT modem sends test signals to all subchannels first.
  - It then calculates the SNRs to dynamically determine the amount of data to be sent in each subchannel.

Table 15.4 History of Digital Subscriber Lines

Name	Meaning	Data Rate	Mode
V.32 or V.34	Voice Band Modems	1.2 to 56 kbps	Duplex
DSL	Digital Subscriber Line	160 kbps	Duplex
HDSL	High Data Rate Digital Subscriber Line	1.544 Mbps or 2.048 Mbps	Duplex
SDSL	Single Line Digital Subscriber Line	1.544 Mbps or 2.048 Mbps	Duplex
ADSL	Asymmetric Digital Subscriber Line	1.5 to 9 Mbps 16 to 640 kbps	Down Up
VDSL	Very high data rate Digital Subscriber Line	13 to 52 Mbps 1.5 to 2.3 Mbps	Down Up

- Table 15.4 offers a brief history of various digital subscriber lines (**xDSL**).

15.3 LAN and WAN

- **LAN** (Local Area Network) is restricted to a small geographical area, usually to a relatively small number of stations.

- **WAN** (Wide Area Network) refers to networks across cities and countries.

- **MAN** (Metropolitan Area Network) is sometimes also used to refer to the network between LAN and WAN.

Local Area Networks (LANs)

- In IEEE 802 Reference Model for LANs, the functionality of the Data Link layer is enhanced, and it has been divided into two sublayers:
  - **Medium Access Control (MAC) layer**:
    (a) Assemble or disassemble frames upon transmission or reception.
    (b) perform addressing and error correction.
    (c) Access control to shared physical medium.
  - **Logical Link Control (LLC) layer**:
    (a) Flow and error control.
    (b) MAC-layer addressing.
    (c) Interface to higher layers. LLC is above MAC in the hierarchy.

Ethernet

- **Ethernet**: A packet-switched **bus** network, the most popular LAN to date.
- **Message Addressing**: An Ethernet address of the recipient is attached to the message, which is sent to everyone on the bus. Only the designated station will receive the message, while others will ignore it.
- **CSMA/CD** (Carrier Sense Multiple Access with Collision Detection) — solves the problem of medium access control:
  - Multiple stations could be waiting and then sending their messages at the same time, causing a **collision**.
  - To avoid collision, the station that wishes to send a message must listen to the network (Carrier Sense) and wait until there is no traffic on the network.

Token Ring

- **Token Ring**: Stations are connected in a **ring** topology, as the name suggests.

- **Collision resolve scheme**:

  – A small frame, called a **token**, circulates on the ring while it is idle.

  – To transmit, a source station S must wait until the token passes by, and then seizes the token and converts it into a front end of its data frame, which will then travel on the ring and be received by the destination station.

  – The data frame will continue travelling on the ring until it comes back to Station S. The token is then released by S and put back onto the ring.

FDDI (Fiber Distributed Data Interface)

- A successor of the original Token Ring. Its Medium Access Control (MAC) is very similar to the MAC for Token Rings.
- Has a dual ring topology with its primary ring for data transmission and secondary ring for fault tolerance.
- Once a station captures a token, the station is granted a time period, and can send as many data frames as it can within the time period.
- The token will be released as soon as the frames are transmitted (early token release).
- Primarily used in LAN or MAN backbones, and supports both *synchronous* and *asynchronous* modes.

Wide Area Networks (WANs)

Instead of broadcast, the following switching technologies are used in WAN:

- **Circuit Switching**: An end-to-end circuit must be established that is dedicated for the entire duration of the connection at a guaranteed bandwidth.
  - Initially designed for voice communications, it can also be used for data transmission — narrow-band ISDN.
  - In order to cope with multi-users and variable data rates, it adopts FDM or Synchronous TDM multiplexing techniques.
  - Inefficient for general multimedia communications, especially for variable (sometimes bursty) data rates.

Wide Area Networks (WANs) (Cont'd)

- **Packet Switching**: used for almost all data networks in which data rates tend to be very much variable, and sometimes bursty.
  - Data is broken into small *packets*, usually of 1,000 bytes or less in length. The header of each packet will carry necessary control information such as destination address, routing, etc.
  - X.25 was the most commonly used protocol for Packet Switching.
  - Two approaches are available to switch and route the packets: **datagram** and **virtual circuits**.

Wide Area Networks (WANs) (Cont'd)

- **Frame Relay**: A cheaper version of packet switching with minimal services, working at the data link control layer. Frame Relay made the following major changes to X.25:
  - **Reduction of error-checking**: no more acknowledgement, no more hop-to-hop flow control and error control.
  - **Reduction of layers**: the multiplexing and switching of virtual circuits are changed from Layer 3 in X.25 to Layer 2. Layer 3 of X.25 is eliminated.
  - **Frames** have a length up to 1,600 bytes. When a bad frame is received, it will simply be discarded — very high data rate: ranging from T1 (1.5 Mbps) to T3 (44.7 Mbps).

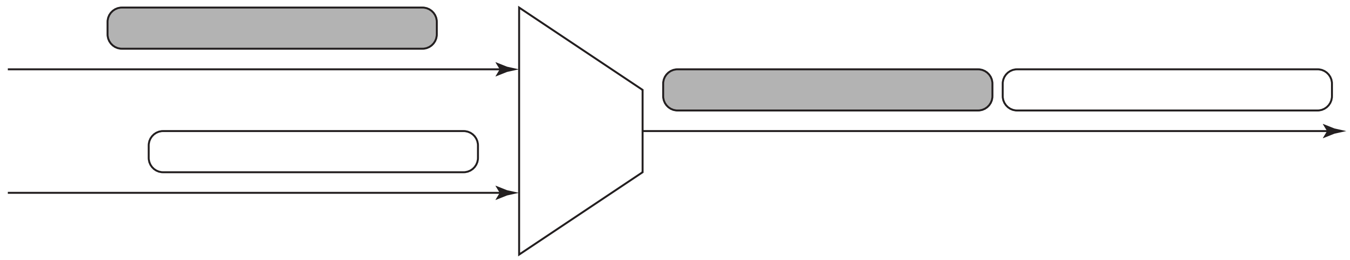
Wide Area Networks (WANs) (Cont'd)

- **Cell Relay — ATM** (Asynchronous Transfer Mode): Small and fixed-length (53 bytes) packets are adopted — *cells*.
  - As shown in Fig. 15.2, the small packet size is beneficial in reducing latency in ATM networks. When the darkened packet arrives slightly behind another packet of a normal size (e.g,. 1 kB):

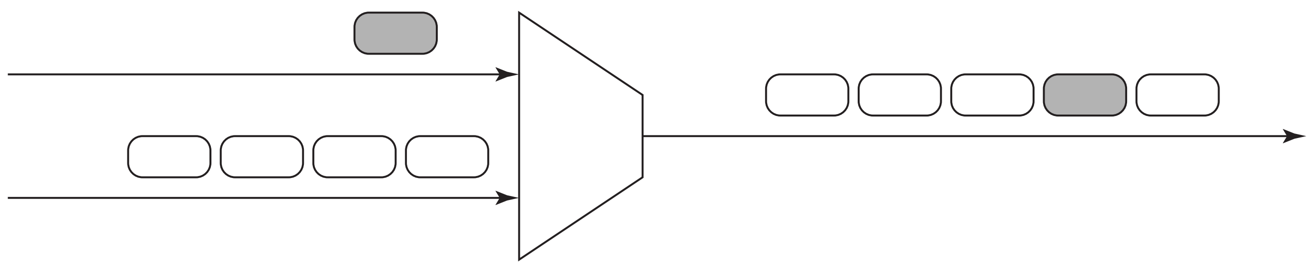
    (a) It must wait for the completion of the other's transmission, hence *serialization delay*.

    (b) Much less waiting time is needed for the darkened cell to be sent.

  - Significantly increases the network throughput — especially beneficial for real-time multimedia applications.



(a)



(b)

Fig. 15.2: Latency: (a) Serialization delay in a normal packet switching network. (b) Lower latency in a cell network.

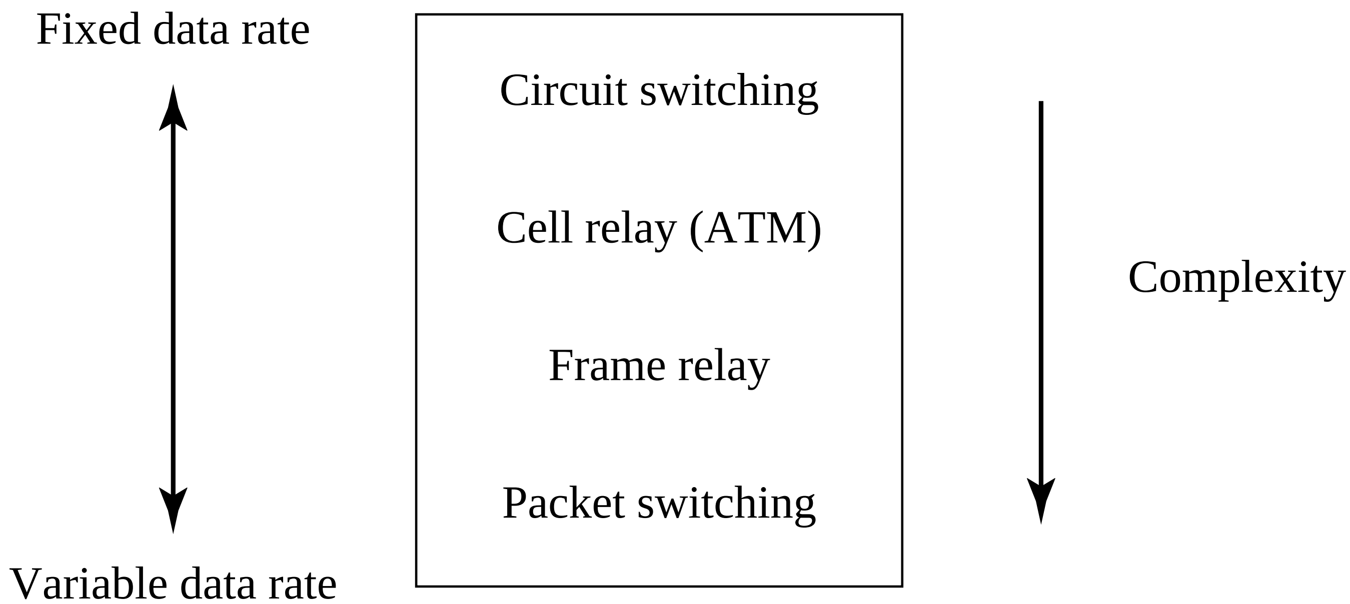


Fig. 15.3: Comparison of Different Switching Techniques.

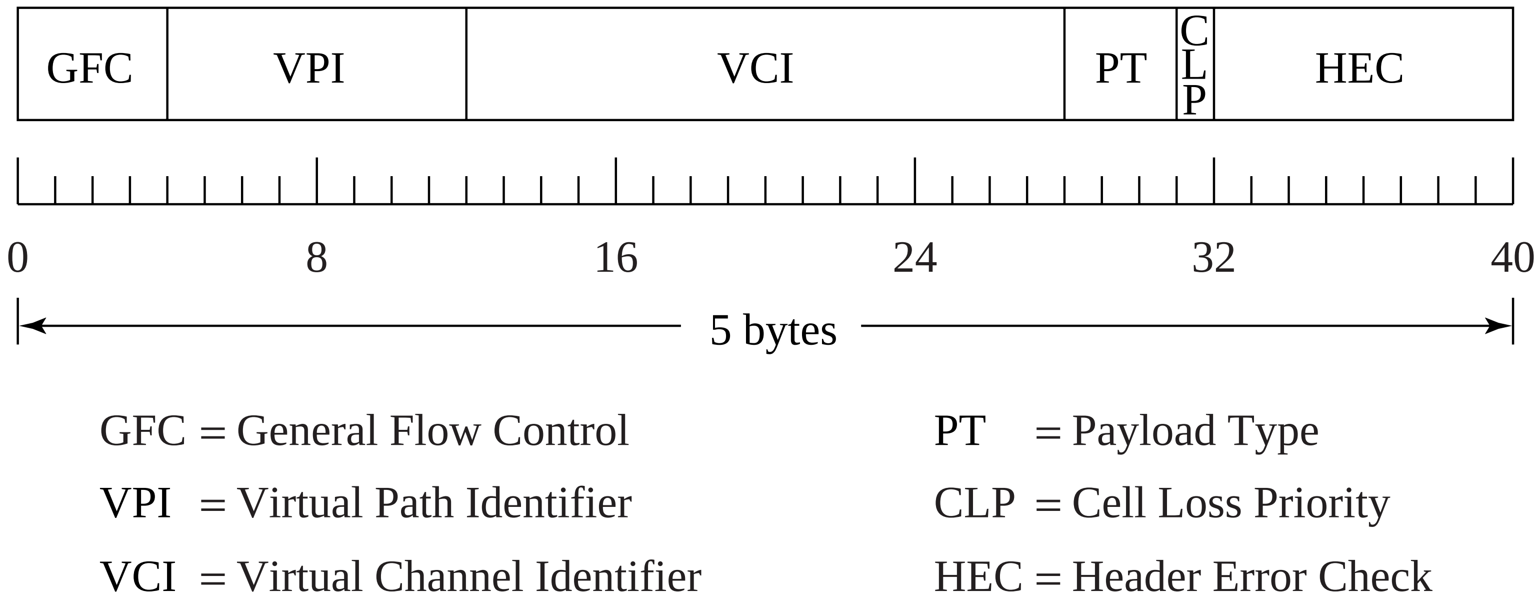
- Fig. 15.3 compares the four switching technologies in terms of their bit rate and complexity. It can be seen that Circuit Switching is the least complex and offers constant (fixed) data rate, and Packet Switching is the opposite.

ATM Cell Structure

- A fixed format: 53 bytes, of which the first 5 bytes are for the cell header, followed by 48 bytes of payload.

- The ATM Layer has two types of interfaces: **UNI** (User-Network Interface) is local, between a user and an ATM network, and **NNI** (Network-Network Interface) is between ATM switches.

- The structure of an ATM UNI cell header:



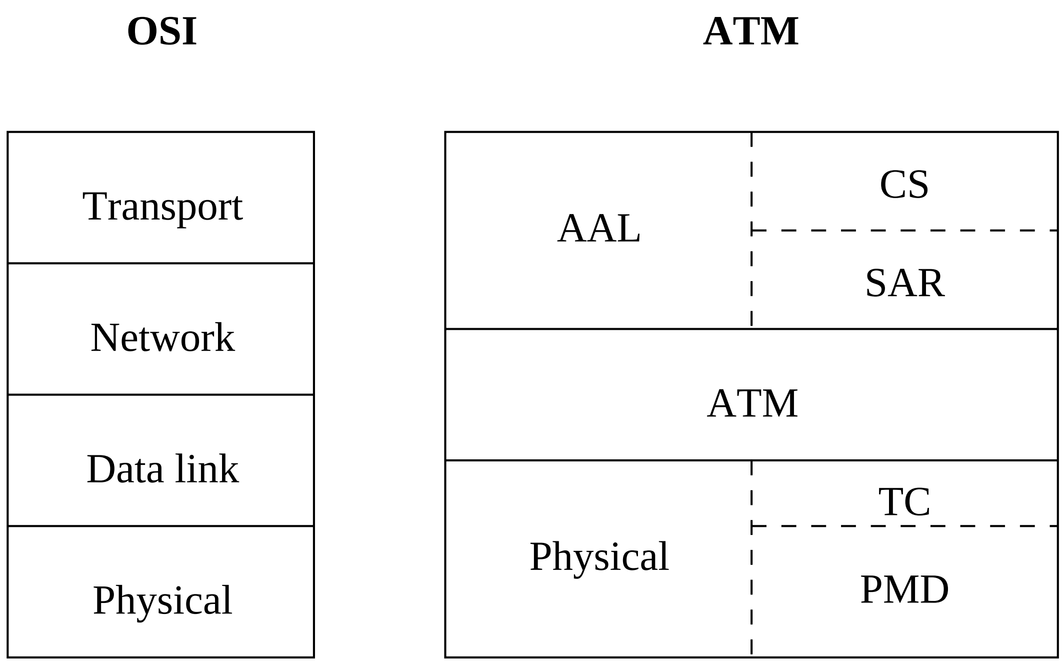
GFC: General Flow Control
VPI: Virtual Path Identifier
VCI: Virtual Channel Identifier

PT: Payload Type
CLP: Cell Loss Priority
HEC: Header Error Check

Fig. 15.4: ATM UNI Cell header

ATM Layers and Sublayers

- As Fig. 15.5 shows, AAL corresponds to the OSI Transport and part of the Network layers. It consists of two sublayers: **CS** and **SAR**:
  - CS provides interface (convergence) to user applications and SAR is in charge of cell segmentation and reassembly.
- The ATM layer corresponds to parts of the OSI Network and Data Link layers. Its main functions are flow control, management of virtual circuit and path, and cell multiplexing and demultiplexing.
- Two sublayers of ATM Physical layer: **TC** and **PMD**.
  - PMD corresponds to the OSI Physical layer, whereas TC does header error checking and packing/unpacking *cells.*



AAL = ATM Adaptation Layer
CS = Convergence Sublayer
SAR = Segmentation and Reassembly
TC = Transmission Convergence
PMD = Physical Medium Dependent

Fig. 15.5 Comparison of OSI and ATM Layers.

15.4 Access Networks

An *access network* connects end users to the core network. It is also known as the "last mile". Beside ADSL, discussed earlier, some known options for access networks are:

- **Hybrid Fiber-Coax (HFC) Cable Network** — Optical fibers connect the core network with Optical Network Units (ONUs) in the neighborhood, each of which typically serves a few hundred homes. All end users are then served by a shared coaxial cable.

- A potential problem of HFC is the noise or interference on the shared coaxial cable. Privacy and security on the upstream channel are also a concern.

- **Fiber To The Curb (FTTC)** — Optical fibers connect the core network with ONUs at the curb. Each ONU is then connected to dozens of homes via twisted-pair copper or coaxial cable.
  - A star topology is used at the ONUs, so the media to the end user are not shared — a much improved access network over HFC.

- **Fiber To The Home (FTTH)** — Optical fibers connect the core network directly with a small group of homes, providing the highest bandwidth.
  - Since most homes have only twisted pairs and/or coaxial cables, the implementation cost of FTTH will be high.

- **Terrestrial Distribution** — uses VHF and UHF spectra (approximately 40–800 MHz). Each channel occupies 8 MHz in Europe and 6 MHz in the U.S., and each transmission covers about 100 kilometers in diameter.
  - The standard is known as *Digital Video Broadcasting-Terrestrial* (DVB-T).
  - Since the return channel (upstream) is not supported in terrestrial broadcasting, a separate POTS or N-ISDN link is recommended for upstream in interactive applications.

- **Satellite Distribution** — uses the Gigahertz spectrum. Each satellite covers an area of several thousand kilometers.
  - Its standard is Digital Video Broadcasting-Satellite (DVB-S). Similar to DVB-T, POTS or N-ISDN is proposed as a means of supporting upstream data in DVB-S.

Table 15.6: Speed of Common Peripheral Interfaces

Type	Data-rate
Serial Port	115 kbps
Standard parallel port	115 kB/s
USB	1.5 MB/s
ECP/EPP parallel port	3 MB/s
IDE	3.3 - 16.7 MB/s
SCSI-1	5 MB/s
SCSI-2 (Fast SCSI, Fast narrow SCSI)	10 MB/s
Fast wide SCSI (Wide SCSI)	20 MB/s
Ultra SCSI (SCSI-3, Ultra narrow SCSI)	20 MB/s
EIDE	33 MB/s
Wide Ultra SCSI (Fast 20)	40 MB/s
Ultra2 SCSI	40 MB/s
IEEE 1394 (FireWire, i.LINK)	1.5 - 50 MB/s
USB 2	60 MB/s
Wide Ultra2 SCSI (Fast 40)	80 MB/s
Ultra3 SCSI	80 MB/s
Ultra ATA 133	133 MB/s
Wide Ultra3 SCSI (Ultra 160 SCSI, Fast 80)	160 MB/s
HIPPI	100 - 200 MB/s
Ultra 320 SCSI	320 MB/s
Fiber Channel	100 - 400 MB/s
Ultra 640 SCSI	640 MB/s

15.6 Further Exploration

- **Text books:**
  - *Computer Networks* by A.S. Tanenbaum
  - *Data & Computer Communications* by W. Stalling

- **Web sites:** ⟶ Link to Further Exploration for Chapter 15.. including:
  - SONET FAQ, etc.
  - xDSL introductions at DSL Forum website.
  - Introductions and White Papers on ATM.
  - FAQ and White Papers on 10 Gigabit Ethernet at the Alliance website.
  - IEEE 802 standards.
  - IETF RFCs: IPv6 (Internet Protocol, Version 6).