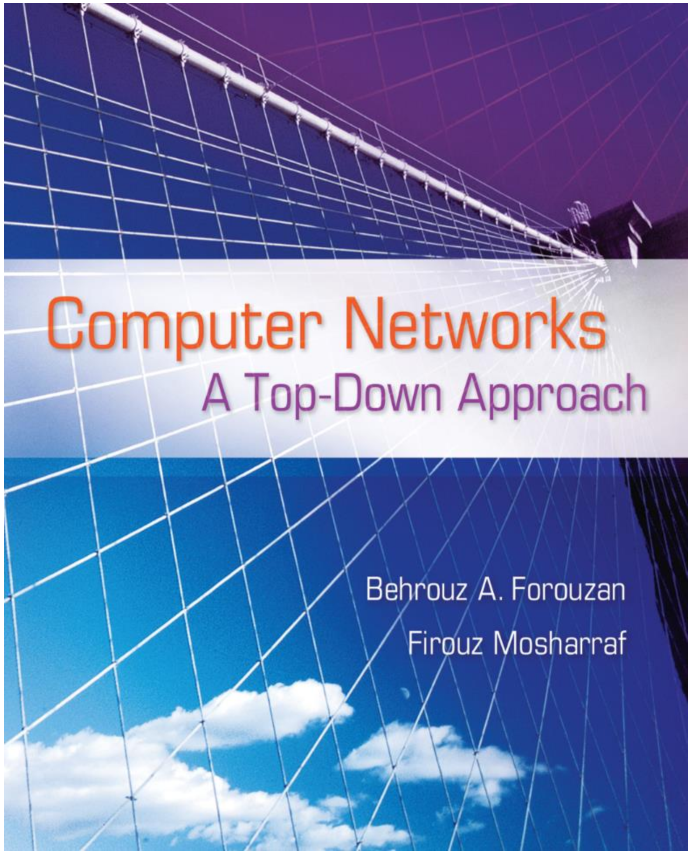
Completion of Chapter 5
WIRED NETWORKS



Chapter 5: Outline

Chapter 5: Objective

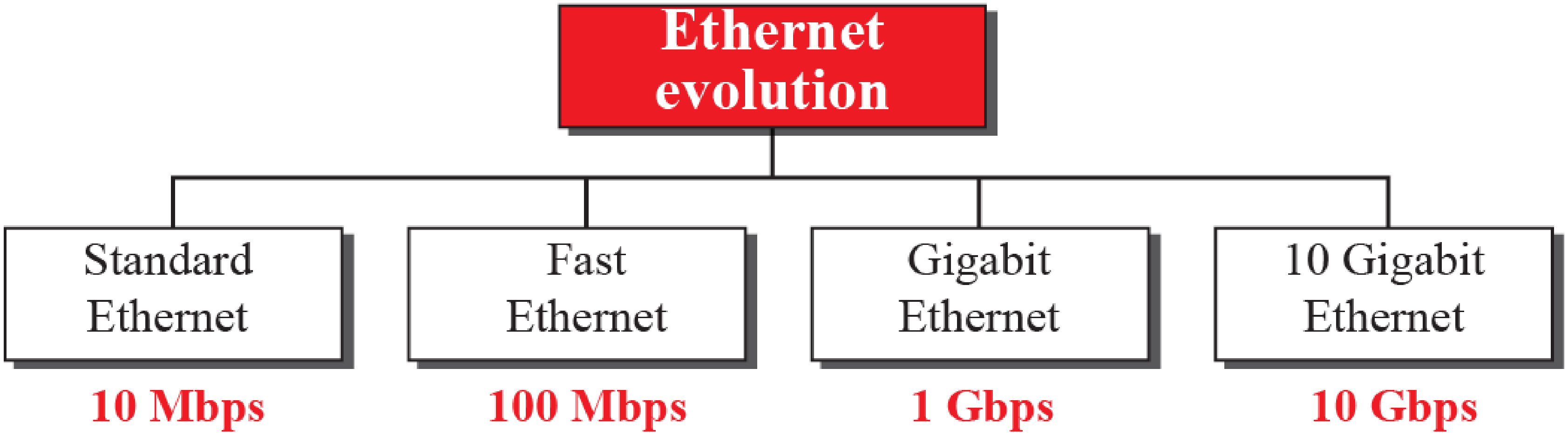
- ***We introduce the wired LANs and in particular Ethernet, the dominant LAN protocol today.***
- ***We move through different generations of Ethernet and show how it has evolved.***
- ***We discuss other wired networks that we encounter in the Internet today, such as point-to-point networks and switched networks.***
- ***We discuss connecting devices used in the lower three layers of the TCP/IP protocol such as hubs, link-layer switches, and routers.***

5-5 WIRED LANS: ETHERNET PROTOCOL

- *TCP/IP accepts any protocol at the data-link and physical layers. These two layers are actually the territory of the local and wide area networks.*
- *This means that when we discuss these two layers, we are talking about networks that are using them. We can have wired or wireless networks.*
- *We discuss wired networks in this Lecture and wireless networks in the next chapter.*

Ethernet Evolution

The Ethernet LAN was developed in the 1970s by Robert Metcalfe and David Boggs. Since then, it has gone through four generations: Standard Ethernet (10 Mbps), Fast Ethernet (100 Mbps), Gigabit Ethernet (1 Gbps), and 10 Gigabit Ethernet (10 Gbps), as shown in Figure. We briefly discuss all these generations.



5.5.1 IEEE Project 802

- *In 1985, the Computer Society of the IEEE started a project, called Project 802*
- *To set standards to enable intercommunication among equipment from a variety of manufacturers.*
- *Project 802 is a way of specifying functions of the physical layer and the data-link layer of major LAN protocols.*

- ❑ ***Logical Link Control (LLC)***
- ❑ ***Media Access Control (MAC)***

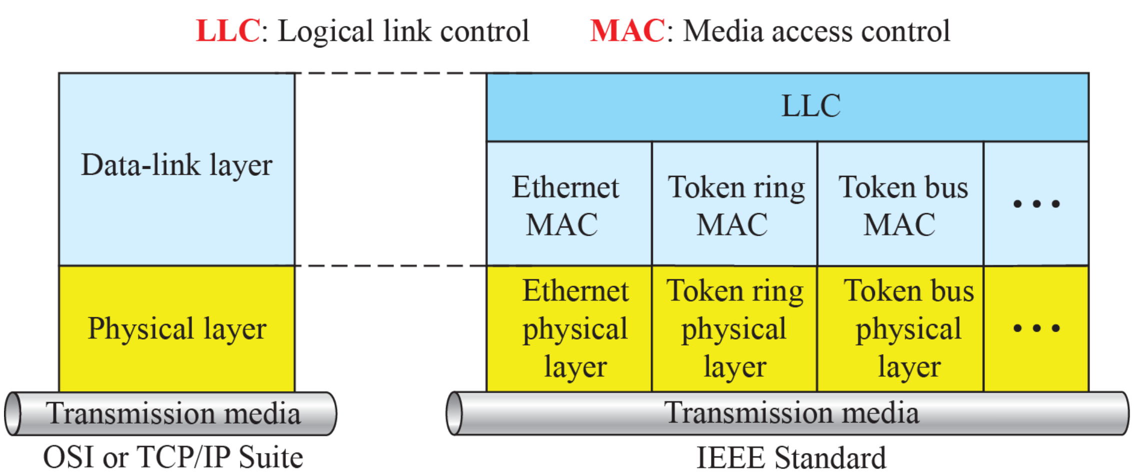


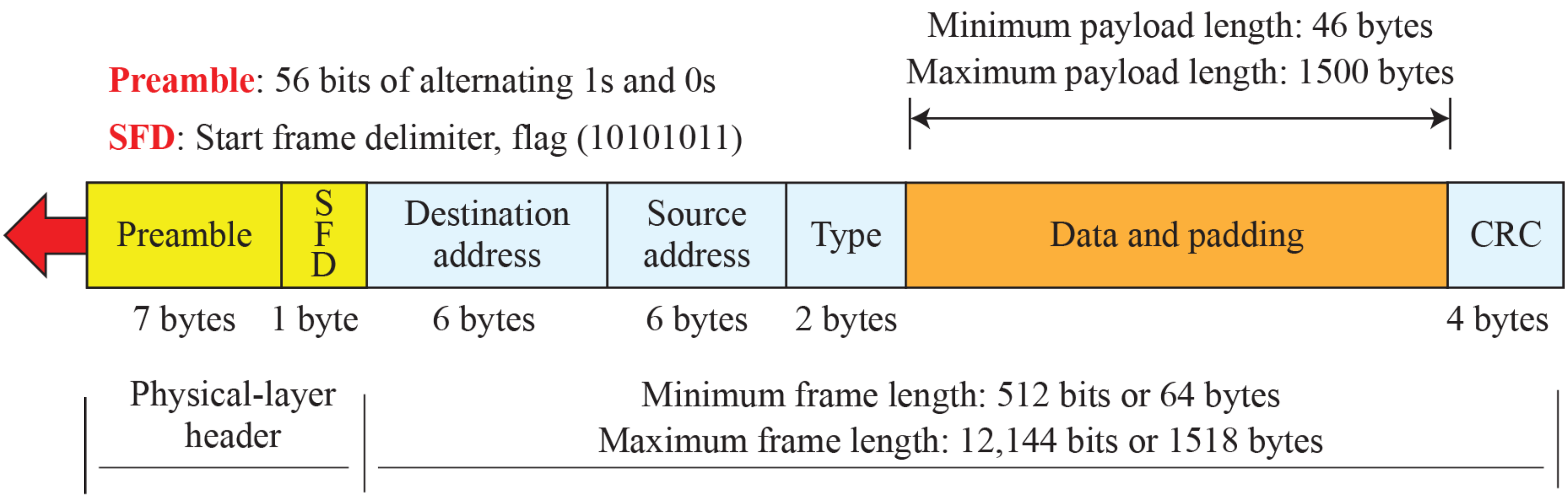
Figure 5.54: IEEE standard for LANs

5.5.2 Standard Ethernet

- *We refer to the original Ethernet technology with he data rate of 10 Mbps as the Standard Ethernet.*
- *Although technology in the Ethernet has evolved, there are some features of the Standard Ethernet that have not changed during the evolution.*
- *We discuss this standard version to pave the way for understanding the other three technologies.*

- *Frame Format*
- *Connectionless and Unreliable Service*
- *Frame Length*
- *Addressing*
  - *Transmission of Address Bits*
  - *Unicast, Multicast, and Broadcast Addresses*
  - *Distinguish between Unicast, Multicast, and Broadcast Transmission*
- *Access Method*
- *Efficiency of Standard Ethernet*
- *Implementation*

Figure 5.55: *Ethernet frame*

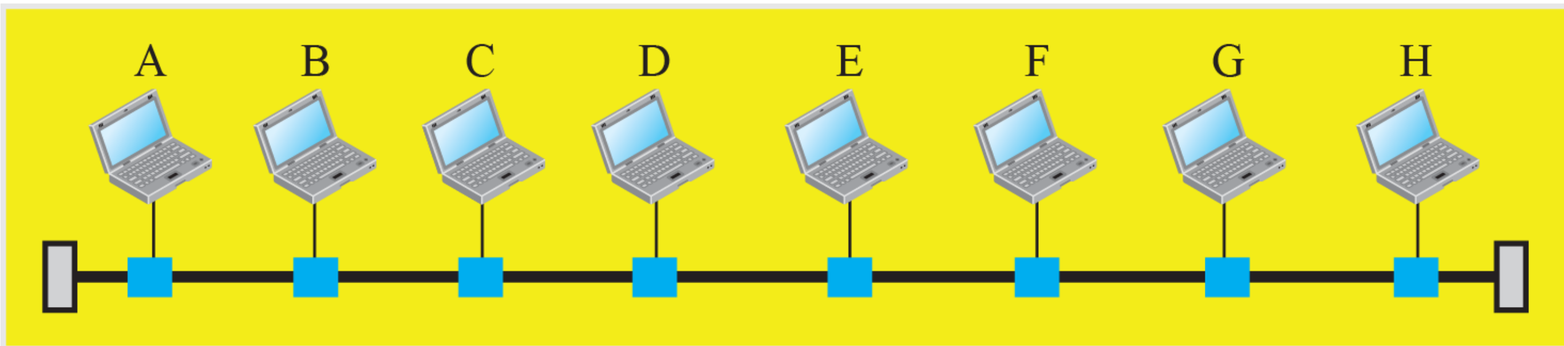


Addressing

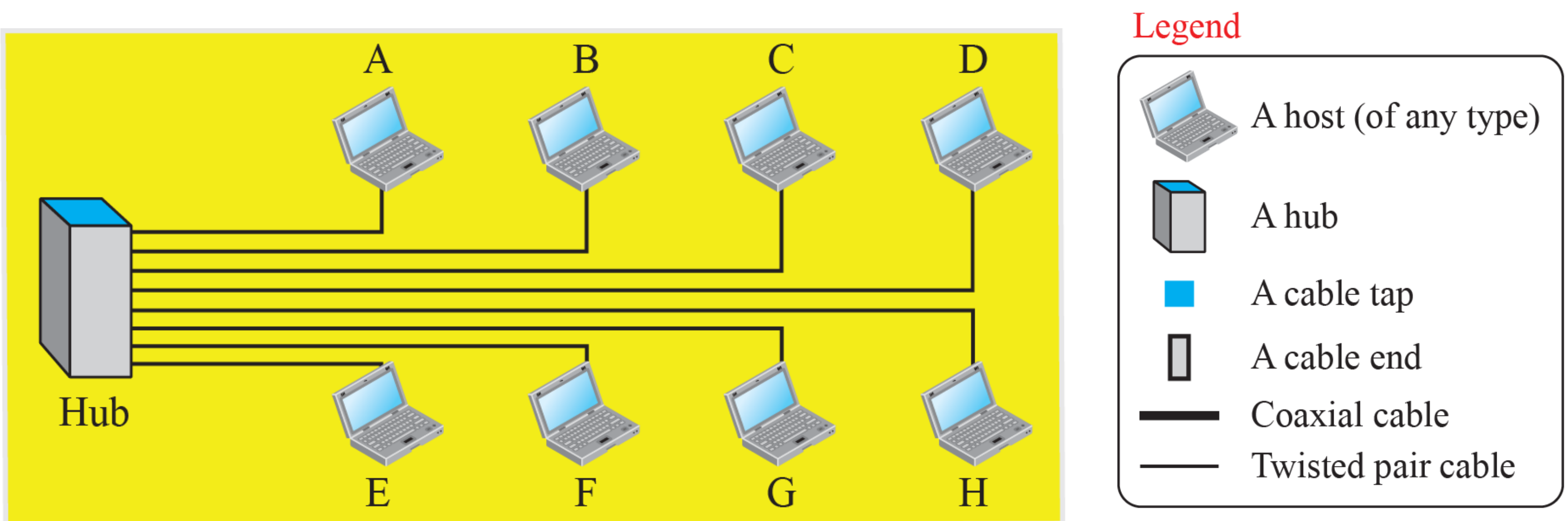
Each station on an Ethernet network (such as a PC, workstation, or printer) has its own network interface card (NIC). The NIC fits inside the station and provides the station with a link-layer address. The Ethernet address is 6 bytes (48 bits), normally written in hexadecimal notation, with a colon between the bytes. For example, the following shows an Ethernet MAC address:

4A:30:10:21:10:1A

Figure 5.57: ***Implementation of standard Ethernet***



a. A LAN with a bus topology using a coaxial cable



b. A LAN with a star topology using a hub

13.2.3 Access Method

Since the network that uses the standard Ethernet protocol is a broadcast network, we need to use an access method to control access to the sharing medium. The standard Ethernet chose CSMA/CD with 1-persistent method. Let us use a scenario to see how this method works for the Ethernet protocol.

Efficiency of Standard Ethernet:

- *The efficiency of the Ethernet is defined as the ratio of the time used by a station to send data to the time the medium is occupied by this station.*
- *The practical efficiency of standard Ethernet has been measured to be in which the parameter "**a**" is the number of frames that can fit on the medium. It can be calculated as **a = (propagation delay)/(transmission delay)***

Efficiency = 1 / (1 + 6.4 x a)

- *Because the transmission delay is the time it takes a frame of average size to be sent out and the propagation delay is the time it takes to reach the end of the medium.*
- *Note that as the value of parameter **a** decreases, the efficiency increases. This means that if the length of the media is shorter or the frame size longer, the efficiency increases.*
- *In the ideal case, **a = 0** and the efficiency is **1**.*

Example 5.20

- *We have Standard Ethernet with the transmission rate of 10 Mbps*
- *we assume that the length of the medium is 2500 m and*
- *The size of the frame is 512 bits.*
- *The propagation speed of a signal in a cable is normally 2×10^8 m/s.*

Propagation delay $= 2500/(2 \times 10^8) = 12.5\ \mu s$	Transmission delay $= 512/(10^7) = 51.2\ \mu s$
$a = 12.5/51.2 = 0.24$	Efficiency $=$ 39%

The example shows that a = 0.24, which means only 0.24 of a frame occupies the whole medium in this case.
The efficiency is 1/((1+6.44x0.24) = 1 / 2.55 = 39 percent, which is considered moderate; it means that only 61 percent of the time the medium is occupied but not used by a station.

13.2.5 Implementation

The Standard Ethernet defined several implementations, but only four of them became popular during the 1980s. Table shows a summary of Standard Ethernet implementations.

Table: Summary of Standard Ethernet implementations

Implementation	*Medium*	*Medium Length*	*Encoding*
10Base5	Thick coax	500 m	Manchester
10Base2	Thin coax	185 m	Manchester
10Base-T	2 UTP	100 m	Manchester
10Base-F	2 Fiber	2000	Manchester

Figure 13.6: Encoding in a Standard Ethernet

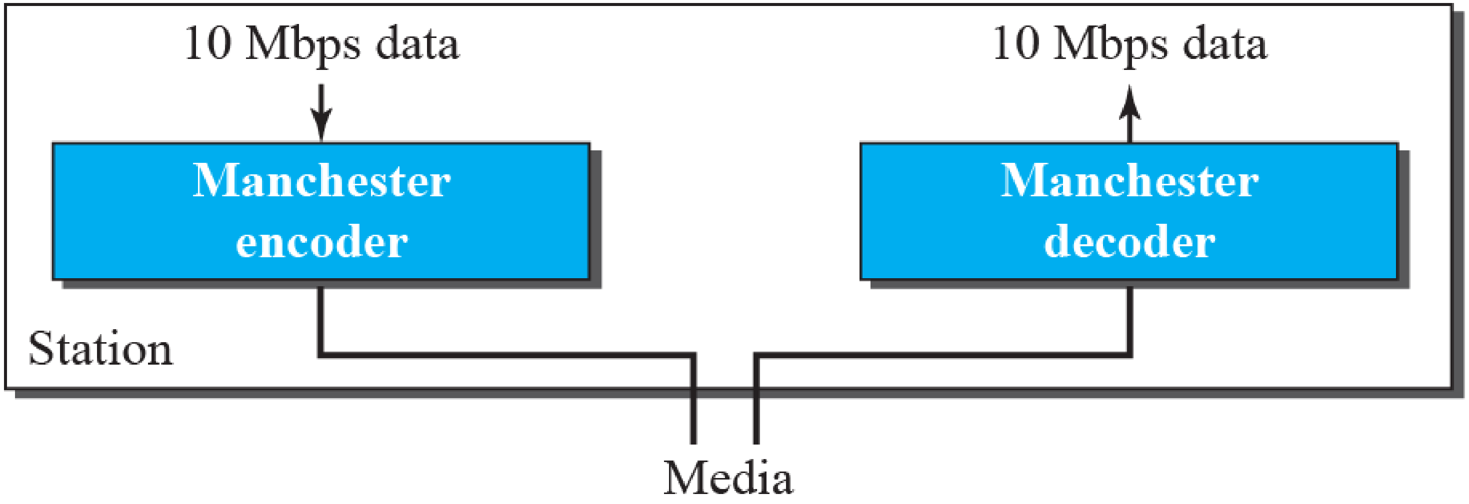


Figure 13.7: 10Base5 implementation

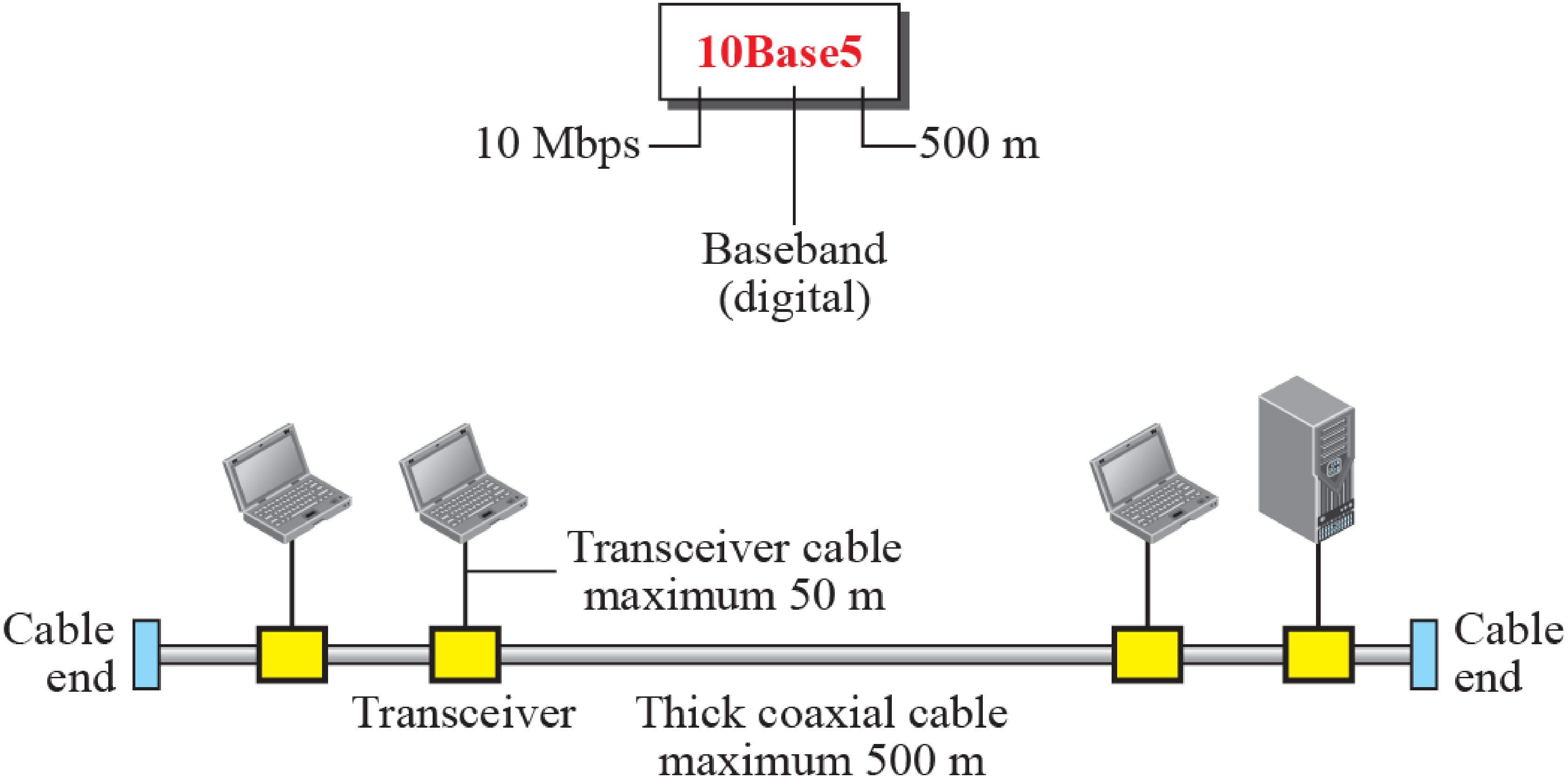


Figure 13.8: 10Base2 implementation

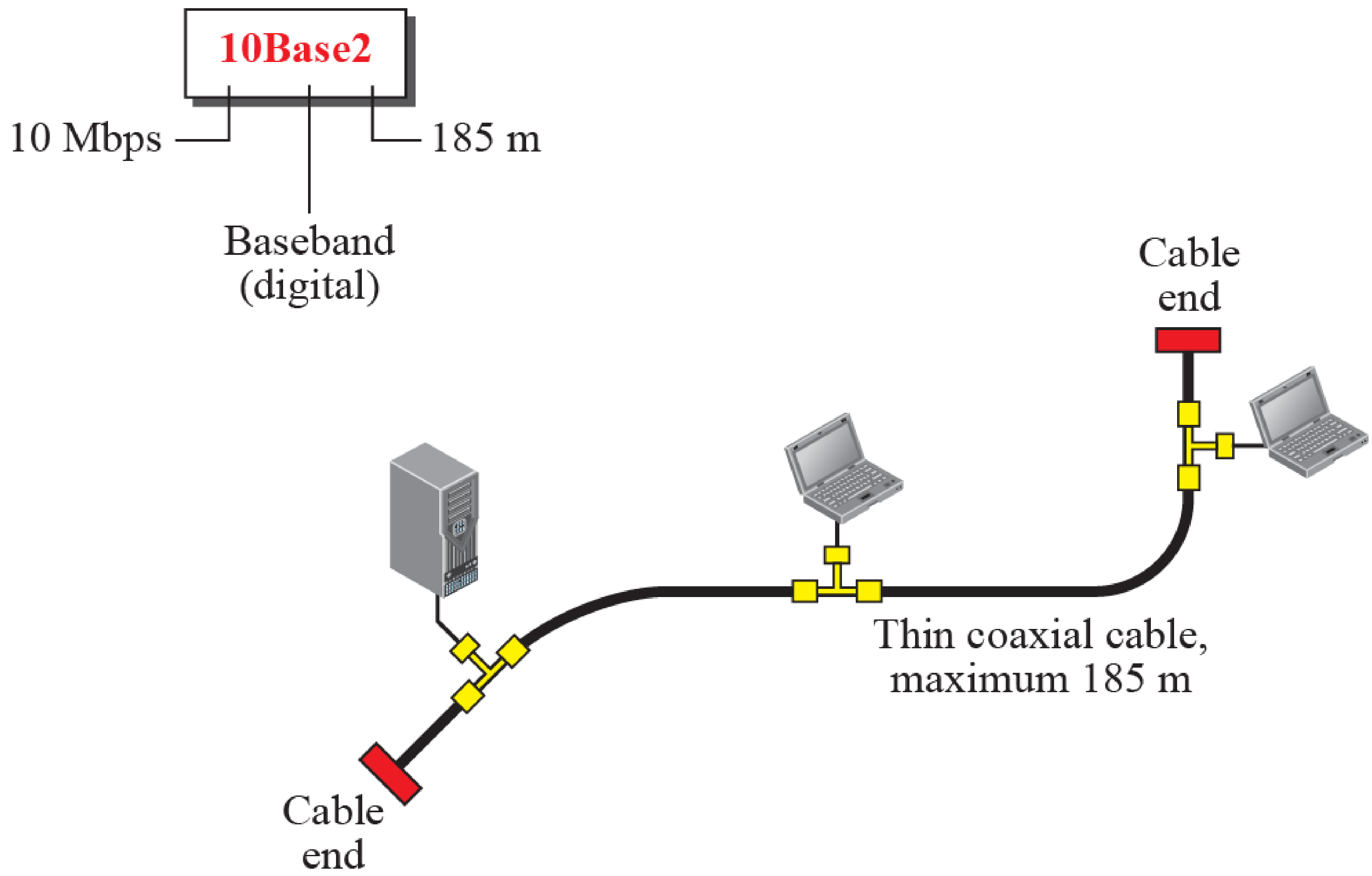


Figure 13.9: 10Base-T implementation

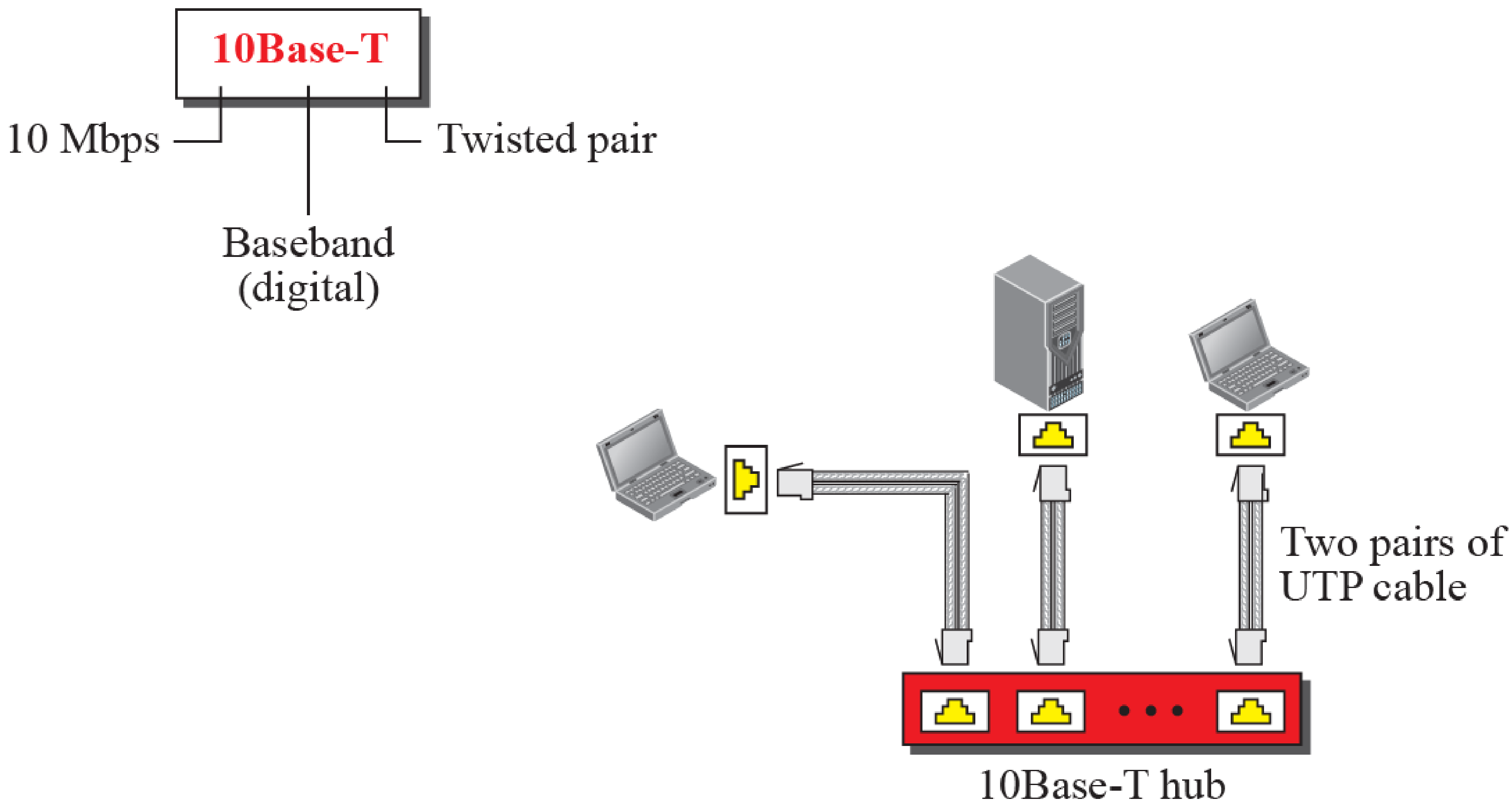
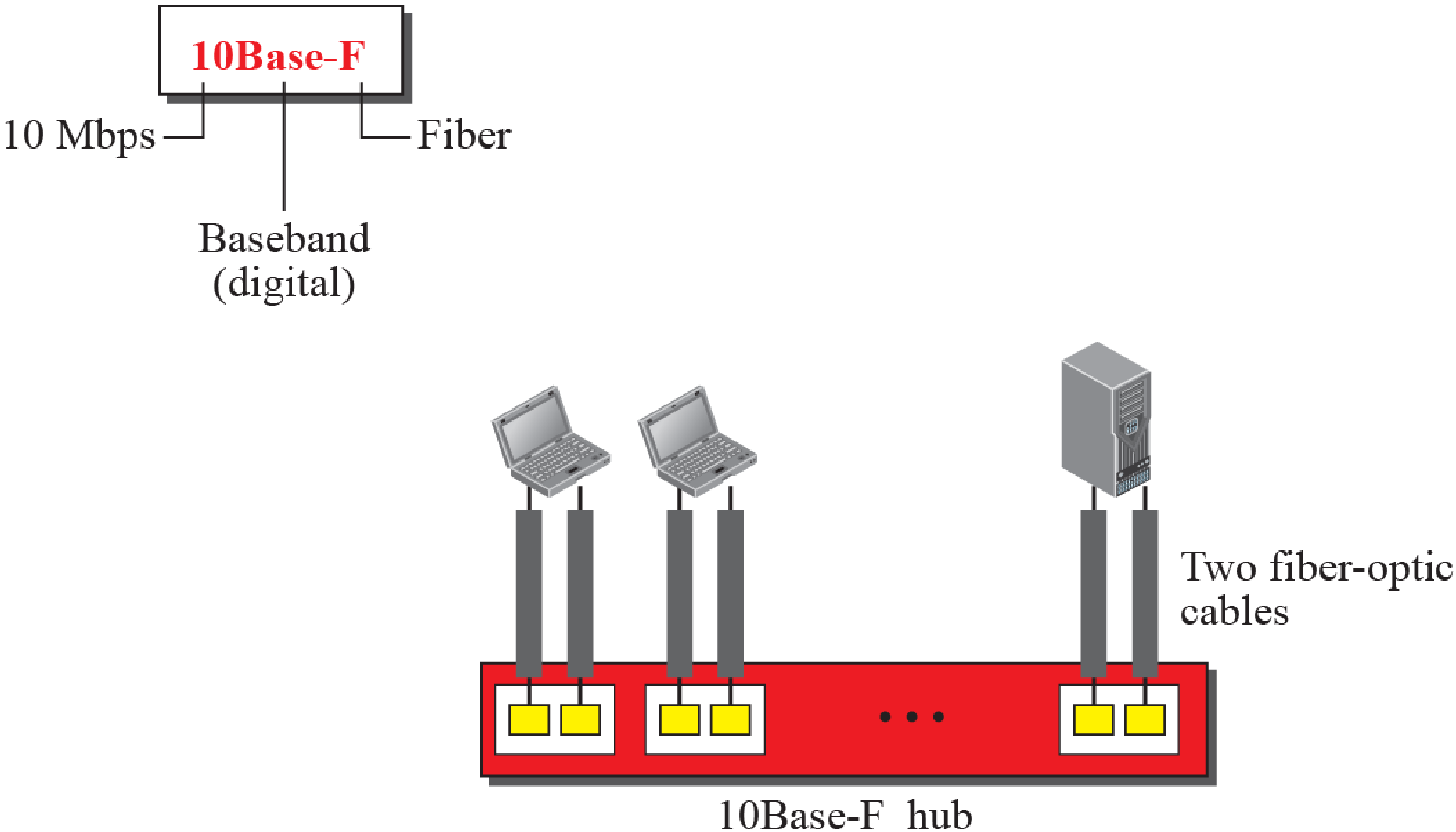


Figure 13.10: 10Base-F implementation



13.2.6 Changes in the Standard

Before we discuss higher-rate Ethernet protocols, we need to discuss the changes that occurred to the 10-Mbps Standard Ethernet. These changes actually opened the road to the evolution of the Ethernet to become compatible with other high-data-rate LANs.

Figure 13.11: *Sharing bandwidth*

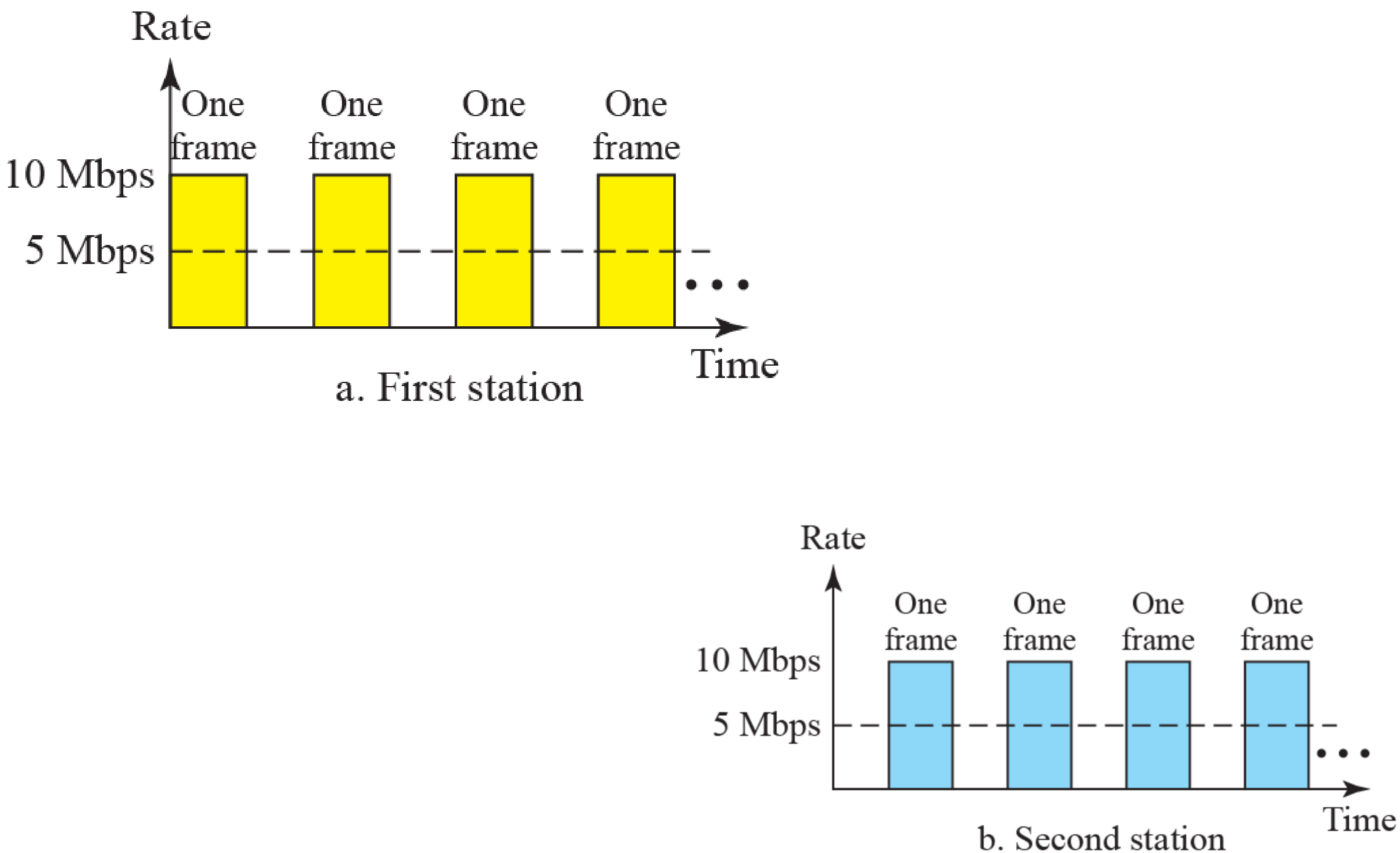
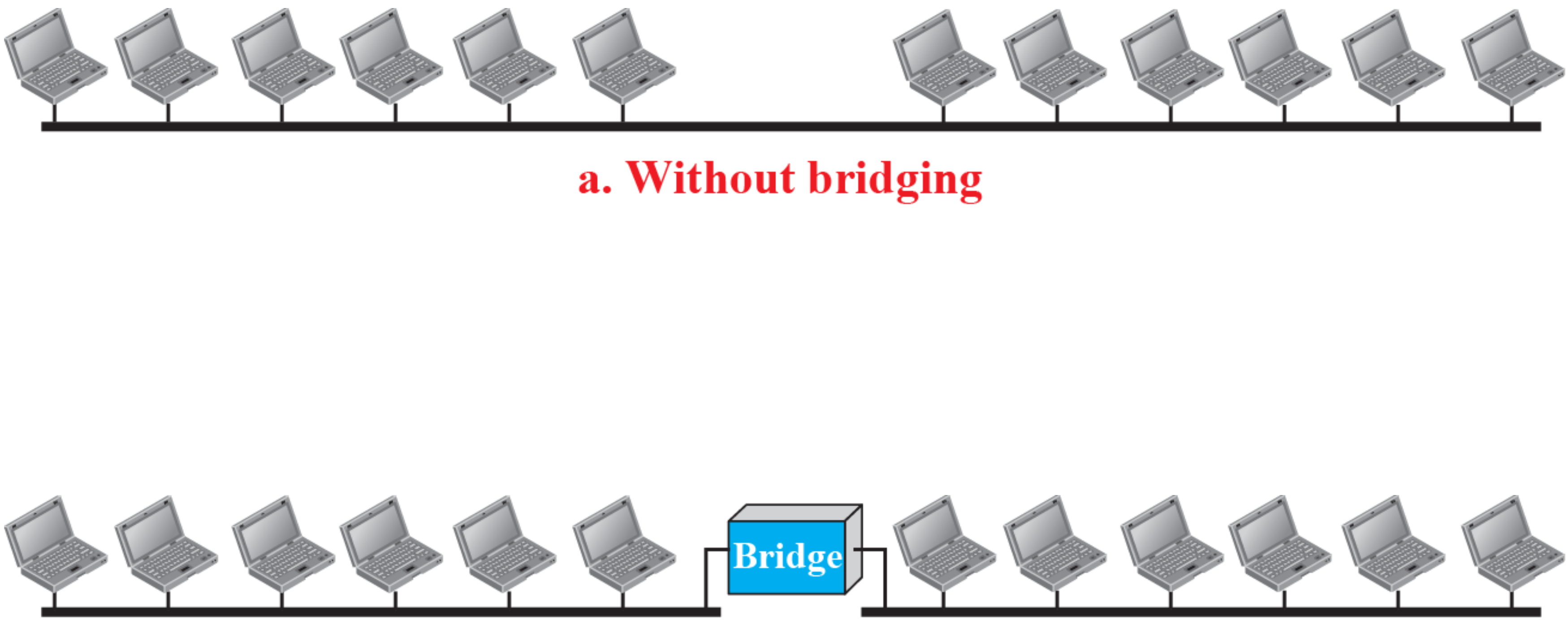


Figure 13.12: A network with and without bridging

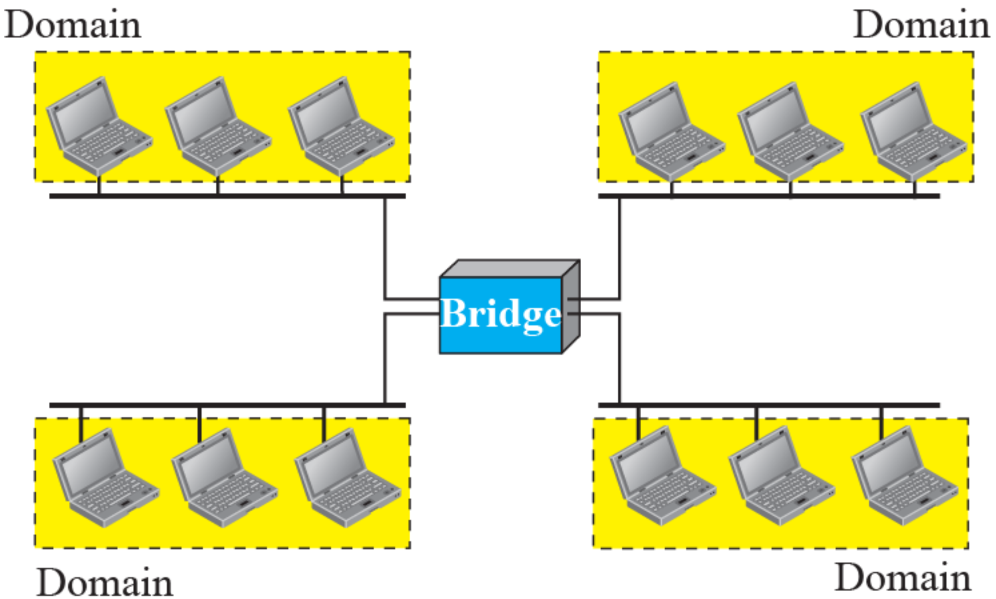


a. Without bridging

b. With bridging

Figure 13.13: *Collision domains*

a. Without bridging



b. With bridging

Figure 13.14: Switched Ethernet

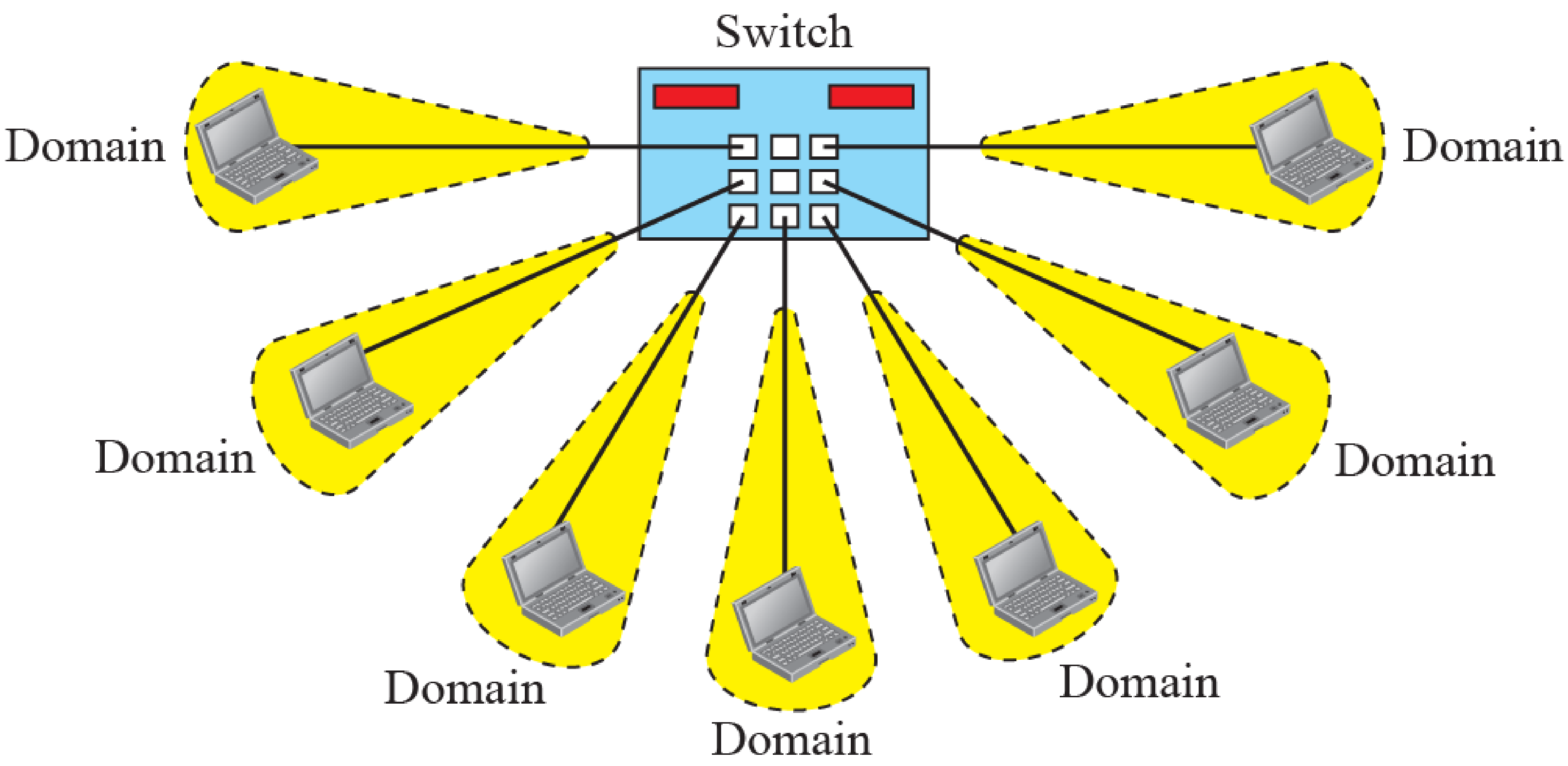
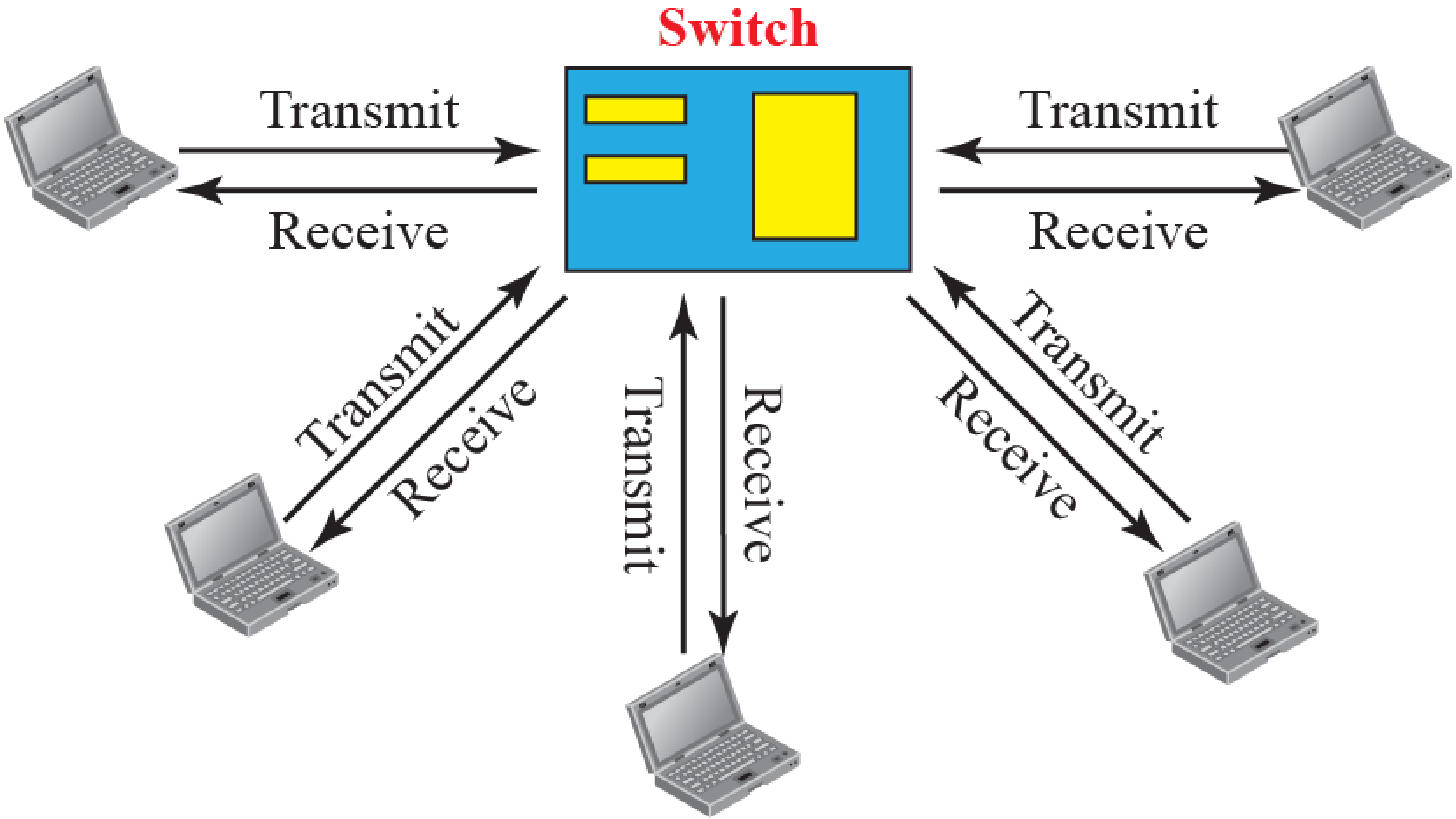


Figure 13.15: Full – duplex switched Ethernet



13-3 FAST ETHERNET

In the 1990s, Ethernet made a big jump by increasing the transmission rate to 100 Mbps, and the new generation was called the Fast Ethernet. The designers of the Fast Ethernet needed to make it compatible with the Standard Ethernet. The MAC sublayer was left unchanged. But the features of the Standard Ethernet that depend on the transmission rate, had to be changed.

5.5.3 Fast Ethernet

- *Fast Ethernet was designed to operate at 100 Mbps.*
- *The designers of the Fast Ethernet needed to make it compatible with the Standard Ethernet.*
- *The MAC sublayer was* ***left unchanged****, which meant the frame format and the maximum and minimum size could also* ***remain unchanged****.*

- ***Access Method***
- ***Auto-negotiation***
- ***Implementation***

Figure 13.16: Encoding for fast Ethernet

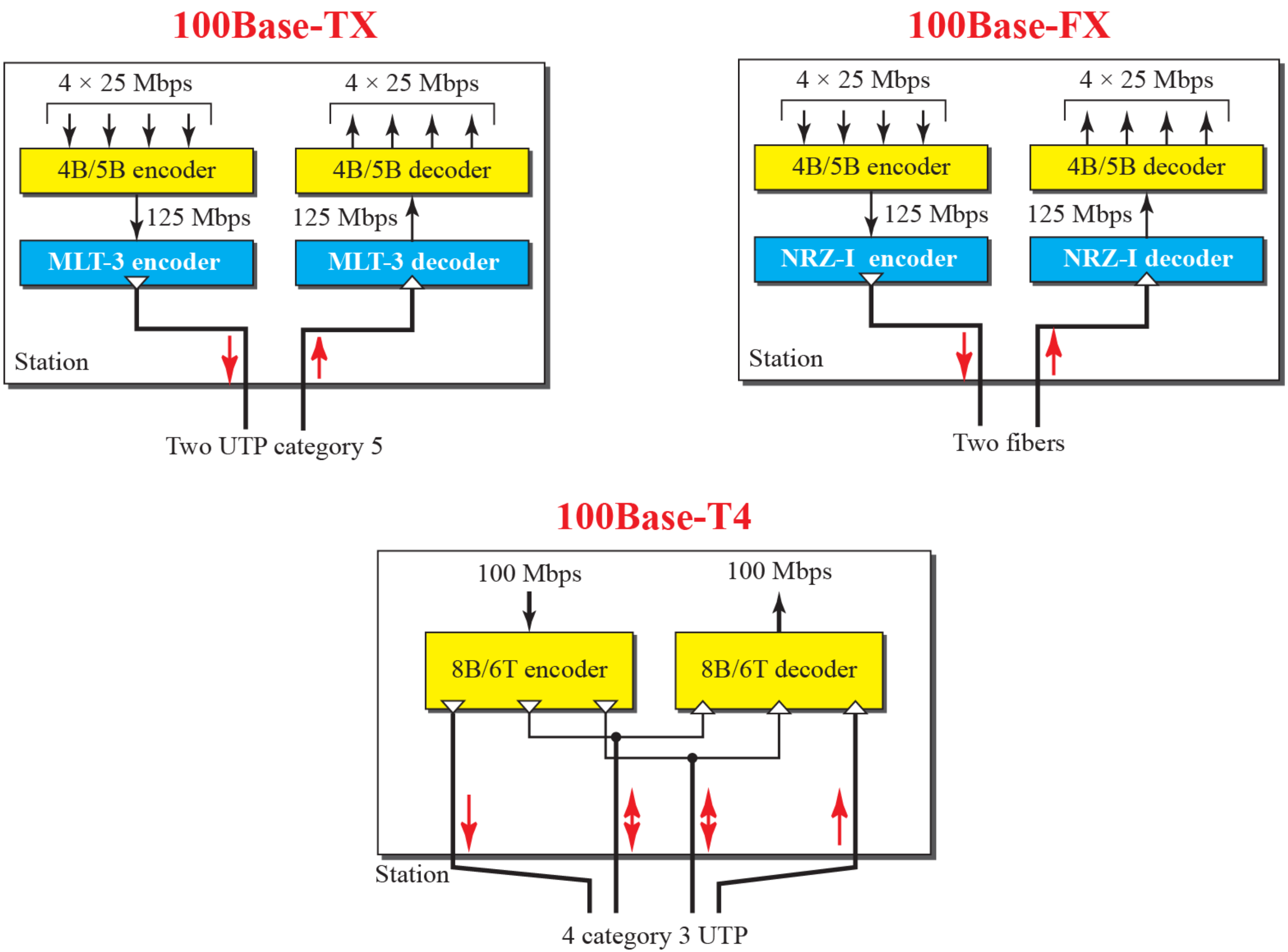


Table: Summary of Fast Ethernet implementations

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
100Base-TX	STP	100 m	2	4B5B + MLT-3
100Base-FX	Fiber	185 m	2	4B5B + NRZ-I
100Base-T4	UTP	100 m	4	Two 8B/6T

5.5.4 Gigabit Ethernet

- *The need for an even higher data rate resulted in the design of the Gigabit Ethernet Protocol (1000 Mbps).*
- *The IEEE committee calls the Standard 802.3z.*
- *The goals of the Gigabit Ethernet were to upgrade the data rate to 1 Gbps,* ***but keep the address length, the frame format, and the maximum and minimum frame length the same.***

- ***MAC Sublayer***
- ***Implementation***

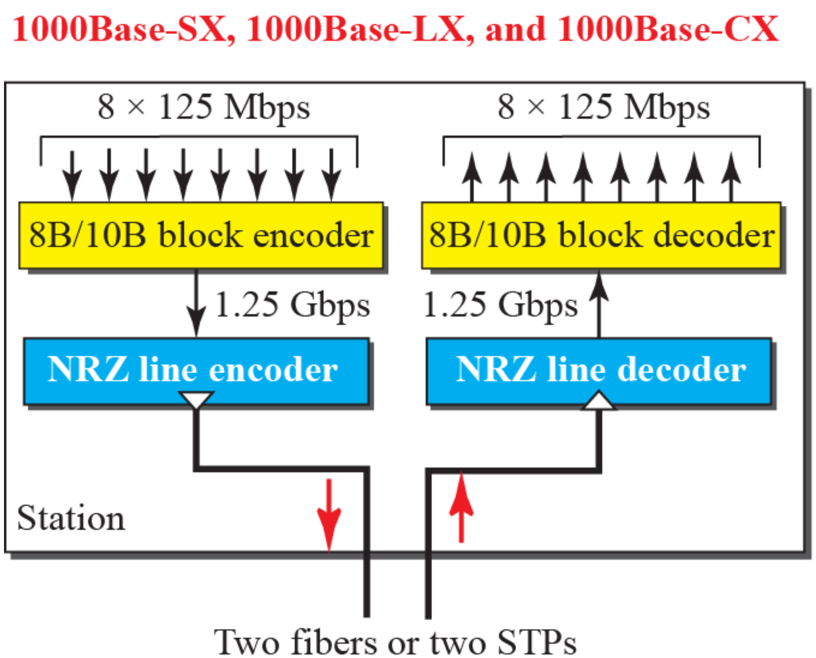
MAC Sublayer

A main consideration in the evolution of Ethernet was to keep the MAC sublayer untouched. However, to achieve a data rate of 1 Gbps, this was no longer possible. Gigabit Ethernet has two distinctive approaches for medium access: half-duplex and full-duplex. Almost all implementations of Gigabit Ethernet follow the full-duplex approach, so we mostly ignore the half-duplex mode.

Physical Layer

The physical layer in Gigabit Ethernet is more complicated than that in Standard or Fast Ethernet. We briefly discuss some features of this layer.

Figure *Encoding in Gigabit Ethernet*



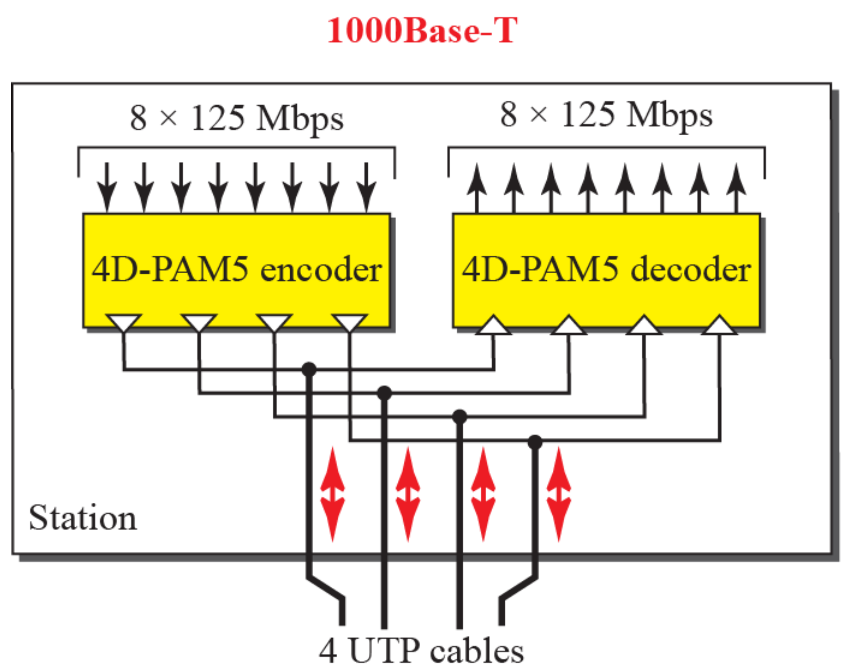


Table Summary of Gigabit Ethernet implementations

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
1000Base-SX	Fiber S-W	550 m	2	8B/10B + NRZ
1000Base-LX	Fiber L-W	5000 m	2	8B/10B + NRZ
1000Base-CX	STP	25 m	2	8B/10B + NRZ
1000Base-T4	UTP	100 m	4	4D-PAM5

5.5.5 10-Gigabit Ethernet

- *In recent times, there has been another look into the Ethernet for use in metropolitan areas.*
- *The idea is to extend the technology, the data rate, and the coverage distance so that the Ethernet can be used as **LAN and MAN** (metropolitan area network).*
- *The IEEE committee created **10-Gigabit Ethernet** and called it Standard 802.3ae.*

❑ *Implementation*

Implementation

10 Gigabit Ethernet operates only in full-duplex mode, which means there is no need for contention; CSMA/CD is not used in 10 Gigabit Ethernet. Four implementations are the most common: 10GBase-SR, 10GBase-LR, 10GBase-EW, and 10GBase-X4. Table 13.4 shows a summary of the 10 Gigabit Ethernet implementations. We discussed the encoding in Chapter 4.

Table Summary of 10-Gigabit Ethernet implementations

Implementation	*Medium*	*Medium Length*	*Number of wires*	*Encoding*
10GBase-SR	Fiber 850 nm	300 m	2	64B66B
10GBase-LR	Fiber 1310 nm	10 Km	2	64B66B
10GBase-EW	Fiber 1350 nm	40 Km	2	SONET
10GBase-X4	Fiber 1310 nm	300 m to 10 Km	2	8B10B

Table 5.6: **Summary of Standard Ethernet implementations**

Implementation	*Medium*	*Medium Length*	*Encoding*
10Base5	Thick coax	500 m	Manchester
10Base2	Thin coax	185 m	Manchester
10Base-T	2 UTP	100 m	Manchester
10Base-F	2 Fiber	2000	Manchester

Table 5.7: **Summary of Fast Ethernet implementations**

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
100Base-TX	STP	100 m	2	4B5B + MLT-3
100Base-FX	Fiber	185 m	2	4B5B + NRZ-I
100Base-T4	UTP	100 m	4	Two 8B/6T

Table 5.8: **Summary of Gigabit Ethernet implementations**

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
1000Base-SX	Fiber S-W	550 m	2	8B/10B + NRZ
1000Base-LX	Fiber L-W	5000 m	2	8B/10B + NRZ
1000Base-CX	STP	25 m	2	8B/10B + NRZ
1000Base-T4	UTP	100 m	4	4D-PAM5

Table 5.9: **Summary of 10-Gigabit Ethernet implementations**

Implementation	*Medium*	*Medium Length*	*Number of wires*	*Encoding*
10GBase-SR	Fiber 850 nm	300 m	2	64B66B
10GBase-LR	Fiber 1310 nm	10 Km	2	64B66B
10GBase-EW	Fiber 1350 nm	40 Km	2	SONET
10GBase-X4	Fiber 1310 nm	300 m to 10 Km	2	8B10B

5.5.6 Virtual LANs

- *A station is considered part of a LAN if it* ***physically belongs to that LAN****.*
- *The criterion of membership is geographic.*
- *What happens if we need a virtual connection between two stations belonging to two different physical LANs?*
- *We can roughly define a* ***virtual local area network (VLAN) as a local area network configured by software, not by physical wiring****.*

- ***Membership***
  - ***Interface Numbers***
  - ***MAC Addresses***
  - ***IP Addresses***
  - ***Multicast IP Addresses***
  - ***Combination***
- ***Configuration***
  - ***Manual Configuration***
  - ***Automatic Configuration***
  - ***Semiautomatic Configuration***
- ***Communication between Switches***
  - ***Table Maintenance***
  - ***Frame Tagging***
  - ***Time-Division Multiplexing (TDM)***
- ***IEEE Standard***
- ***Advantages***
  - ***Cost and Time Reduction***
  - ***Creating Virtual Work Groups***
  - ***Security***

Figure 5.58: ***A switch connecting three LANs without any VLAN's***

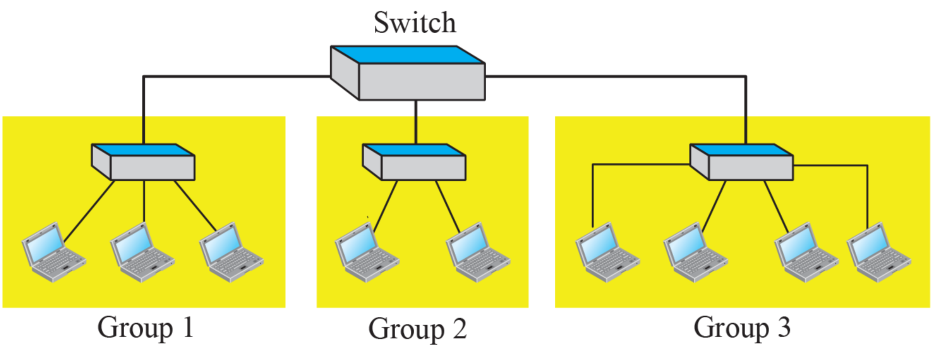
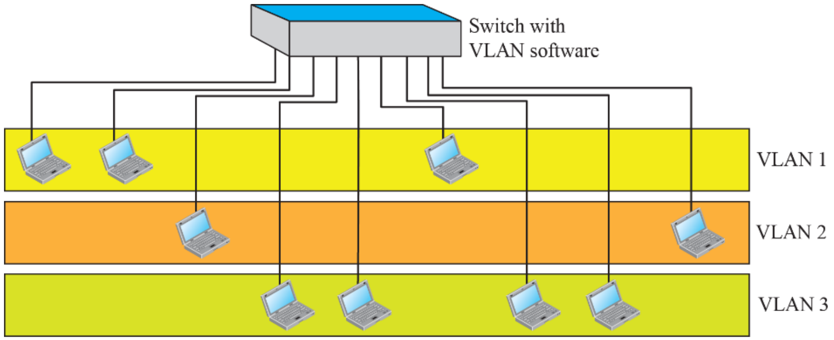


Figure 5.59: ***A single switch with three VLAN's configured using software***



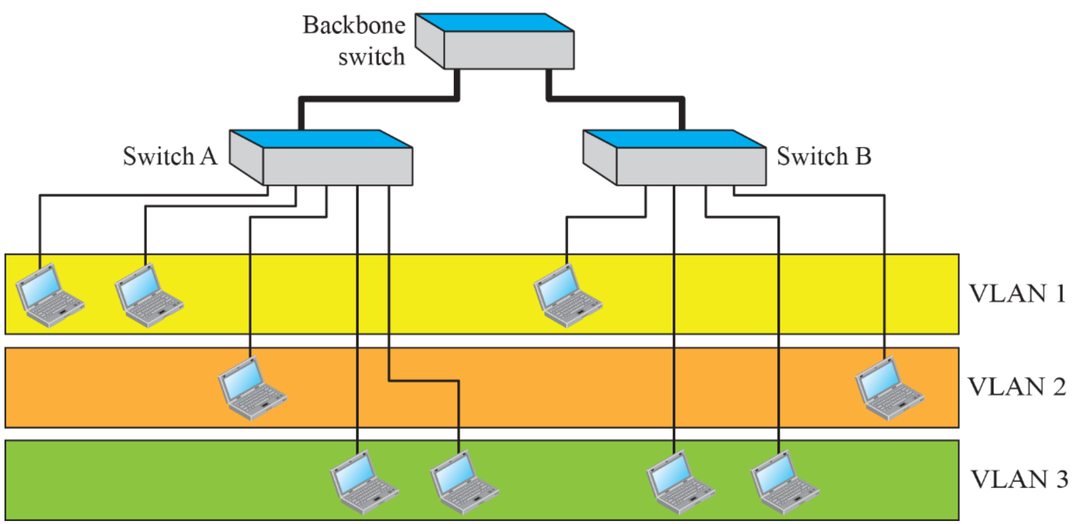


Figure 5.60: ***Two switches in a backbone with three VLAN's configured using software***

5-6 OTHER WIRED NETWORKS

- *As we discussed in Lecture 1, the networks that we encounter in the Internet are either LANs or WANs.*
- *However, sometimes the terminology is under dispute.*
- *For example, some access networks such as dial-up connection or cable connection are called WANs by some people and MANs by others.*

5.6.1 Point-to-Point Networks

- *Some point-to-point networks, such as dial-up, DSL / ADSL & cable are used to provide internet access from Internet user premises.*
- *Such networks use a dedicated connection between the two devices, they do not use media access control (MAC).*
- *The only protocol that is needed is PPP, as we discussed before.*

- ***Digital Subscriber Line (DSL)***
  - *Using Existing Local Loops*
- ***Cable***
  - *Hybrid Fiber-Coaxial (HFC) Network*

Figure 5.61: *Dial-up network to provide Internet access*

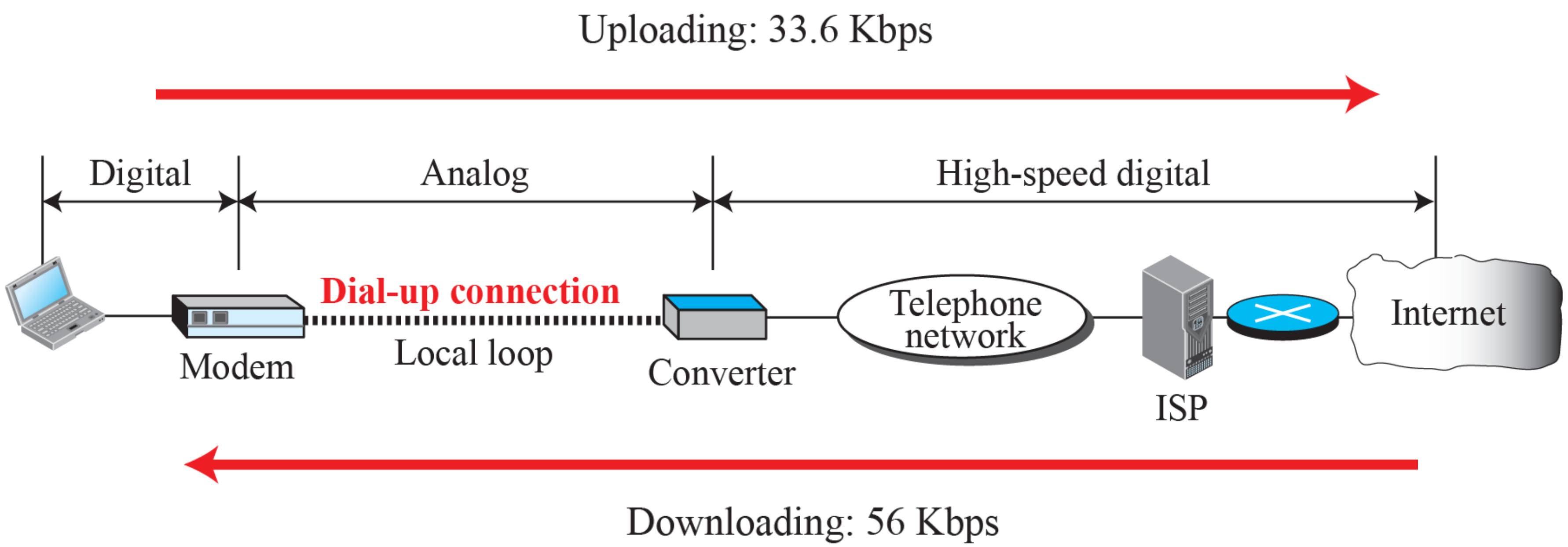
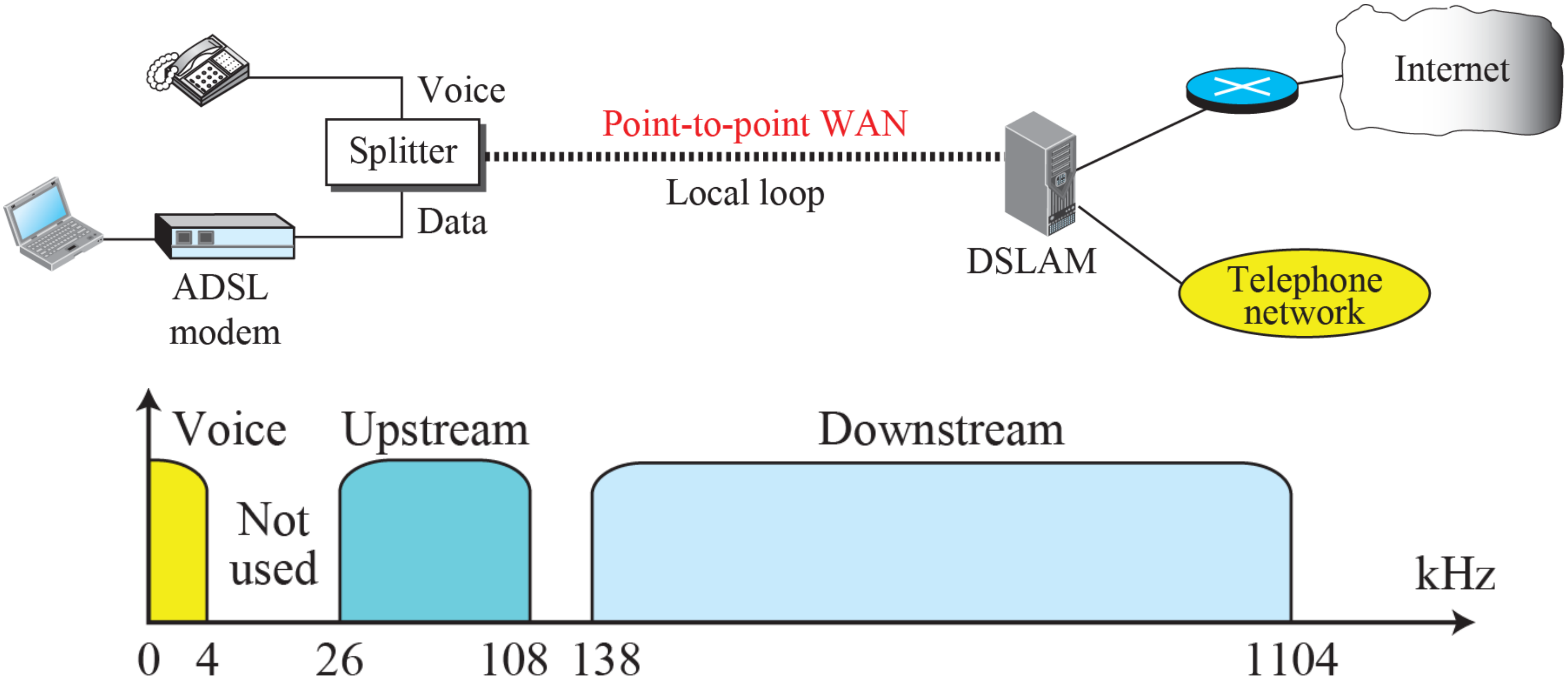
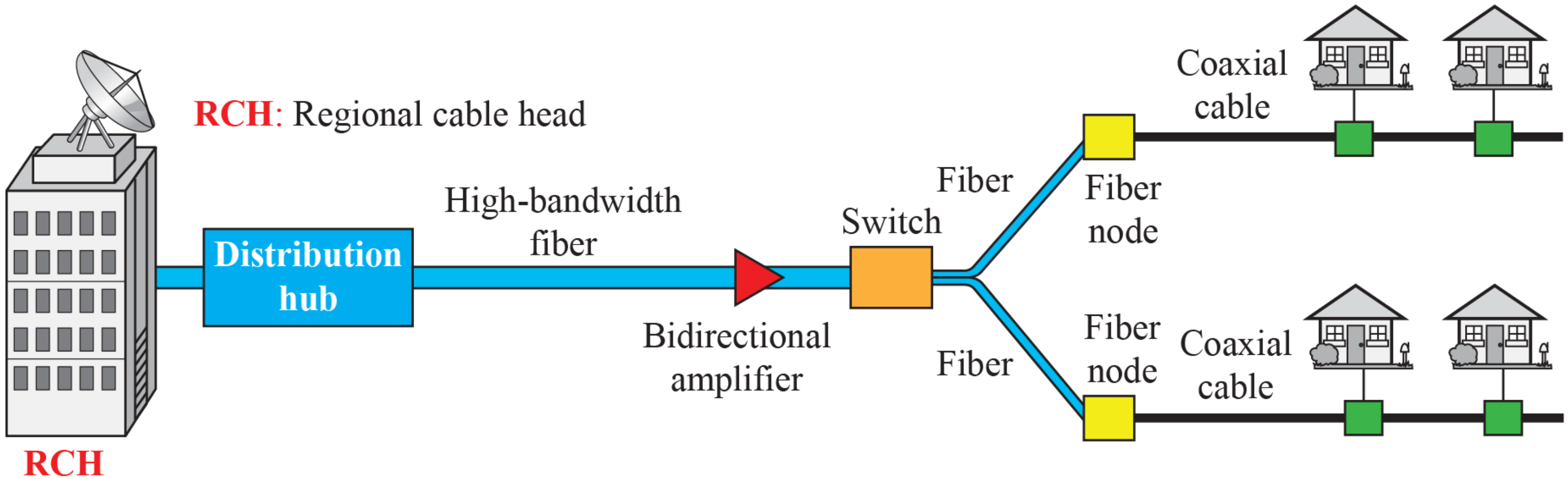


Figure 5.62: *ASDL point-to-point network*



Using Existing Local Loops: *ADSL uses the existing telephone lines (local loop). The telephone lines has bandwidths up to 1.1 MHz, but the filter(splitter) installed at the end office filters the bandwidth to 4 kHz (for voice communication). Typically, an available bandwidth of 1.104 MHz is divided into a* ***voice channel****, an* ***upstream channel****, and a* ***downstream channel****.*

Figure 5.64: Hybrid Fiber-Coaxial (HFC) Network



5.6.2 SONET

- *High-speed backbone networks, SONET is used as a transport network to carry loads from other networks.*

Table 5.10: SONET rates

STS	*OC*	*Rate (Mbps)*	*STS*	*OC*	*Rate (Mbps)*
STS-1	OC-1	51.840	STS-24	OC-24	1244.160
STS-3	OC-3	155.520	STS-36	OC-36	1866.230
STS-9	OC-9	466.560	STS-48	OC-48	2488.320
STS-12	OC-12	622.080	STS-96	OC-96	4976.640
STS-18	OC-18	933.120	STS-192	OC-192	9953.280

Figure 5.67: A simple network using SONET equipment

ADM: Add/drop multiplexer

STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

R: Regenerator

T: Terminal

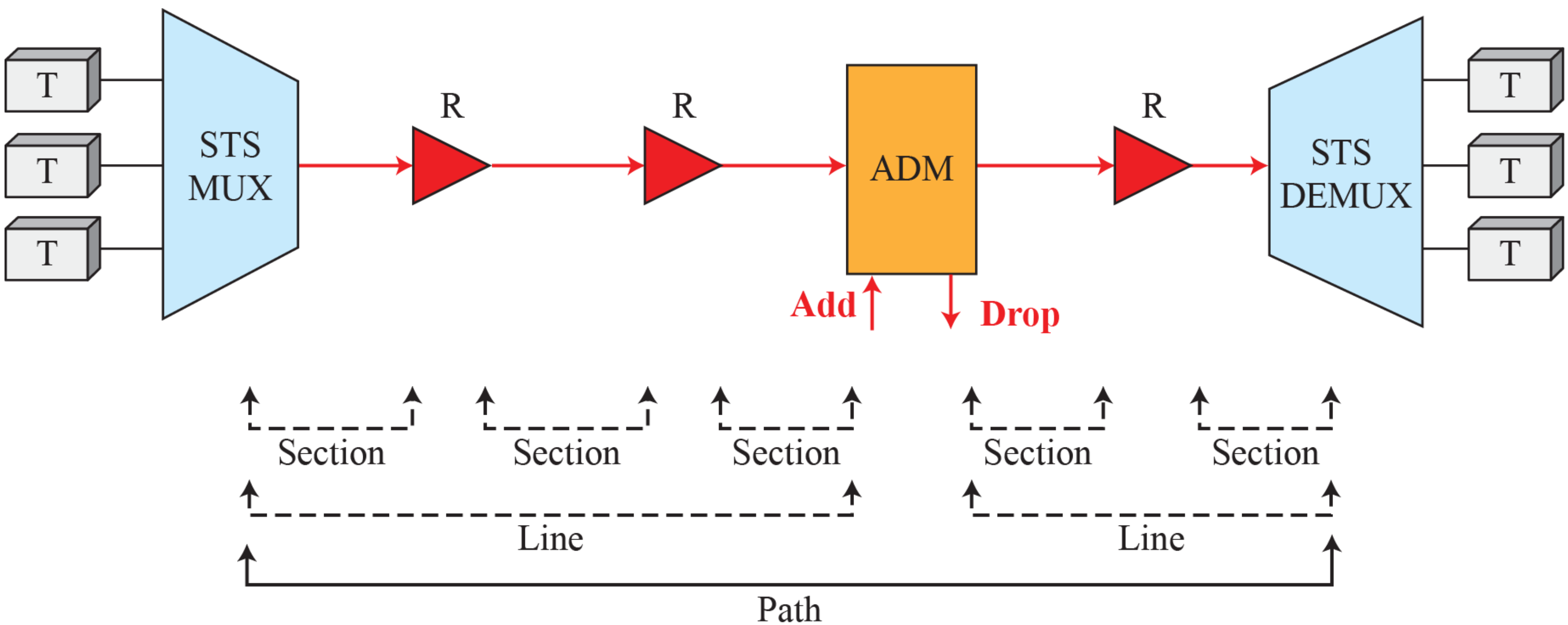
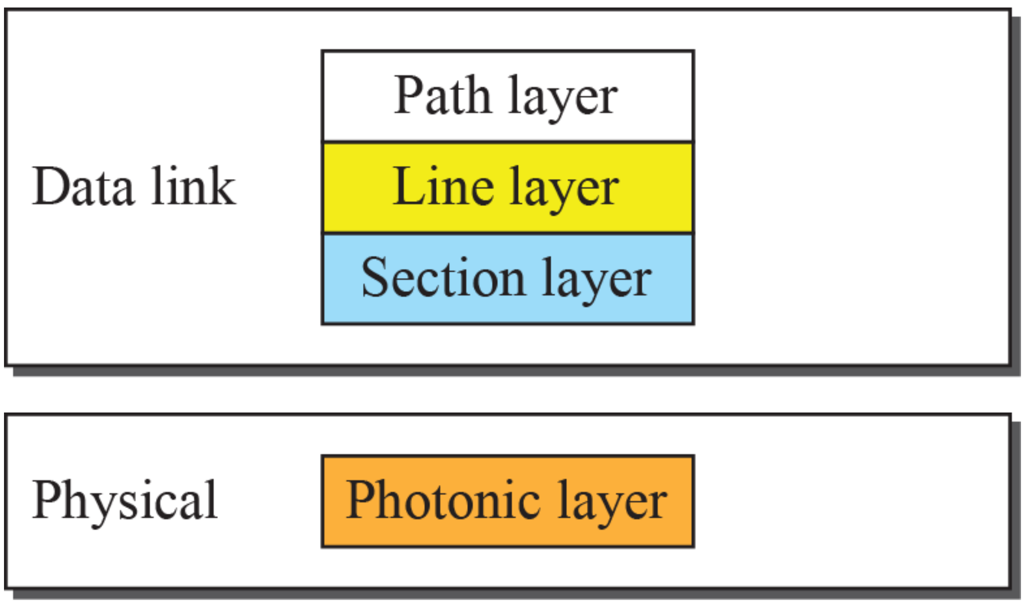
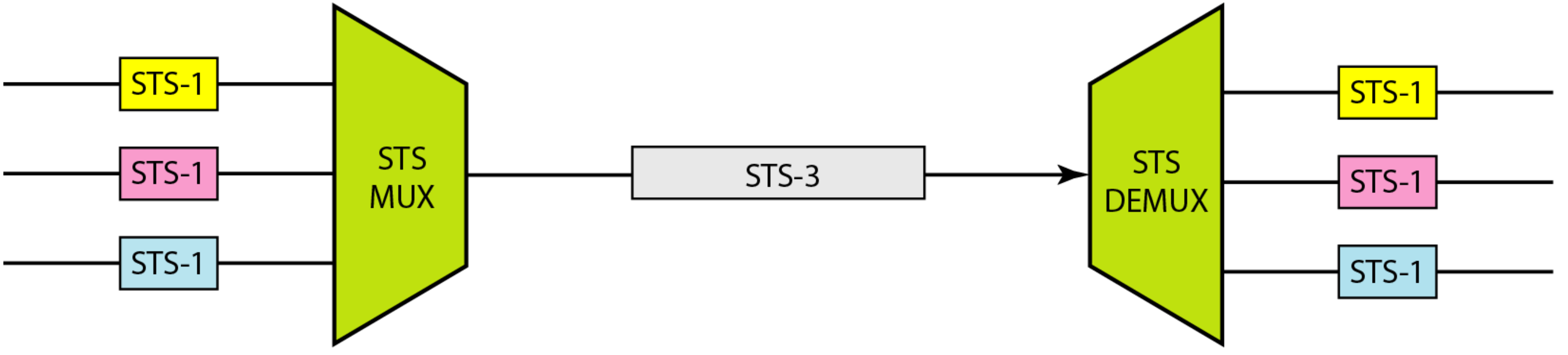


Figure 5.68: SONET layers compared with OSI or the Internet layers

The SONET standard includes four functional layers: the photonic, the section, the line, and the path layer. They correspond to both the physical and the data link layers.



STS multiplexing/demultiplexing



5.6.3 Switched Network: ATM

Asynchronous Transfer Mode (ATM) is a switched wide area network based on the cell relay protocol designed by the ATM forum and adopted by the ITU-T.

❑ *Architecture*

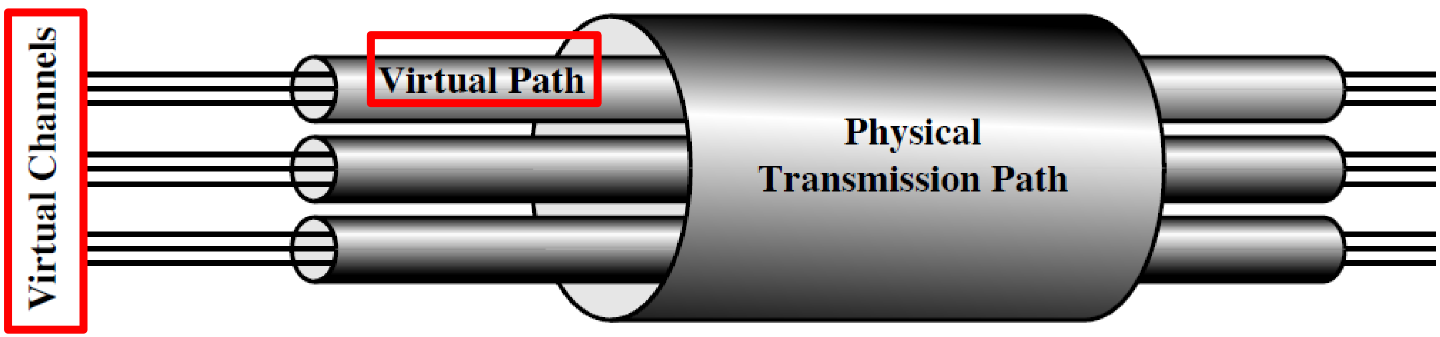
- ❖ ***ATM Terminology – Connection address***
- ❖ ***Virtual channels & Virtual paths***
- ❖ ***ATM cell Header Formats***
- ❖ ***ATM service Categories***
- ❖ ***Applications***

Asynchronous Transfer Mode (ATM)

- Also known as Cell Relay
- Operates at high data rates in the WAN
- Resembles packet switching
  - Involves data transfer in discrete chunks, like packet switching
  - Allows multiple logical connections to be multiplexed over a single physical interface
- *Minimal error and flow control capabilities reduces overhead processing and size*
- Fixed-size cells simplify processing at ATM nodes

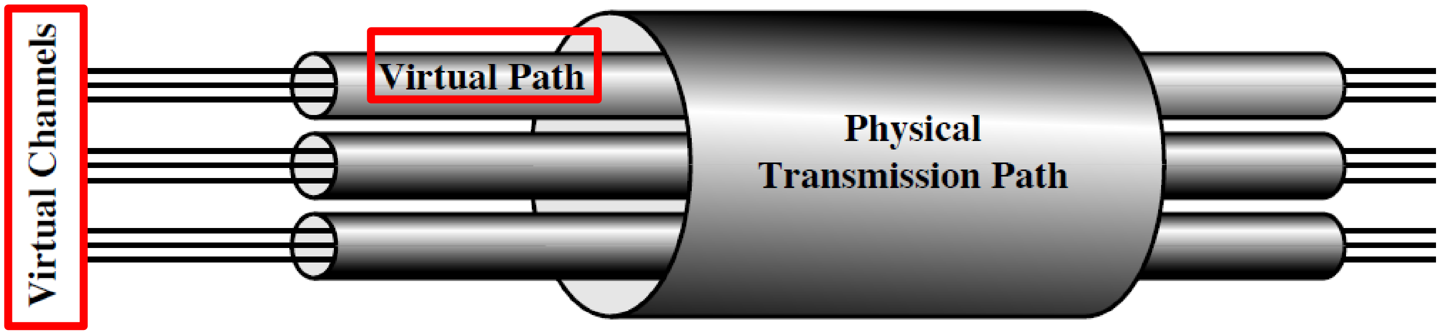
ATM Terminology – Connection address

- **Virtual channel** connection (VCC)
  - Logical connection in ATM
  - Basic unit of switching in ATM network
  - Analogous to a virtual circuit in packet switching networks
  - Exchanges **variable-rate**, full-duplex flow of fixed-size cells
- **Virtual path** connection (VPC)
  - Bundle of VCCs that have the same end points

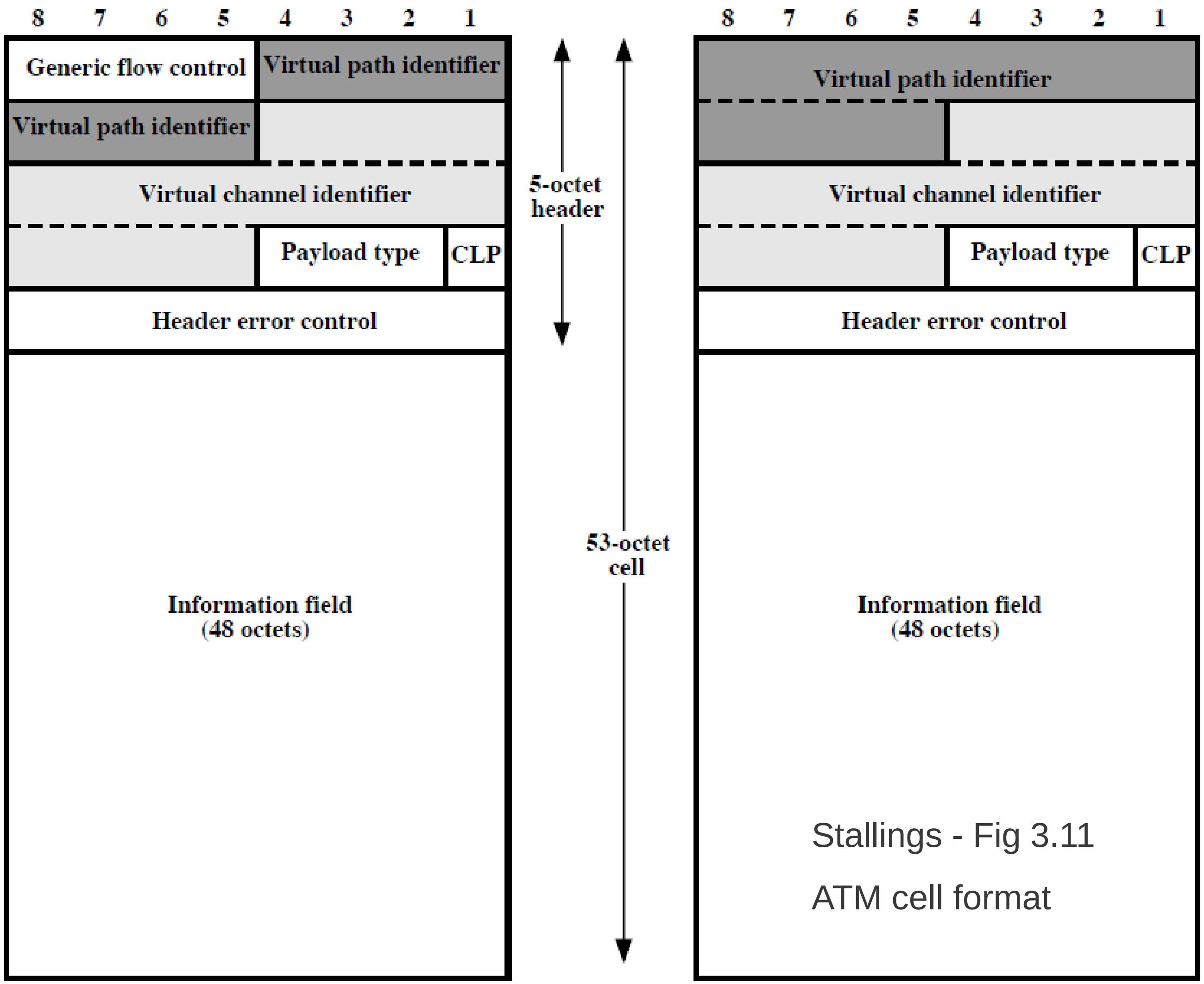


Advantages of Virtual Paths

- Simplified network architecture
- Increased network performance and reliability
- Reduced processing and short connection setup time
- Enhanced network services



ATM Cell Header Format



(a) User-Network Interface

(b) Network-Network Interface

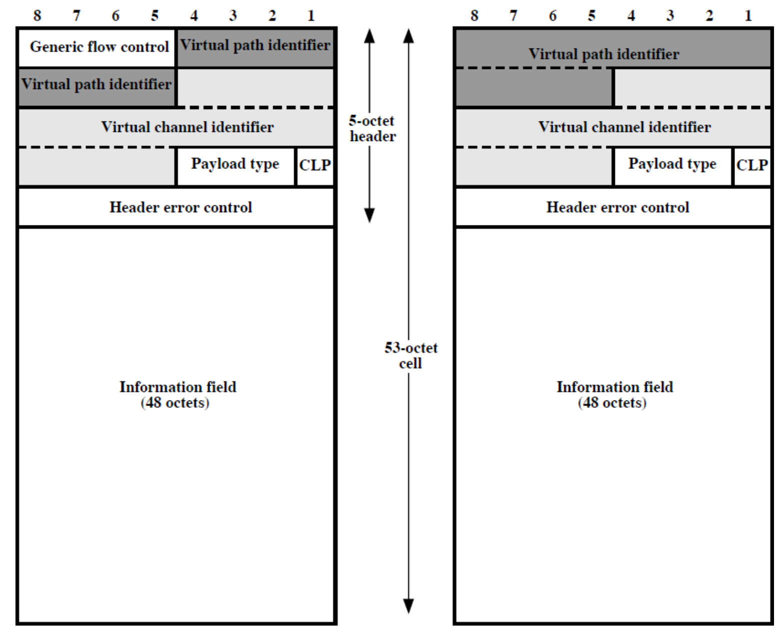
Stallings - Fig 3.11

ATM cell format

ATM Cell Header Format

- Generic flow control (GFC)
  - 4 bits, used **only** in user-network interface (UNI)
  - Used to alleviate short-term overload conditions in network
- Virtual path identifier (VPI)
  - 8 bits at the user-network interface (UNI)
    12 bits at network-network interface (NNI)
  - Routing field
- Virtual channel identifier (VCI) – 8 bits
  - Used for routing to and from end user

ATM Cell Header Format



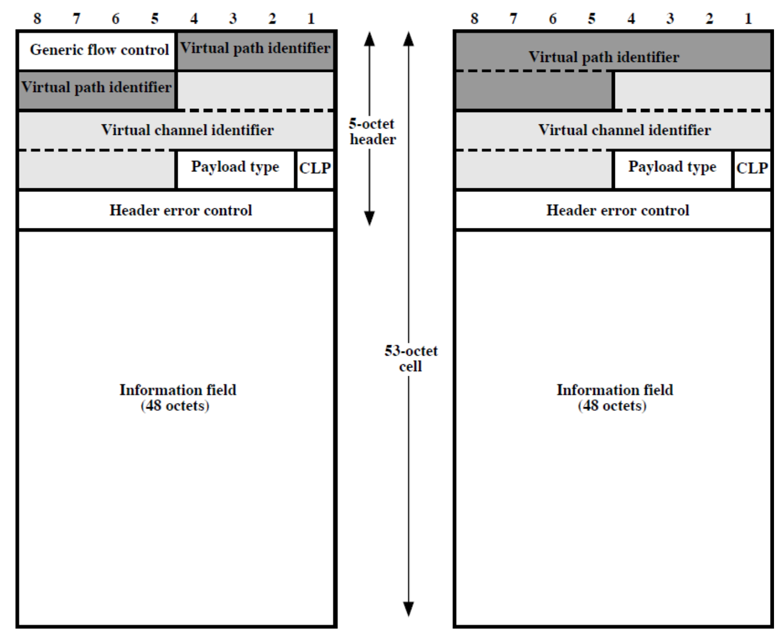
(a) User-Network Interface

(b) Network-Network Interface

ATM Cell Header Format

- Payload type (PT) – 3 bits
  - Indicates type of information in information field
- Cell loss priority (CLP) – 1 bit
  - Provides guidance to network in the event of congestion
- Header error control (HEC) – 8 bit
  - Error code

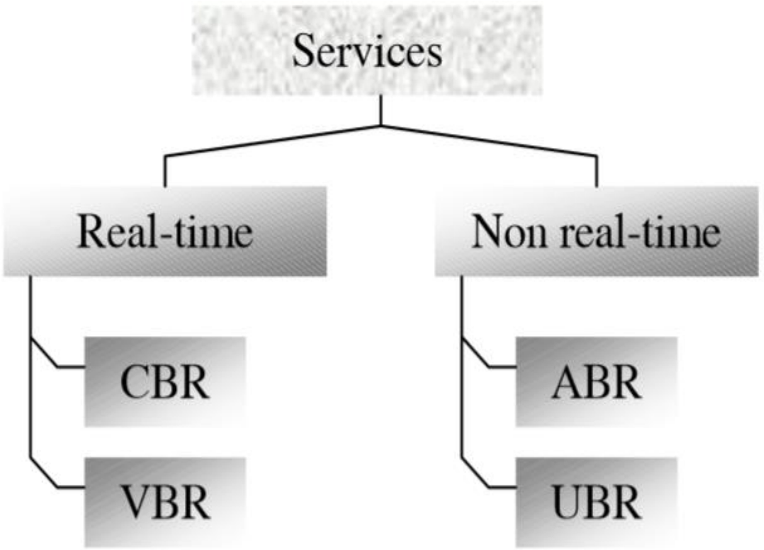
ATM Cell Header Format



(a) User-Network Interface
(b) Network-Network Interface

ATM Service Categories

- Real-time service
  - Constant bit rate (CBR)
  - Real-time variable bit rate (rt-VBR)
- Non-real-time service
  - Non-real-time variable bit rate (nrt-VBR)
  - Available bit rate (ABR)
  - Unspecified bit rate (UBR)



Classes of service in ATM networks

Examples of CBR Applications

- Real-time service
  - Constant bit rate (CBR)
  - Real-time variable bit rate (rt-VBR)

- Videoconferencing
- Interactive audio
  - e.g., telephony
- Audio/video distribution
  - e.g., television, distance learning, pay-per-view
- Audio/video retrieval
  - e.g., video-on-demand, audio library

Examples of UBR applications

- Non-real-time service
  – Non-real-time variable bit rate (nrt-VBR)
  – Available bit rate (ABR)
  – Unspecified bit rate (UBR)

- Text/data/image
  – transfer, messaging, distribution, retrieval
- Remote terminal
  – e.g., telecommuting

5-7 CONNECTING DEVICES

- *Hosts and networks do not normally operate in isolation. We use connecting devices to connect hosts together to create networks or to connect networks together to make an internet.*
- *Connecting devices can operate in different layers of the Internet model.*
- *We discuss three kinds of connecting devices: repeaters, link-layer switches, and routers.*

5.7.1 Repeater or Hubs

- *A **repeater** is a device that operates only in the physical layer.*
- *Signals that carry information within a network can travel a fixed distance before attenuation endangers the integrity of the data.*
- *A repeater receives a signal and, before it becomes too weak or corrupted, regenerates and retimes the original bit pattern.*

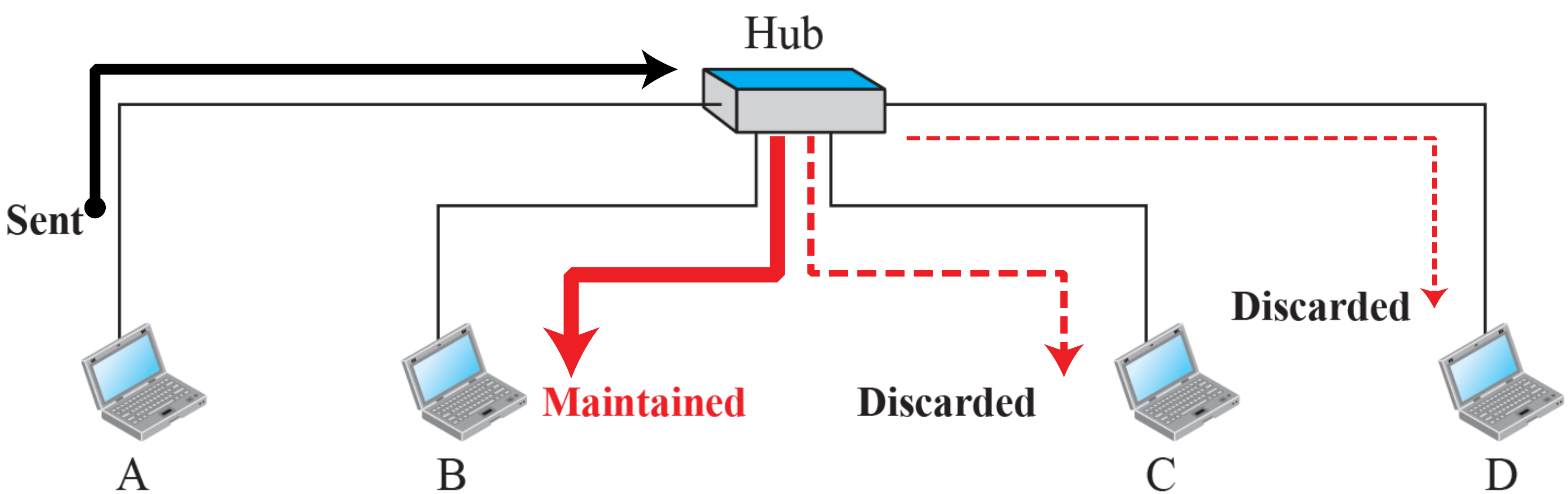


***Figure 5.84:* Repeater or hub**

5.7.2 Link-Layer Switches

A ***link-layer switch*** *operates in both the* ***physical*** *and the* ***data-link layers****.*

As a physical layer device, it regenerates the signal it receives. As a link-layer device, the link-layer switch can check the MAC addresses (source and destination) contained in the frame and frame errors.

- ***Filtering***
- ***Transparent Switches***
  - ***Forwarding***
  - ***Learning***

Switching table

Address	Port
71:2B:13:45:61:41	1
71:2B:13:45:61:42	2
64:2B:13:45:61:12	3
64:2B:13:45:61:13	4

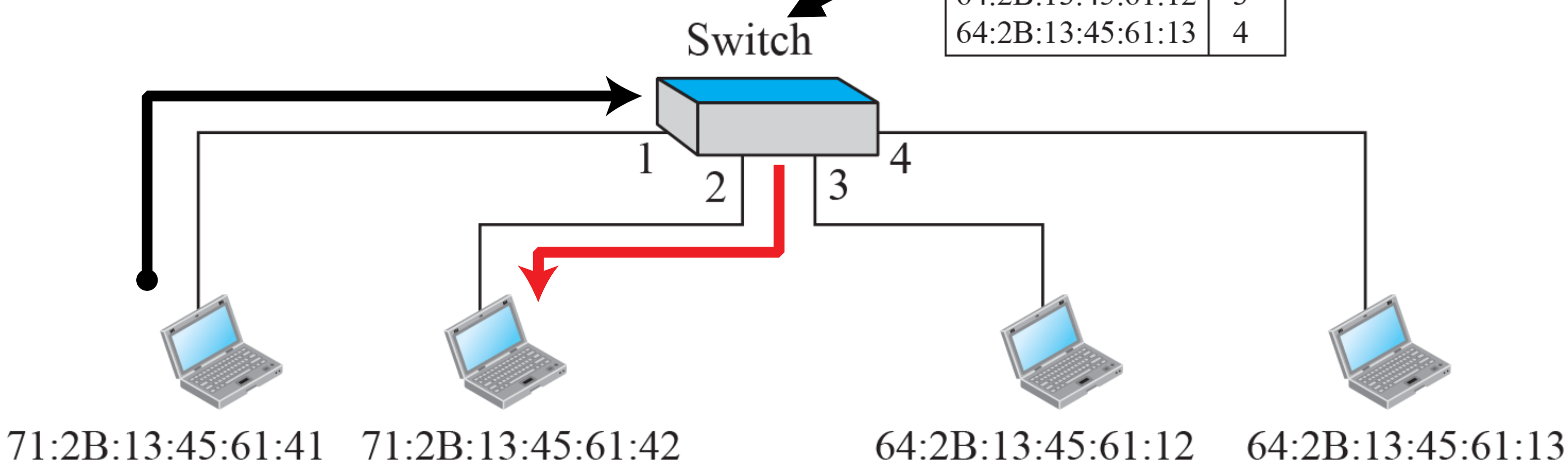


Figure 5.85: ***Link-Layer Switch***

Figure 5.86: Learning switch

Address	Port

a. Original

Address	Port
71:2B:13:45:61:41	1

b. After A sends a frame to D

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4

c. After D sends a frame to B

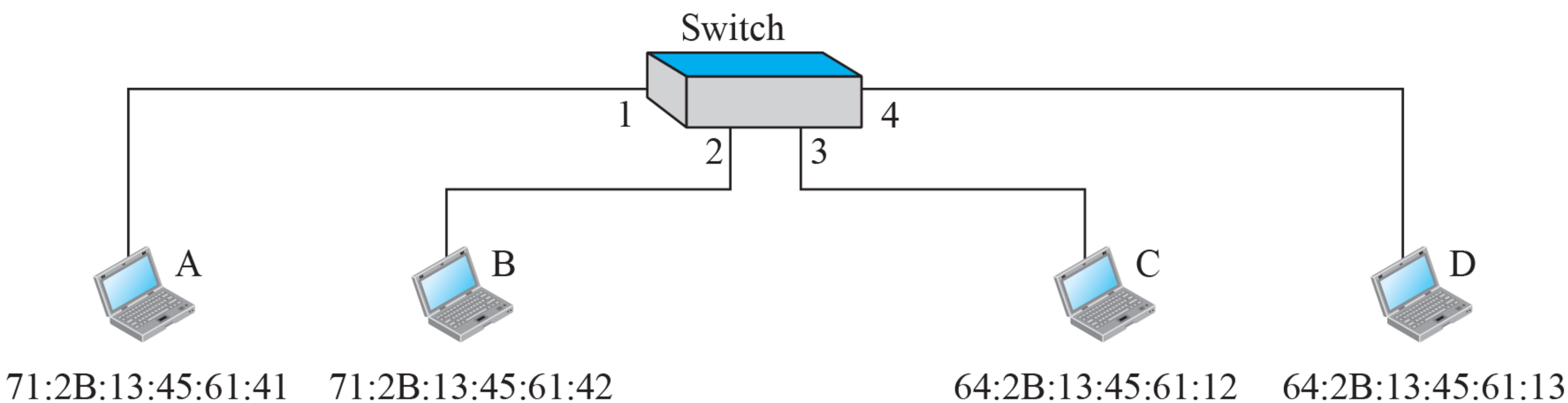
Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2

d. After B sends a frame to A

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2
64:2B:13:45:61:12	3

e. After C sends a frame to D

Gradual building of Table



5.7.3 Routers

We discussed routers in network layer, here we compare routers with a two-layer switch and a hub.

A router is a three-layer device; it operates in the ***physical***, ***data-link***, *and* ***network*** *layers.*

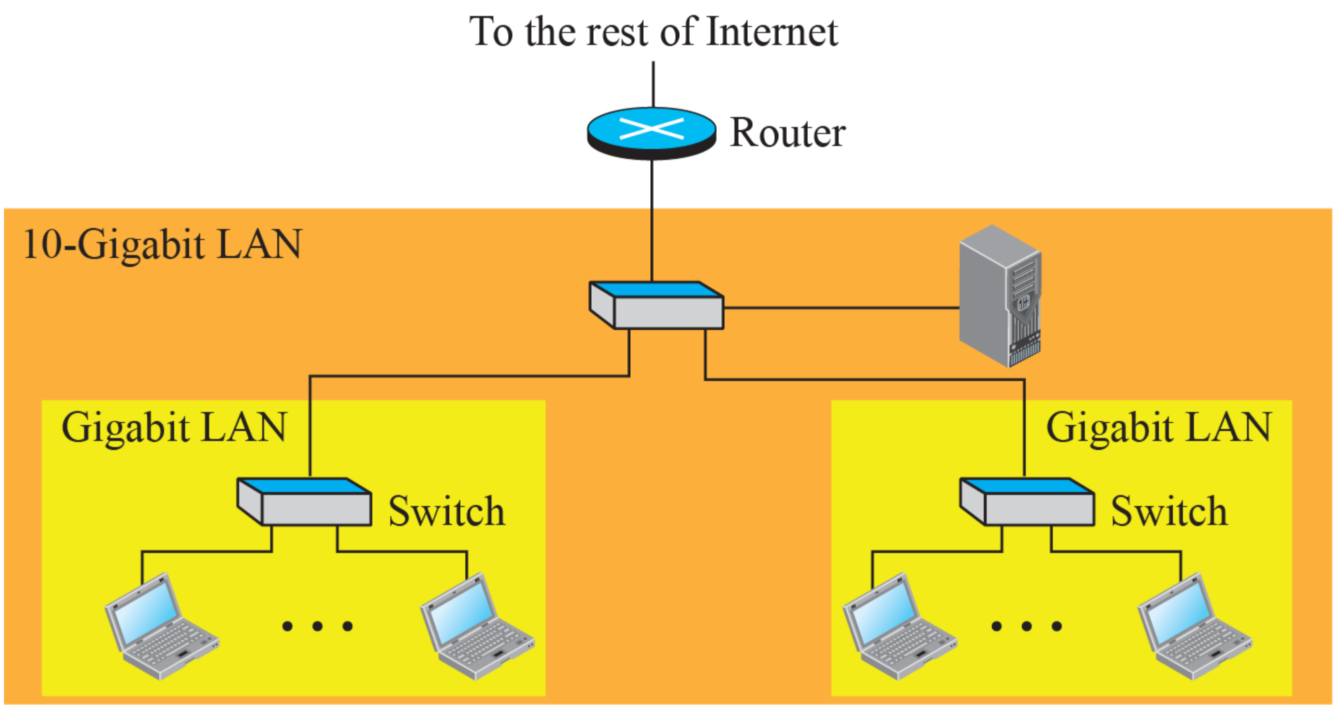


***Figure 5.87:* Routing example**

Chapter 5: Summary

- *Discussed WIRED LANS: ETHERNET, FASTETHERNET, GIGABIT AND 10 GIGABIT ETHERNET*
- *Discussed other Wired Networks*
- *A virtual local area network (VLAN) is configured by software, not by physical wiring. Membership in a VLAN can be based on port numbers, MAC addresses, IP addresses, IP multicast addresses, or a combination of these features.*
- *We discussed two access networks: DSL and Cable. We also discussed two wide area networks: SONET and ATM.*

We also discussed connecting devices.

- *A **repeater** is a connecting device that operates in the physical layer of the Internet model.*
- *A **switch** is a connecting device that operates in the physical and data-link layers of the Internet model. A transparent switch can forward and filter frames and automatically build its forwarding table.*
- *A **router** is a connecting device that operates in the first three layers of the TCP/IP suite.*