Data Communication (DC)

Lecture 5b

Overview of the contents

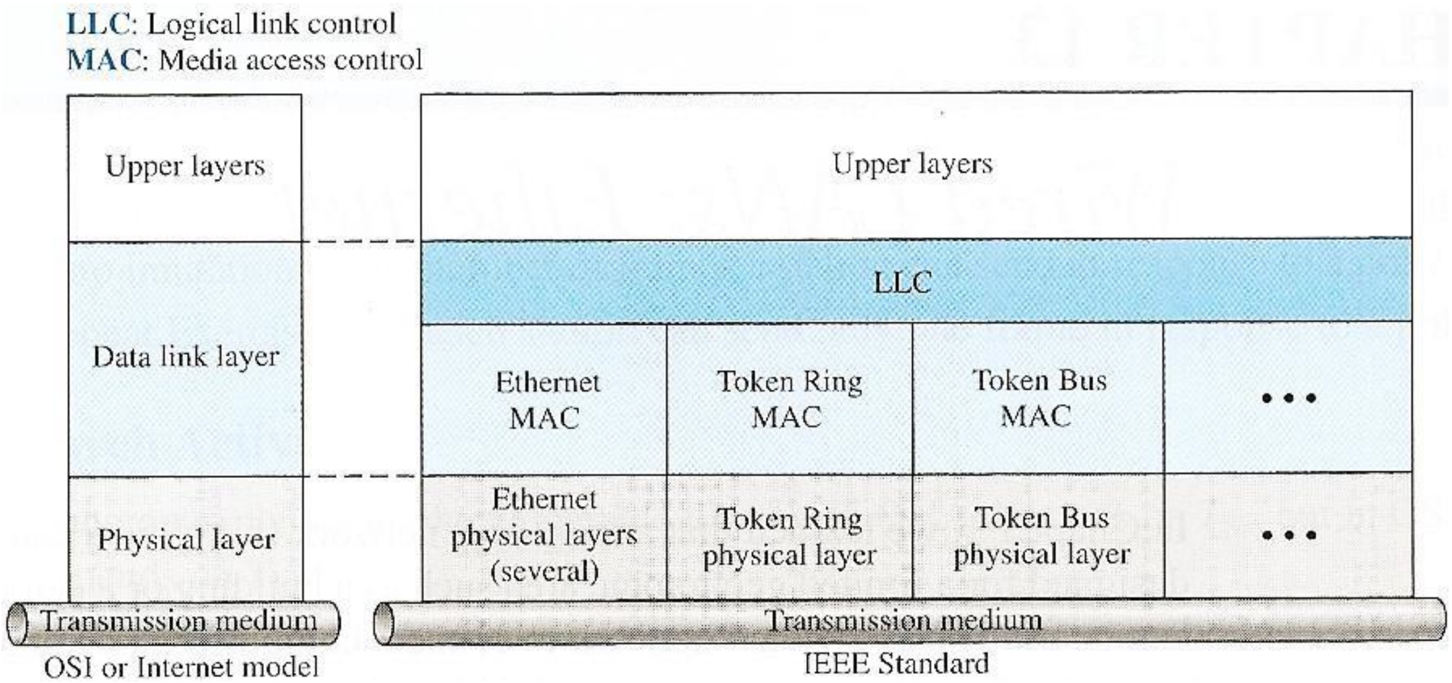
- Ethernet protocol
- Standard Ethernet
- Fast Ethernet
- Gigabit Ethernet

Data Link layer

IEEE Standards

The standard we will look at here is from 1985, when the IEEE started a **project 802**. The standard was approved by the **A**merican **N**ational **S**tandards **I**nstitute (**ANSI**) and the **I**nternational **O**rganization for **S**tandardization (**ISO**) in 1987.

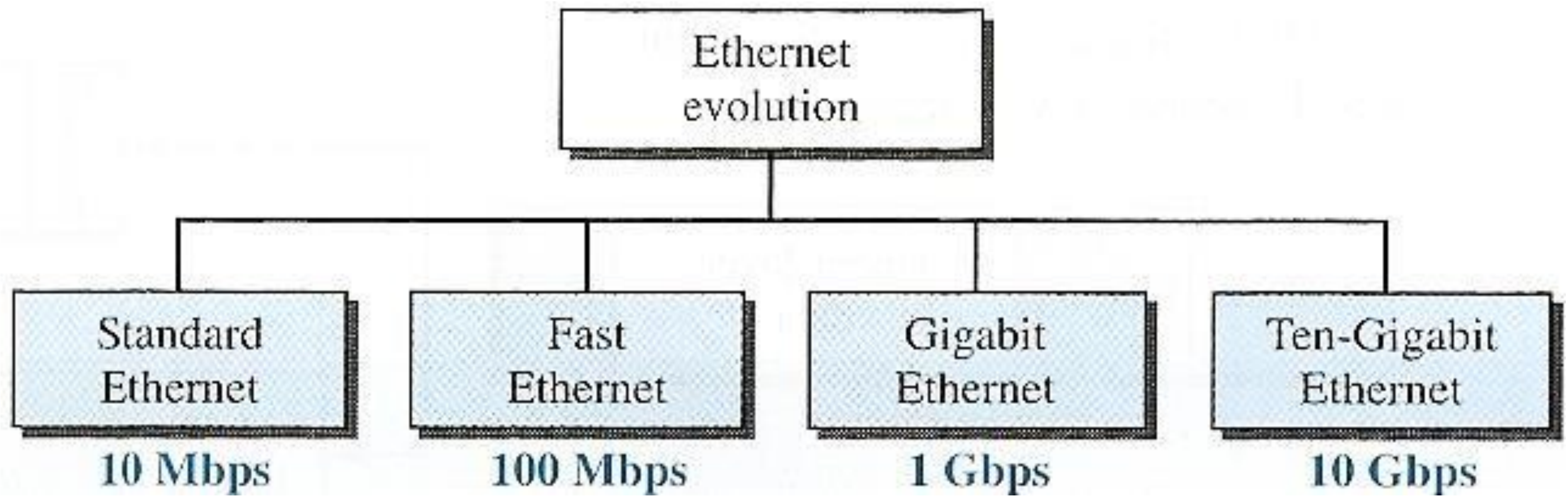
IEEE had subdivided the Data Link layer into **Logical Link Control (LLC)** and **Media Access Control (MAC)**. IEEE had also made different physical-Layer standards for different LAN protocols.



Data Link layer

IEEE Standards: Standard Ethernet

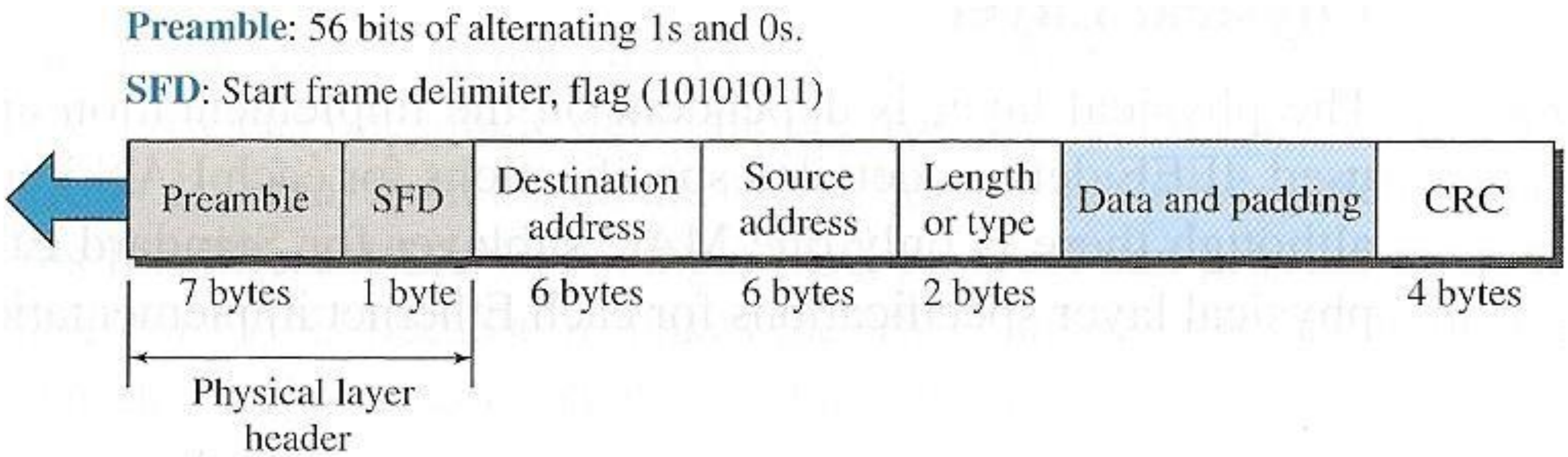
Originally, The Ethernet LAN was developed in the 1970s by Robert Metcalfe and David Boggs. Since then, it has gone through four generations as the demands for higher data rate have been increasing, we will look at 3 of them:



Data Link layer

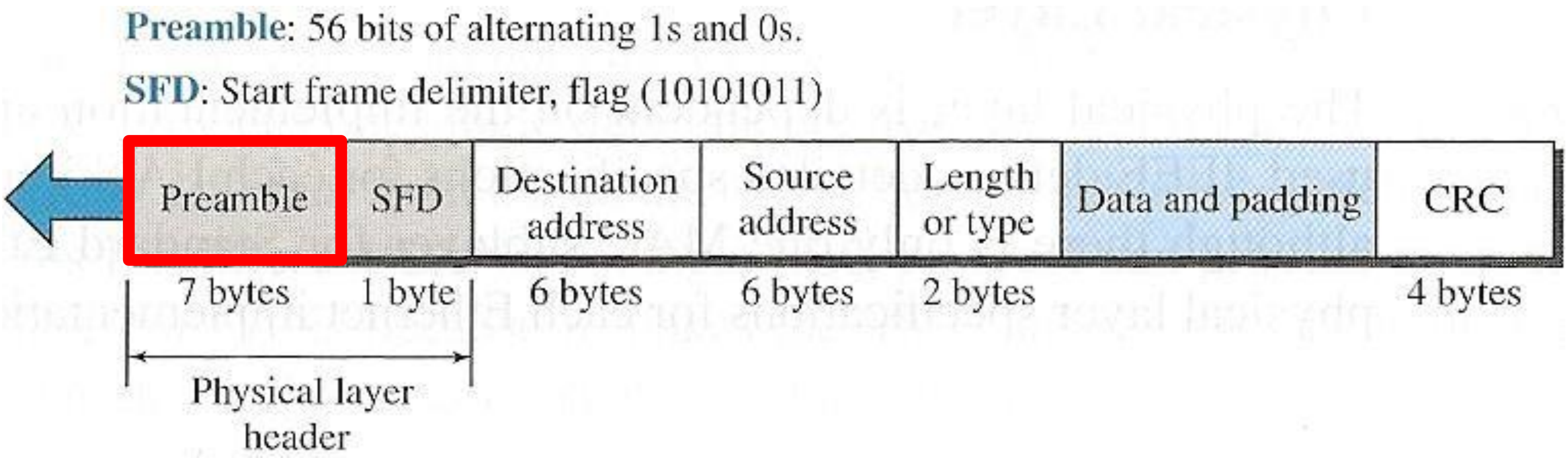
Standard Ethernet: Frame format for MAC-frame

- Ethernet has no mechanisms to acknowledge received frames.
- Therefore, it is considered an unreliable medium.
- If a receipt is to be received for received frames, it must be implemented in higher layers.



Data Link layer

Standard Ethernet: Frame format for MAC-frame

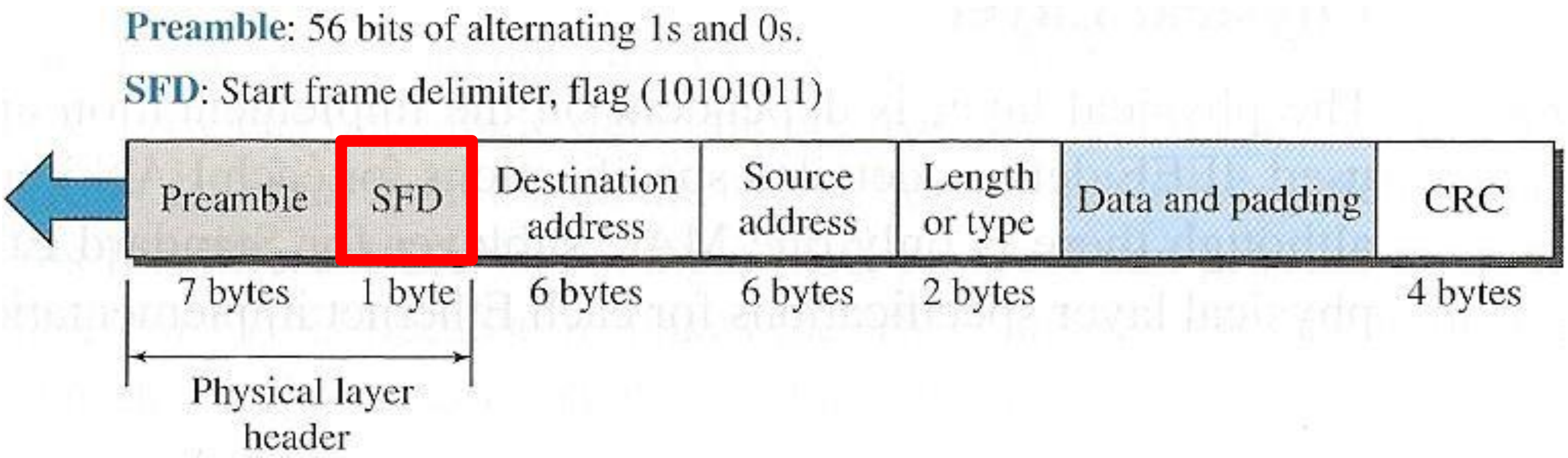


Preamble: This field consists of 7 bytes (56 bits) of alternating 0s and 1s. The field is used to alert the receiver to the coming frame and allows the receiver to synchronize its clock with the sender.

In fact, this field is actually added at the physical layer and is therefore not officially part of the frame.

Data Link layer

Standard Ethernet: Frame format for MAC-frame

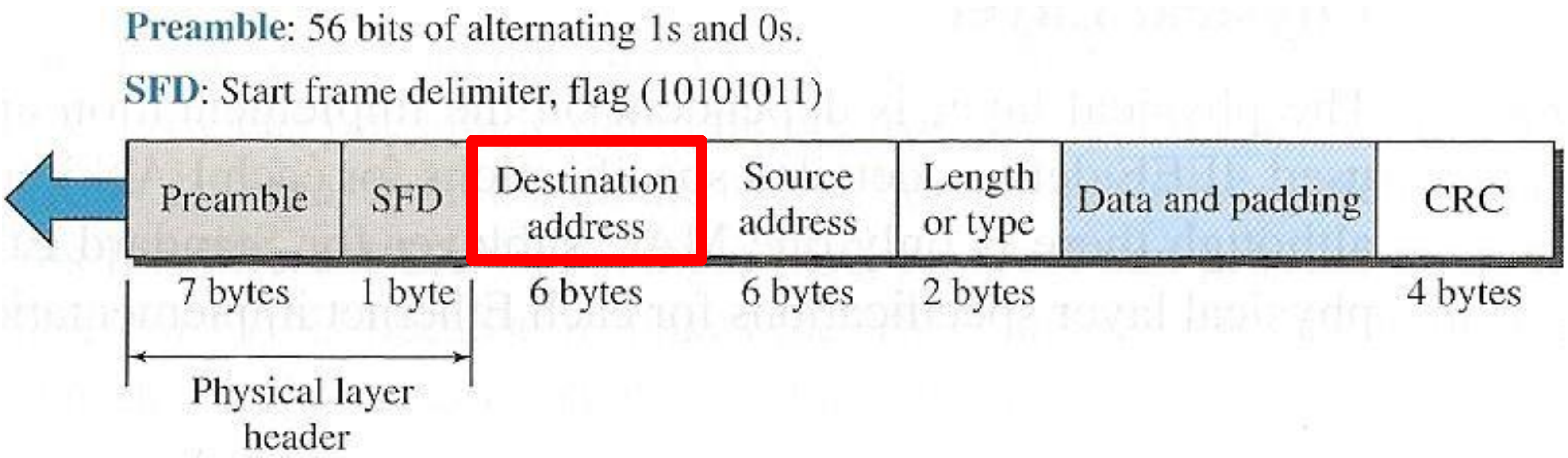


Start frame delimiter (SFD): This field has 1 byte and contains a constant value 10101011. It signals the start of a frame. The receiver is warned that this is the last chance to get ready to receive the coming frame.

This field is also added at the physical Layer.

Data Link layer

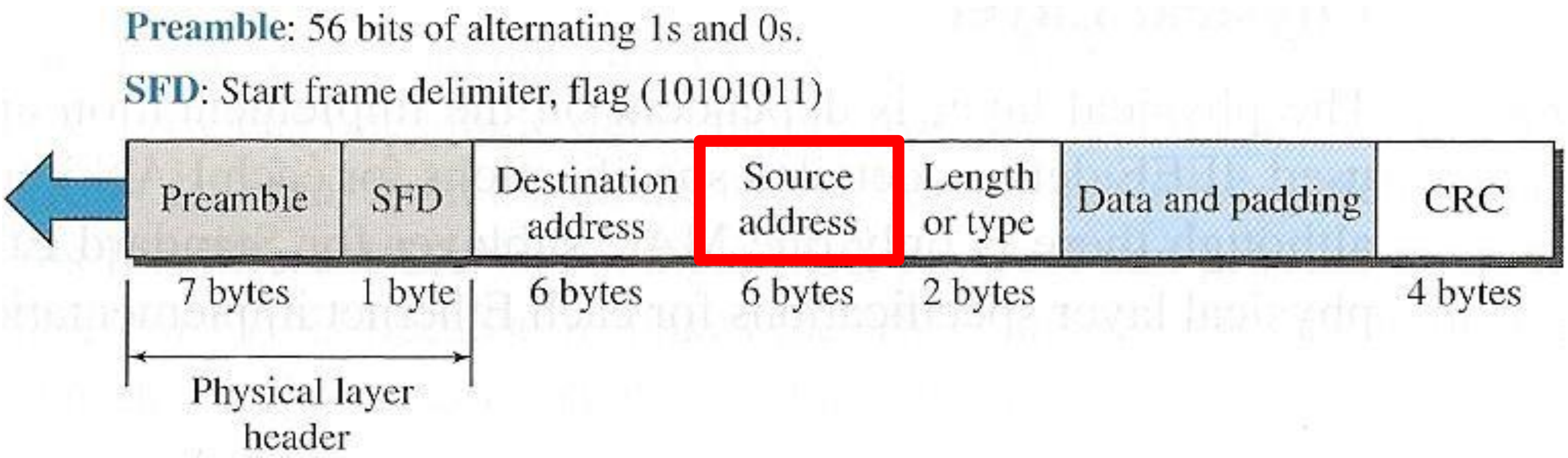
Standard Ethernet: Frame format for MAC-frame



Destination address (DA): This field has 6 bytes and contains the link-layer address of the destination station or stations, i.e.,receiver(s).

Data Link layer

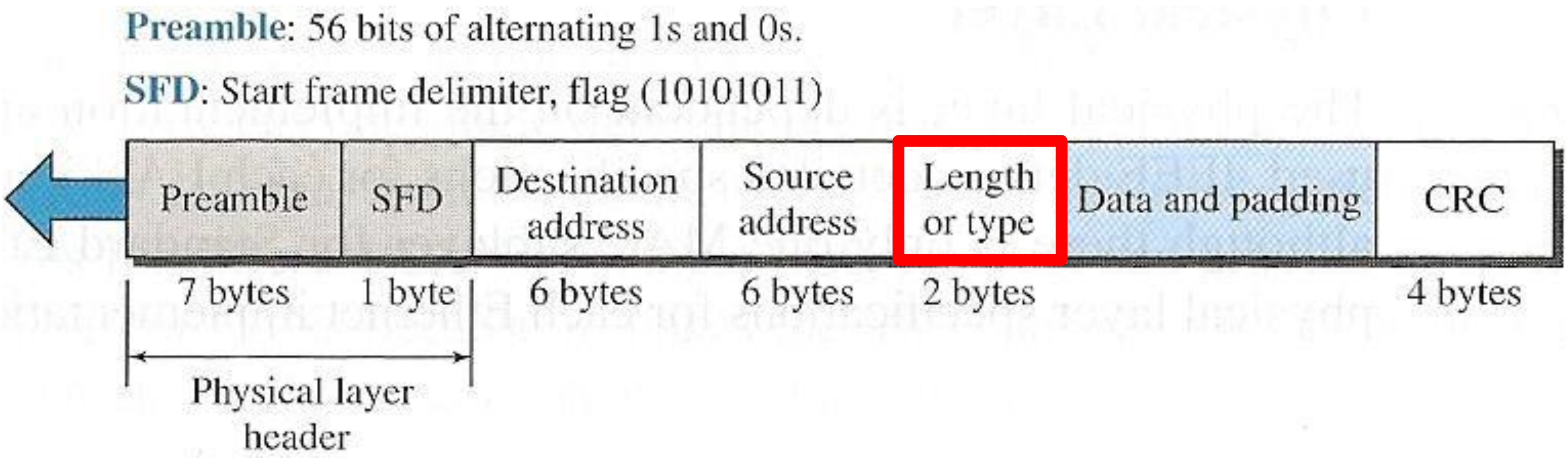
Standard Ethernet: Frame format for MAC-frame



Source address (SA): This field has 6 bytes and contains the link-layer address of the sender of the packet.

Data Link layer

Standard Ethernet: Frame format for MAC-frame



Length or Type: The standard Ethernet uses this field for type indication, while IEEE uses the field to specify the number of bytes in the data field.

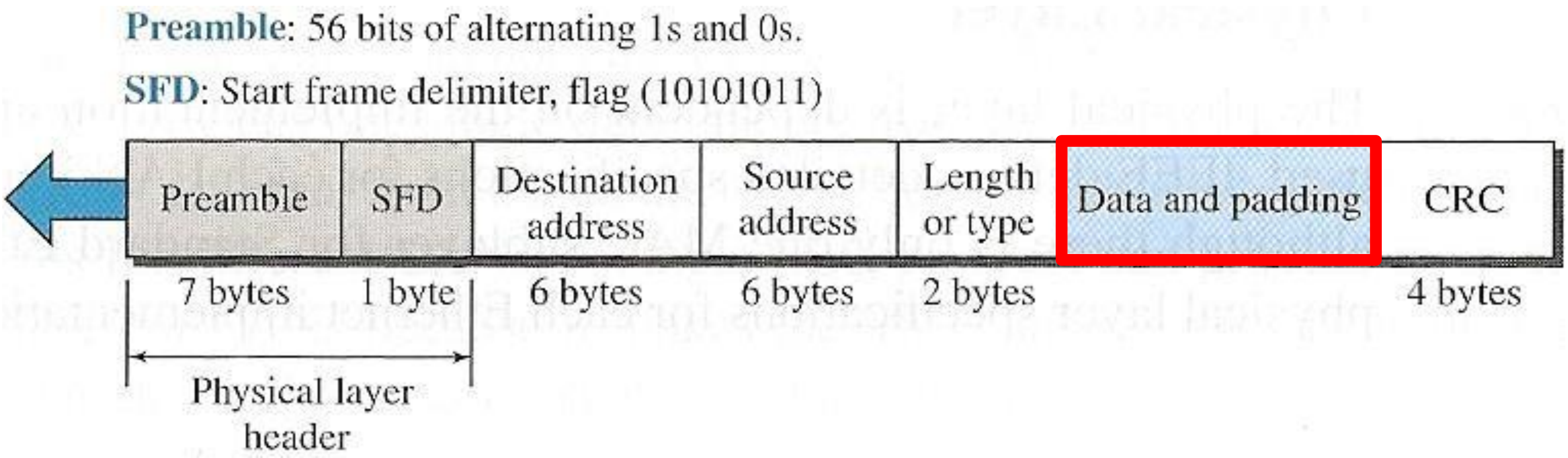
Both statements are common today.

If **type** is used, this value is larger than *1536 (0x0600)* and indicates the upper-layer protocol whose packet is encapsulated in the frame. Here, ***interpackets gap*** (which is the distance between frames = 12 byte) is used to detect the frame length.

E.g.: 0x0806 = ARP and 0x86DD = IPv6

Data Link layer

Standard Ethernet: Frame format for MAC-frame

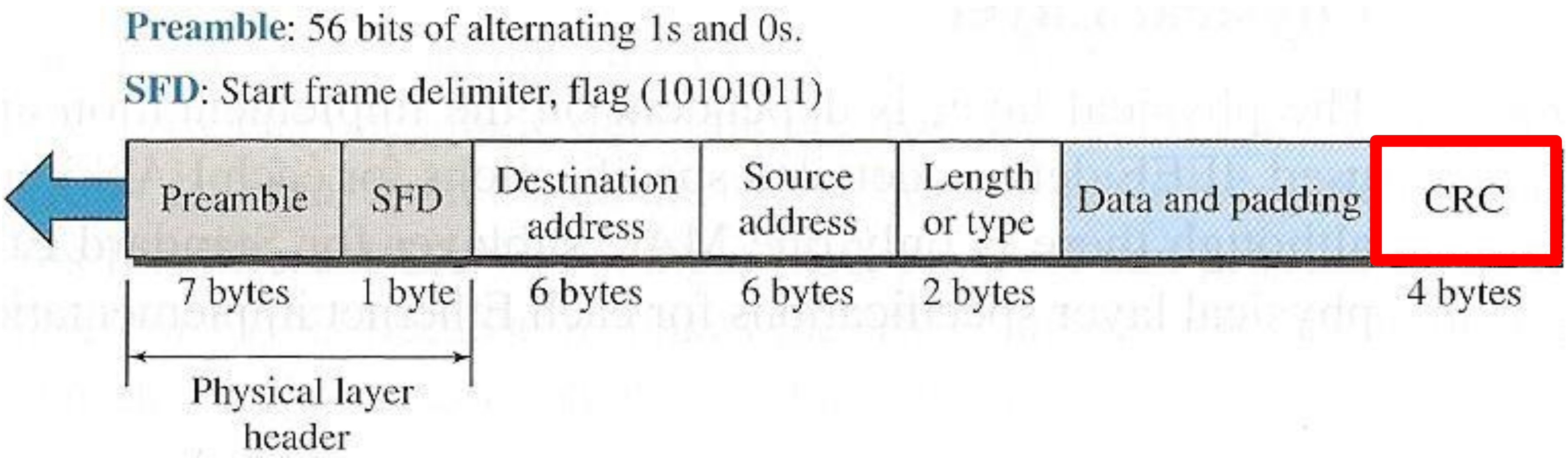


Data: This field contains data encapsulated from the upper layers. The size is between 46 and 1500 bytes.

If data in this field is less than 46 bytes, then 0s are inserted (padding).

Data Link layer

Standard Ethernet: Frame format for MAC-frame

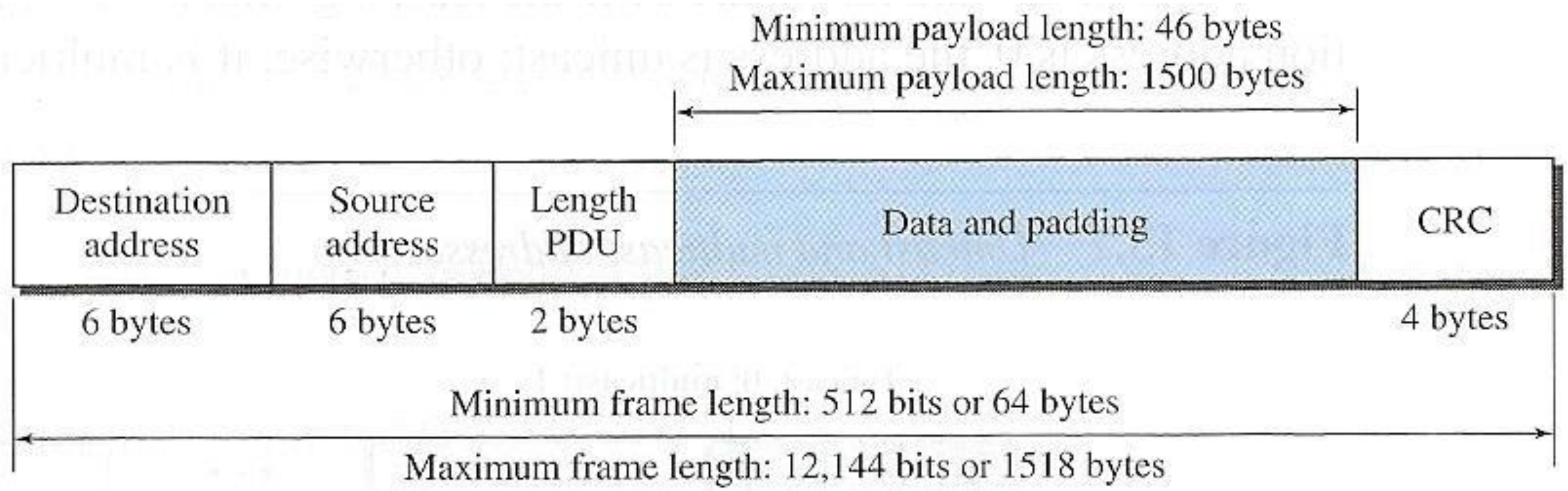


CRC: This field contains error detection information, in this case CRC-32.

Data Link layer

Standard Ethernet: Frame length

Ethernet has restrictions on both the minimum and maximum lengths of a frame.

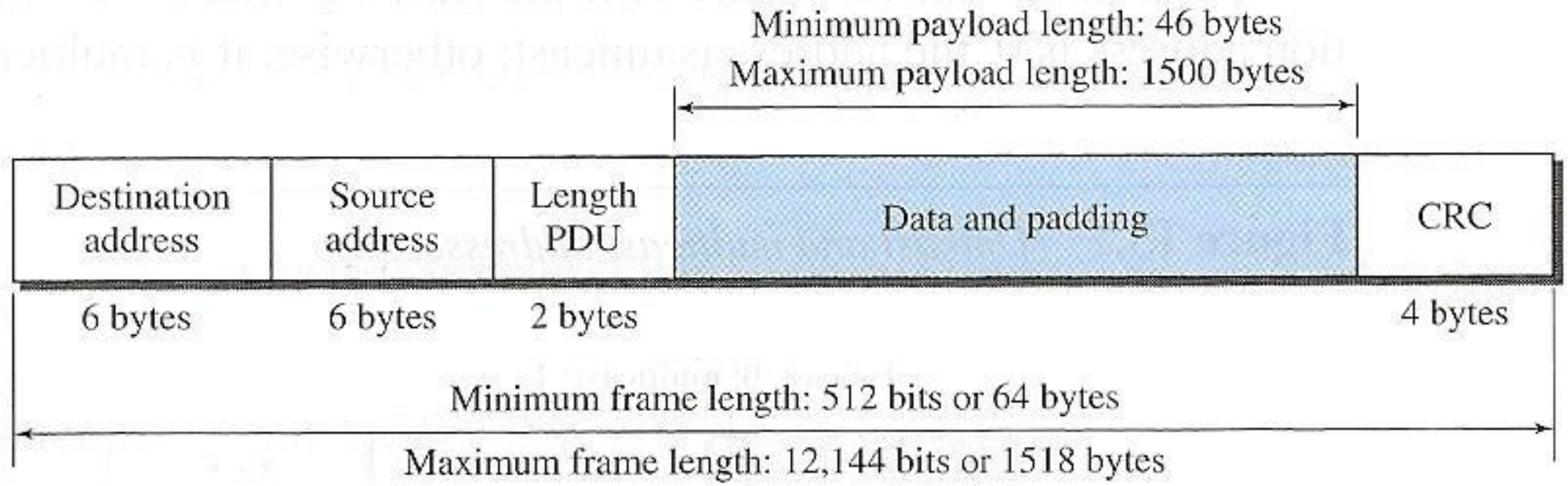


The minimum length is a requirement for the proper functioning of CSMA/CD. It is set to be at least 512 bits or 64 bytes.
The reason is that the transmission time for a frame (T_{fr}) must be at least $2xT_p$ (propagation) for collision detection.
If the upper layer delivers less than 46 bytes to the MAC layer, then some padding is conducted to fit.

Data Link layer

Standard Ethernet: Frame length

Ethernet has restrictions on both the minimum and maximum lengths of a frame.



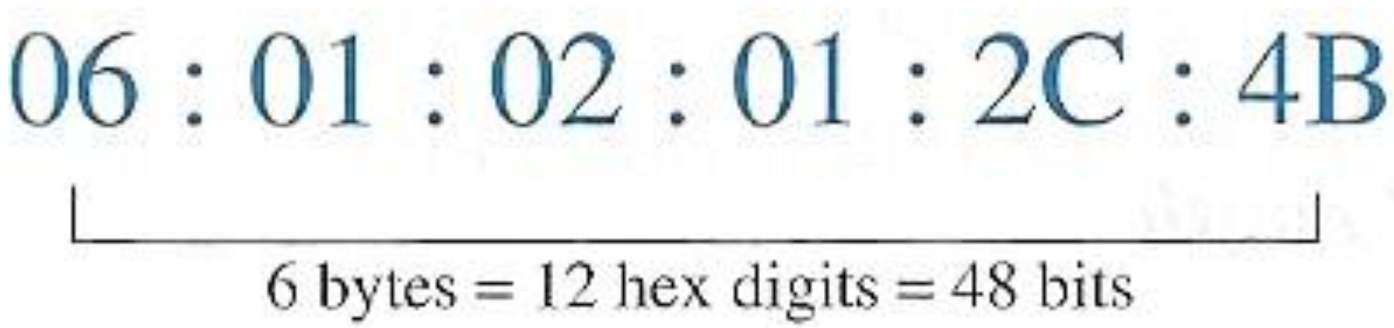
The maximum limit has two historical reasons.

- In the early days of Ethernet, memory was very expensive. By limiting the size, one could also limit the size of buffers.
- The maximum limit should help ensure that a station does not monopolize the shared medium for too long at a time.

Data Link layer

Standard Ethernet: 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.

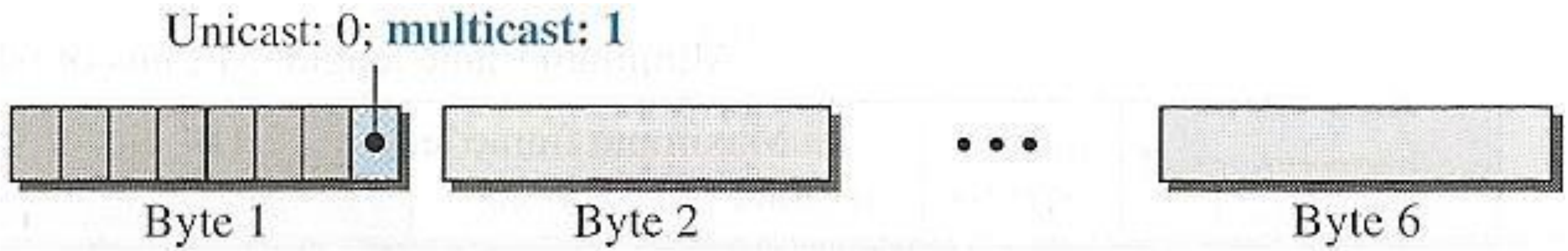


Data Link layer

Standard Ethernet: Unicast, Multicast and Broadcast addresses

A source address is always a unicast address, the frame only comes from one station. But the destination address can be unicast, multicast or broadcast addresses.

- If the least significant bit (lsb) in the first byte is **0**, then it is a unicast address.
- If the lsb in the first byte is **1**, then it is a multicast address.
- If all bits in the address are **1** (FF:FF:FF:FF:FF:FF), then it is a broadcast address.



Data Link layer

Standard Ethernet

Access method

Standard Ethernet uses CSMA/CD with 1-persistent method.

Slot time

The slot time is referred to as the time it takes to send 512 bits.

This means that the slot time depends on the data rate.

For traditional **10-Mbps** Ethernet, the slot time is **51,2μs**.

Data Link layer

Standard Ethernet

Slot time and collision detection

The choice of a 512-bit slot time is not random. It is selected for CSMA/CD to work properly.

In Ethernet, **roundtrip** time is the time it takes for a frame to be transmitted from one end of a network to the other and back again.

$$Slot\ time = roundtrip\ time$$

This is equivalent to two nodes (A and B) furthest apart in a network doing the following:

- Node A transmits 512 bit.
- Just before the first of the 512 bits arrives at node B, B also sends 512 bits.
- When B's first bit arrives at A, then A must not have sent its last bit.

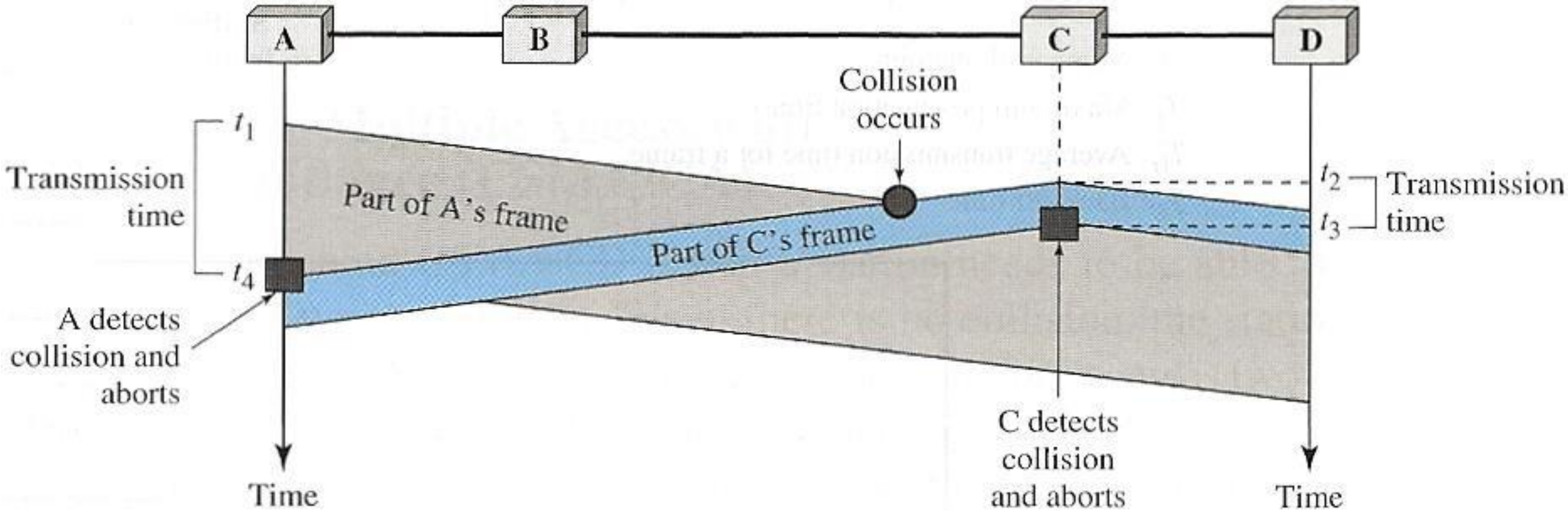
Remember A and B only do collision detection while transmitting!

Data Link layer

Standard Ethernet

Slot time and collision detection

The choice of a 512-bit slot time is not random. It is selected for CSMA/CD to work properly.



Data Link layer

Standard Ethernet

Slot time and maximum network length

There is a relationship between the slot time and the maximum length of a network (the collision domain).

It depends on the propagation rate. In most transmission media, signals move at a speed of $2x10^8$ m/s (equivalent to 2/3 of the propagation rate in air).

We can thus calculate:

$$\max length = propagation\ rate \cdot \frac{Slot\ time}{2}$$

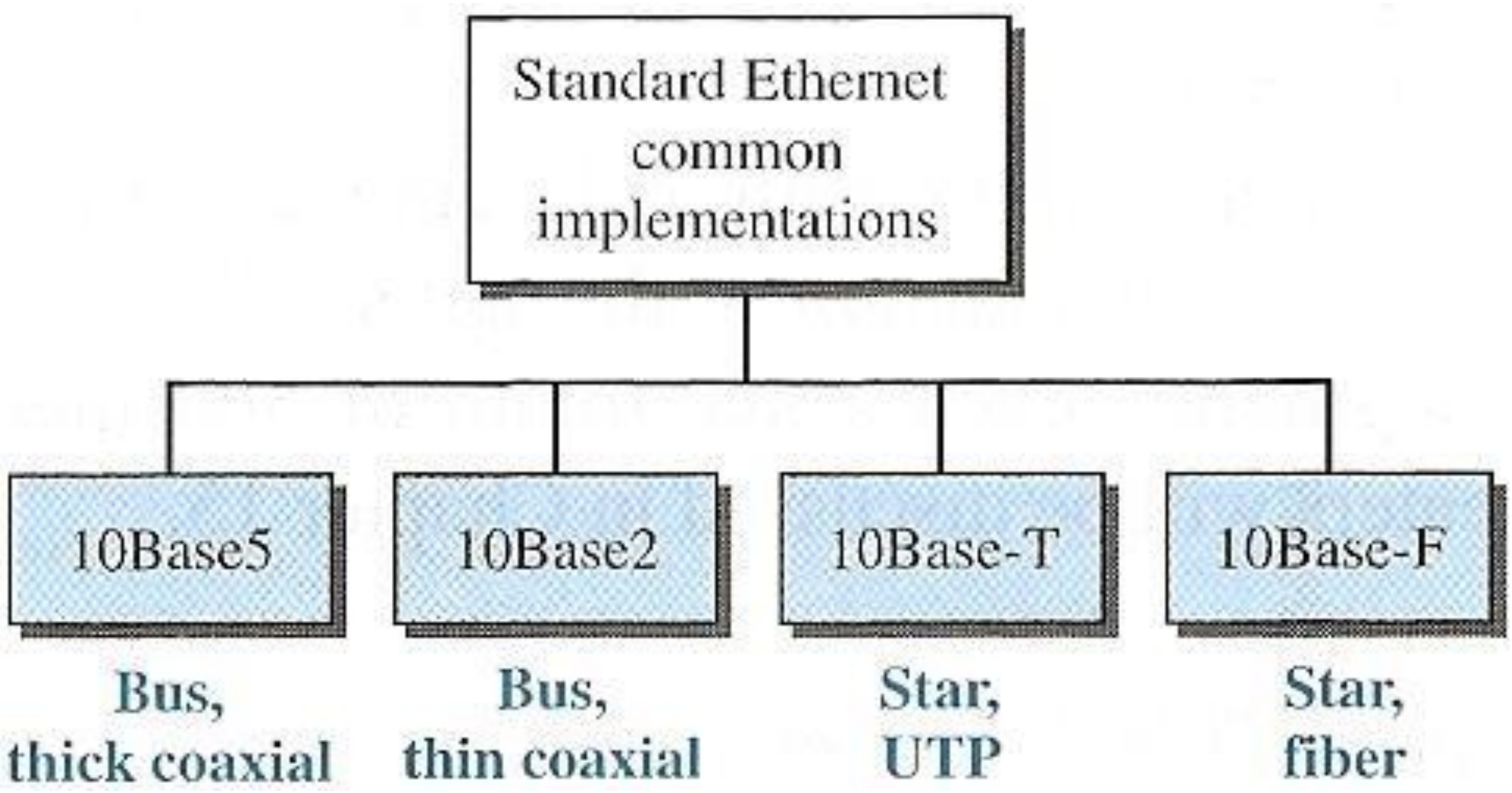
$$\max length = 2 \cdot 10^8 \cdot \frac{51.2 \cdot 10^{-6}}{2} = 5120\ m$$

However, we should also consider delays in repeaters and interfaces, as well as the time required to send jam signals. These circumstances in practice reduce the **maximum length to 2500 m** (48% of the theoretical value).

Data Link layer

Standard Ethernet: Physical layer

Standard Ethernet defines a number of physical layer implementations. But only four of them became popular during the 1980s.

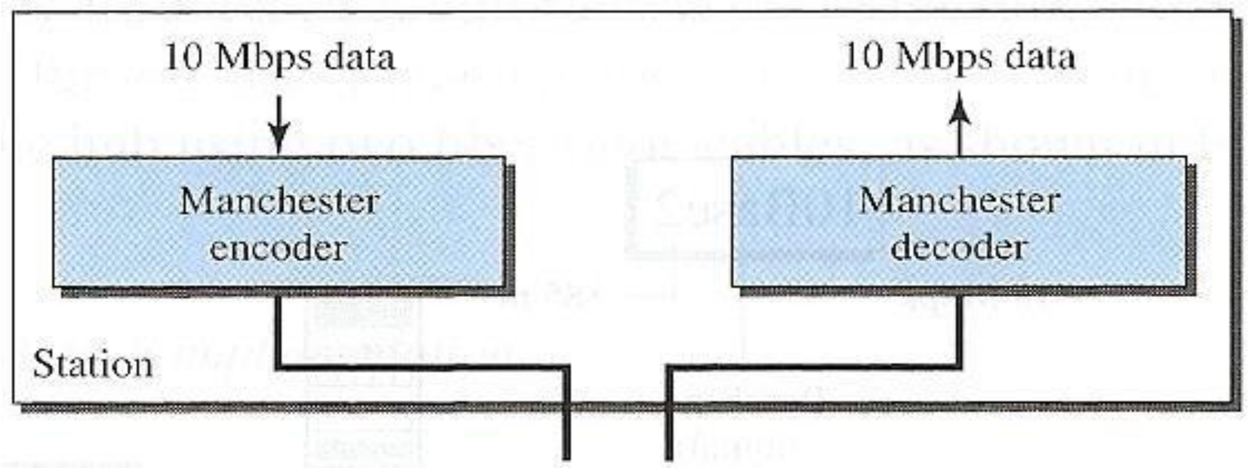


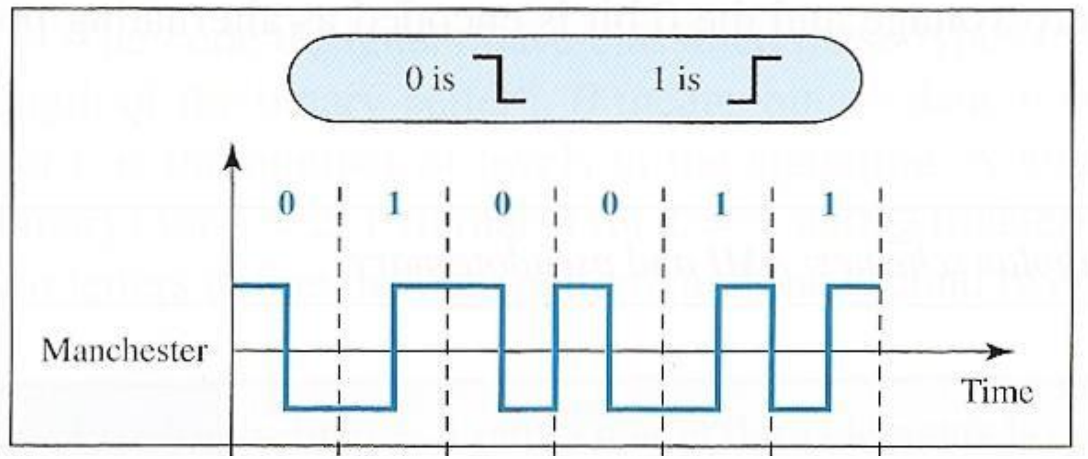
UTP = Unshielded Twisted Pair.

Data Link layer

Standard Ethernet: Physical layer

Standard Ethernet uses Manchester coding

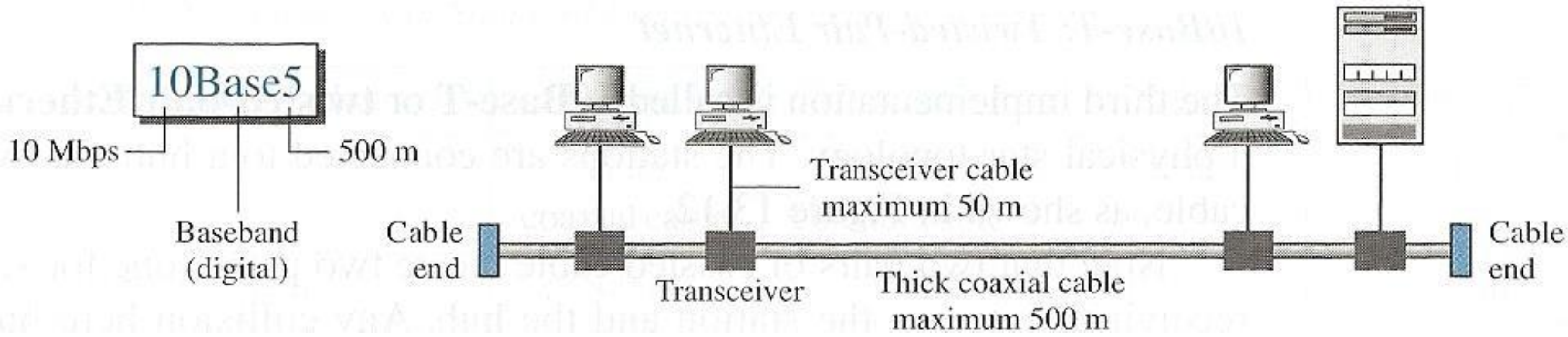




Data Link layer

10Base5: Thick Ethernet

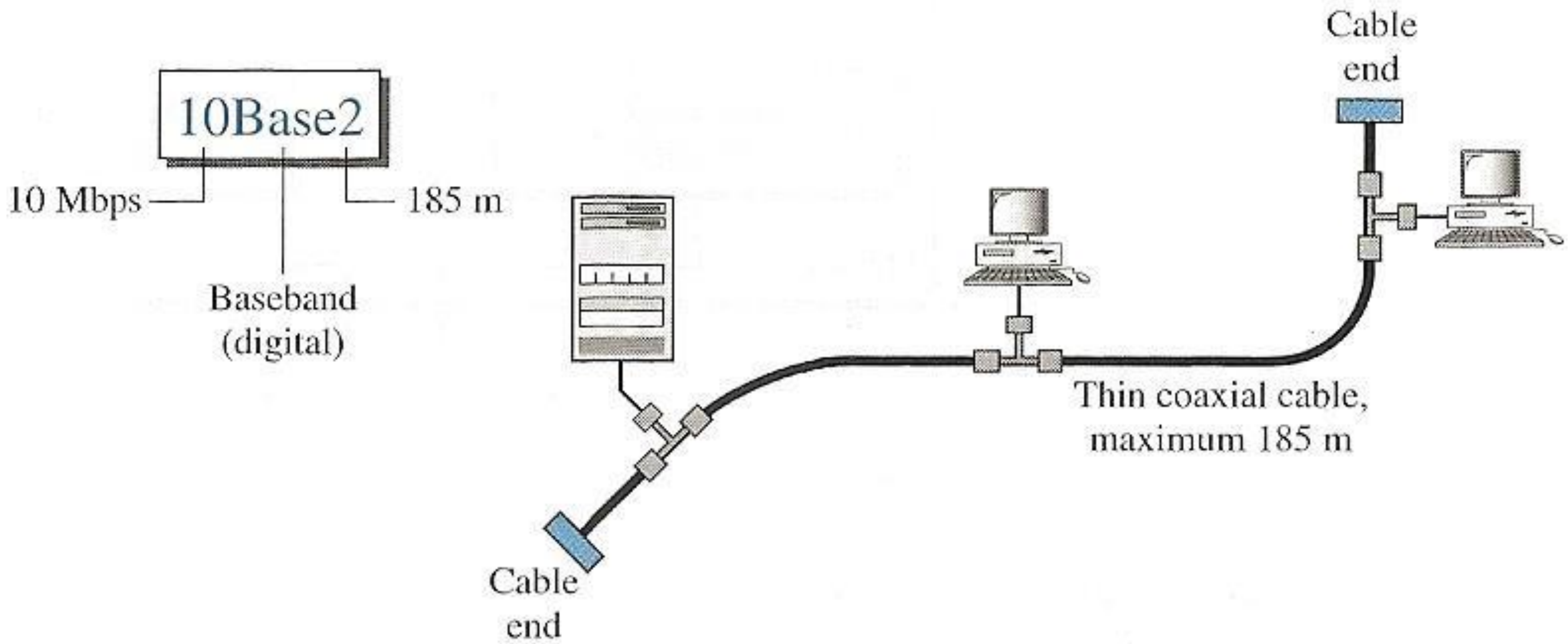
This was the first specification of Ethernet that used **bus topology** with an external transceiver (transmitter/receiver) connected via a tap to a thick coaxial cable. The cables were large and difficult to bend.



Data Link layer

10Base2: Thin Ethernet

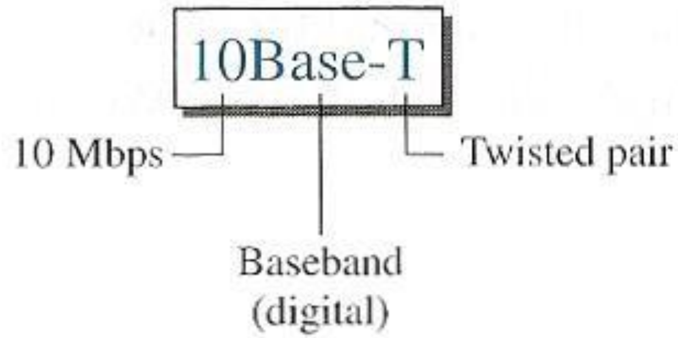
10Base2 also uses a bus topology, but with thinner cables and cheaper hardware.

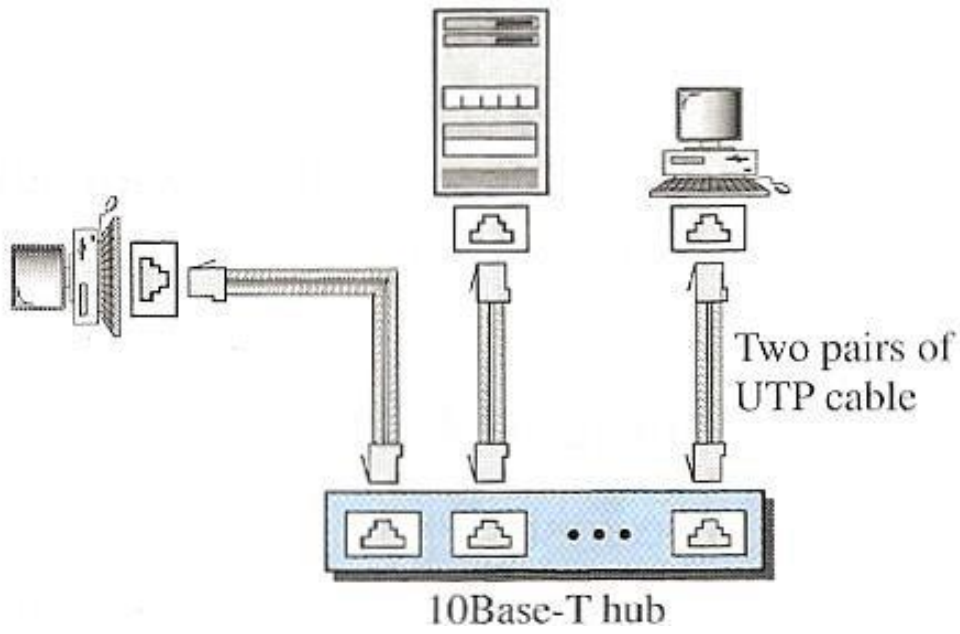


Data Link layer

10Base-T: Twisted-pair Ethernet.

10Base-T uses a star topology.
The stations are connected to a hub via two pairs of twisted cables.
(2 pairs = 1 pair for sending and 1 for receiving)



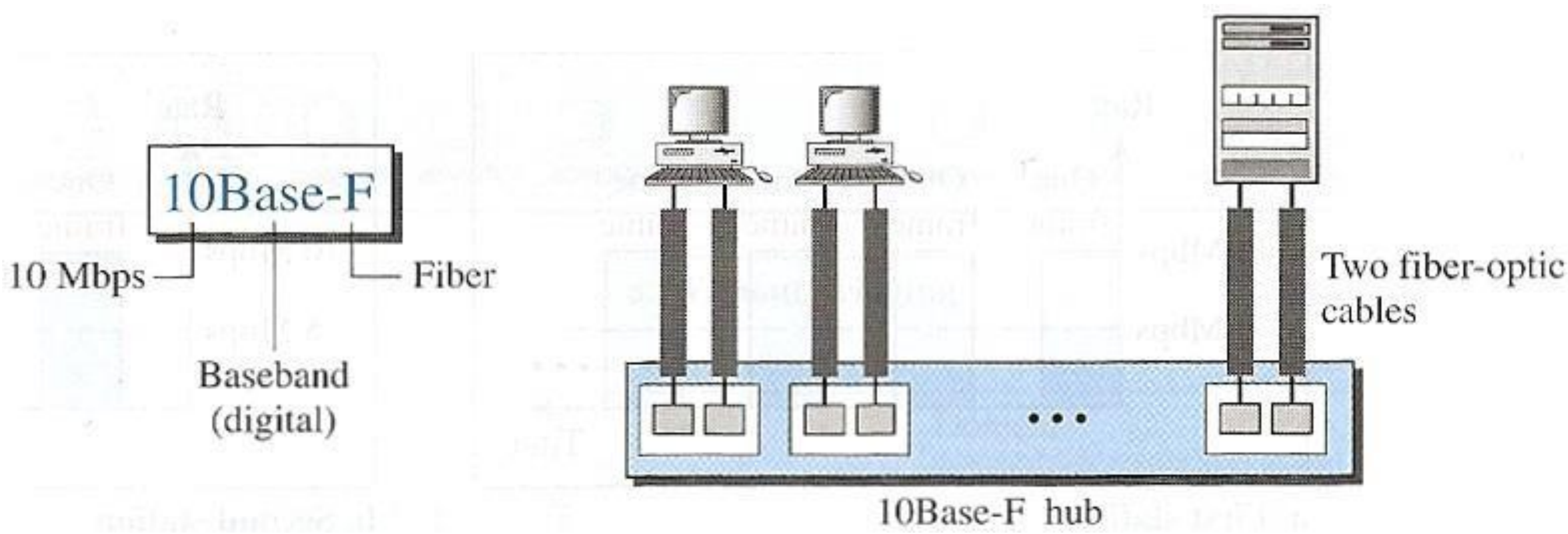


In this setup, the maximum length of the cables is set to 100 m, to minimize the effect of attenuation in the twisted cable.

Data Link layer

10Base-F: Fiber Ethernet

Star topology is also used here.
For each connection, one fiber is used for sending and the other one for receiving.



Data Link layer

Summary

Characteristics	10Base5	10Base2	10Base-T	10Base-F
Medium	Thick coaxial cable	Thin coaxial cable	2 pairs of UTP cables	2 fiber-optic cables
Max. length	500 m	185 m	100 m	2000 m
Line coding	Manchester	Manchester	Manchester	Manchester

Data Link layer

Changes in standard

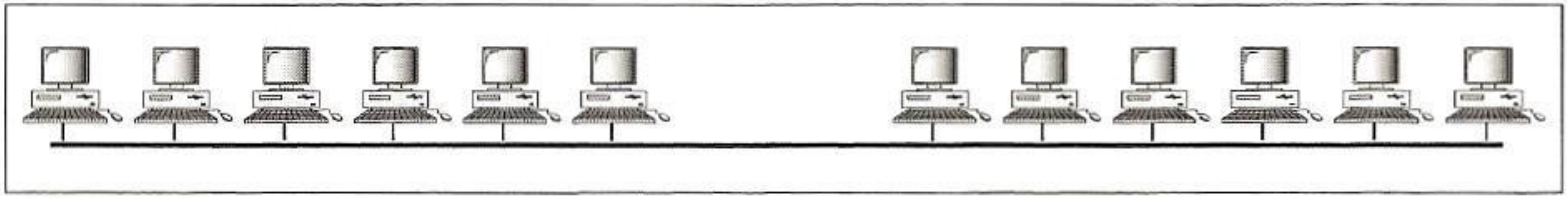
10 Mbps standard Ethernet underwent a number of changes before adapting to higher data rates.

This actually opened up opportunities to evolve Ethernet so that it became compatible with other high-speed LANs.

Data Link layer

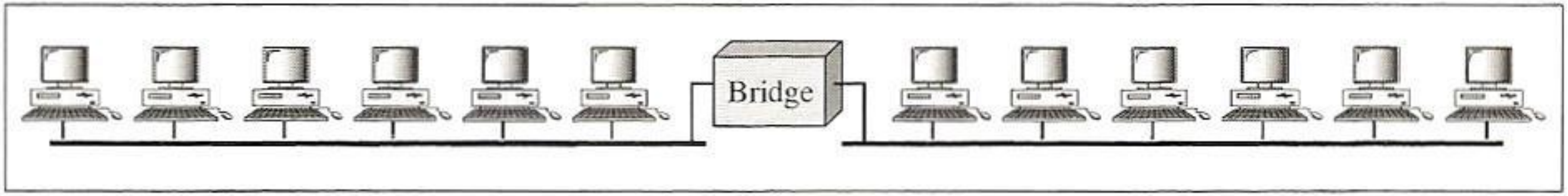
Changes in standard: Bridged Ethernet

Splitting the collision domain means greater mean bandwidth



a. Without bridging

Bandwidth is shared between 12 stations (average bandwidth 10/12 Mbps)



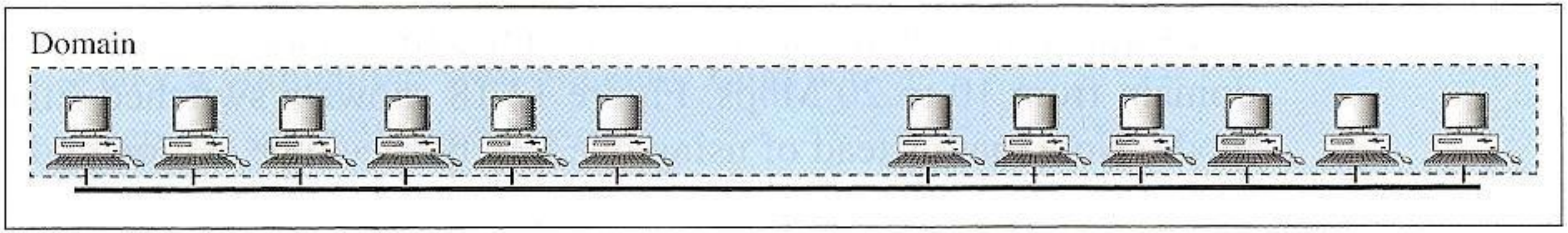
b. With bridging

Bandwidth is shared between 6 stations and the bridge (average bandwidth 10/7 Mbps)

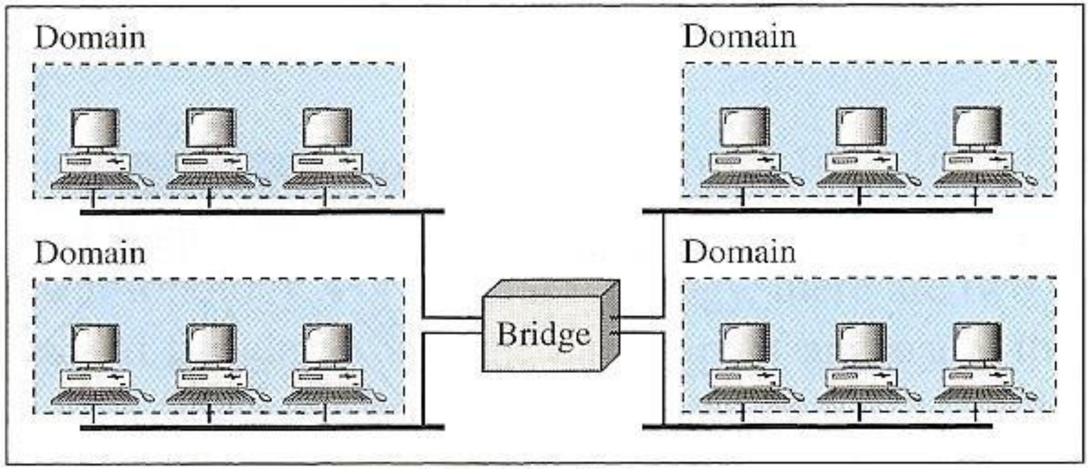
Data Link layer

Changes in standard: Bridged Ethernet

Another example



a. Without bridging



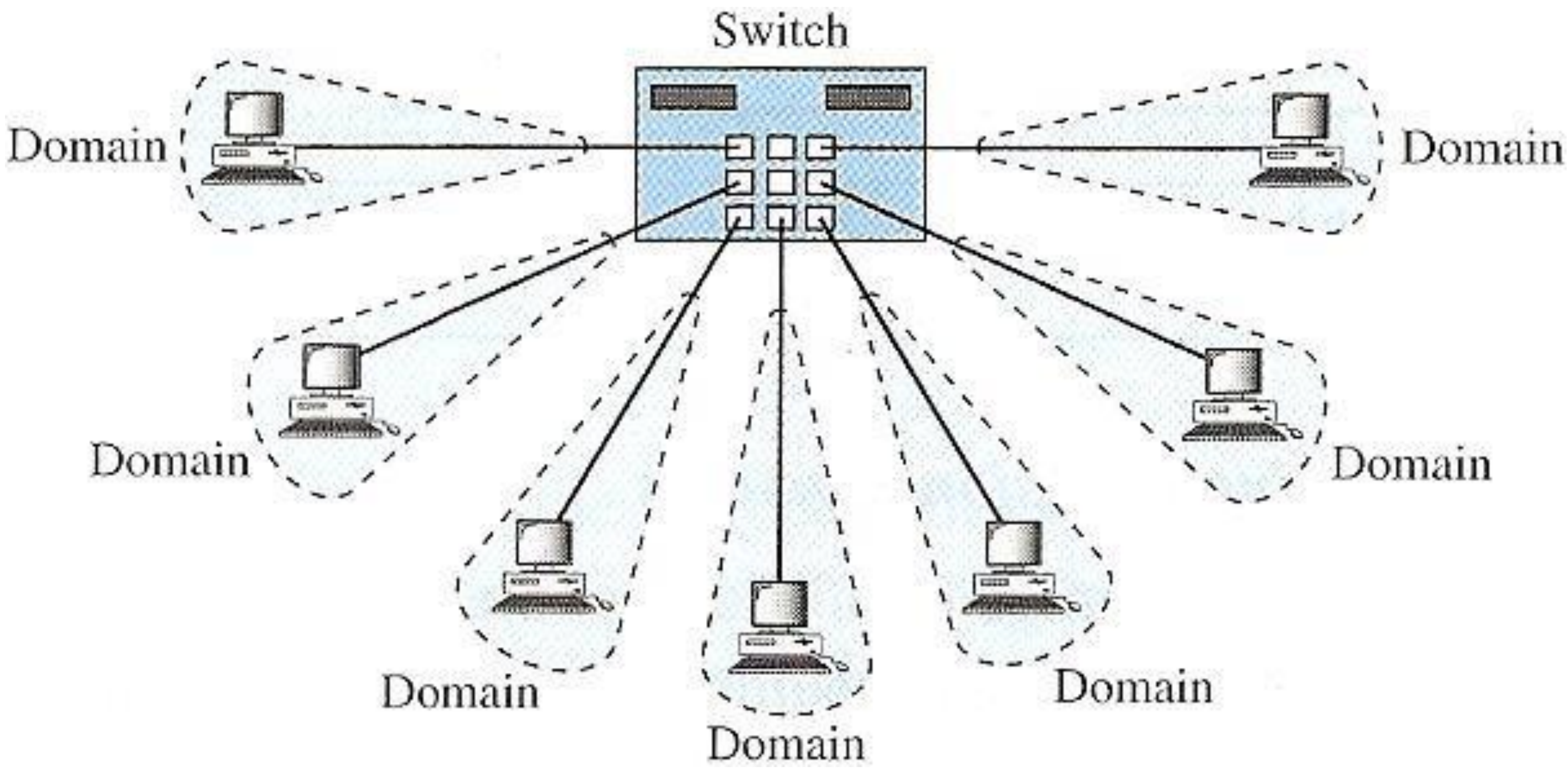
b. With bridging

Bandwidth is shared between three stations and the bridge. (average bandwidth 2.5 Mbps or 10/4 Mbps)

Data Link layer

Changes in standard: Switched Ethernet

A layer-2 switch is an N-port Bridge, which with additional sophistication, that allows faster handling of the packets.

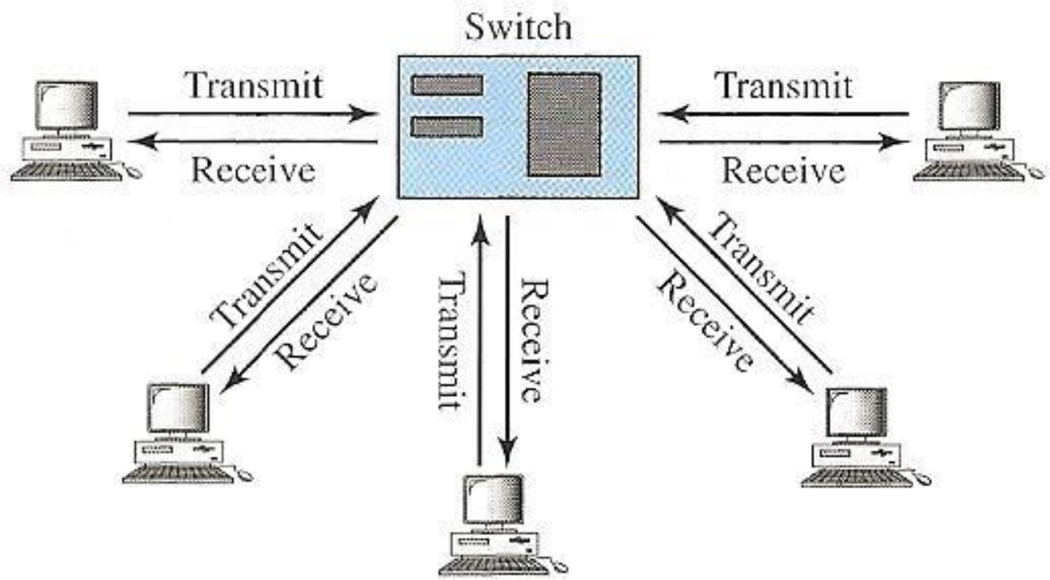


(5 Mbps for each)

Data Link layer

Changes in standard: Full-Duplex Switched Ethernet

One of the limitations of 10Base5 og 10Base2 is that communication takes place in half-duplex (10Base-T is always full-duplex).



This will increase the capacity of each domain from 10 Mbps to 20 Mbps.

This means that collision detection is no longer needed as each station is connected to the switch via two separate links. Each link can be considered a point-to-point connection, where the data stream only goes one way.

Data Link layer

Changes in standard: MAC control

Since standard Ethernet was designed as a connectionless protocol without Flow- and Error-control. Then it was necessary to add a layer in between the LLC layer and the MAC layer that could handle these controls. This layer is called **MAC Control Layer**.

Data Link layer

Fast Ethernet

Fast Ethernet was designed to compete with other high-speed LAN protocols. IEEE created Fast Ethernet as **standard 802.3u**.

Fast Ethernet is backward compatible with Standard Ethernet, but the speed is 10 times higher with a data rate of **100 Mbps**.

The following goals for Fast Ethernet can be summarized:

1. Upgrade the speed to 100 Mbps.
2. Make it compatible with Standard Ethernet.
3. Keep the same 48-bit MAC address.
4. Keep the same Frame format.
5. Maintain the same minimum and maximum lengths for frames.

Data Link layer

Fast Ethernet: Autonegotiation

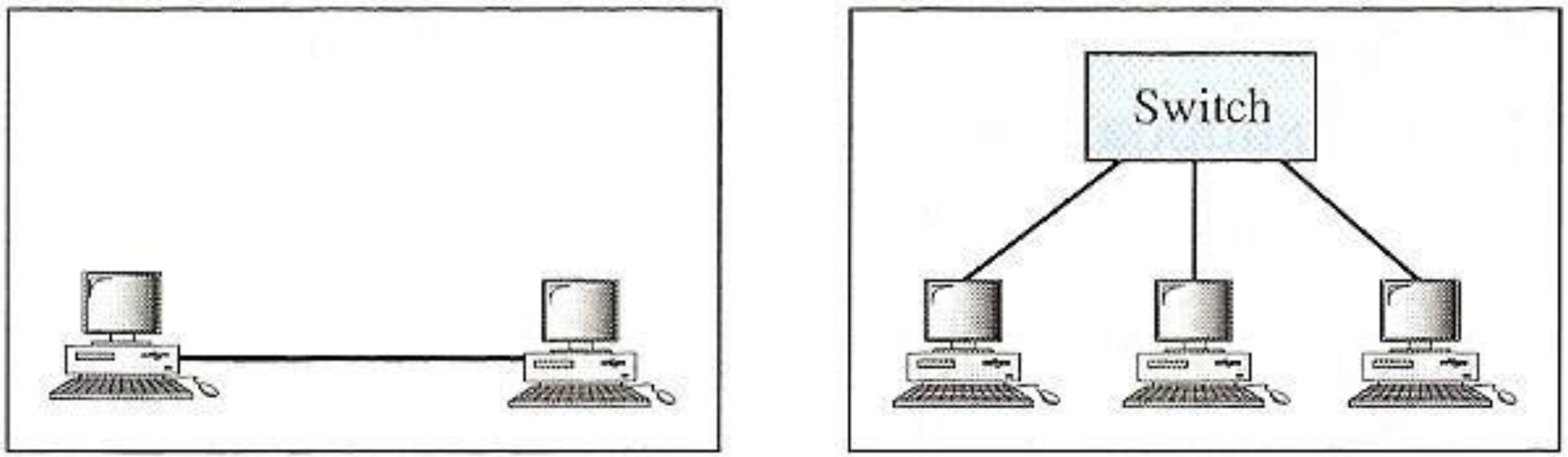
A new feature is added and called **Autonegotiation (automatic negotiation)**
The purpose is as follows:

- Allow incompatible devices to connect to each other. E.g., 10Mbps device can communicate with 100Mbps device.
- Allow one device to have multiple capabilities.
- Allow a station to check the capabilities of a hub.

Data Link layer

Fast Ethernet: Physical layer

The physical layer of Fast Ethernet is more complex than Standard Ethernet. Two stations can be connected as **Point-To-Point** and three or more stations need to be connected in **star topology** (with a hub or switch in the middle).



a. Point-to-point

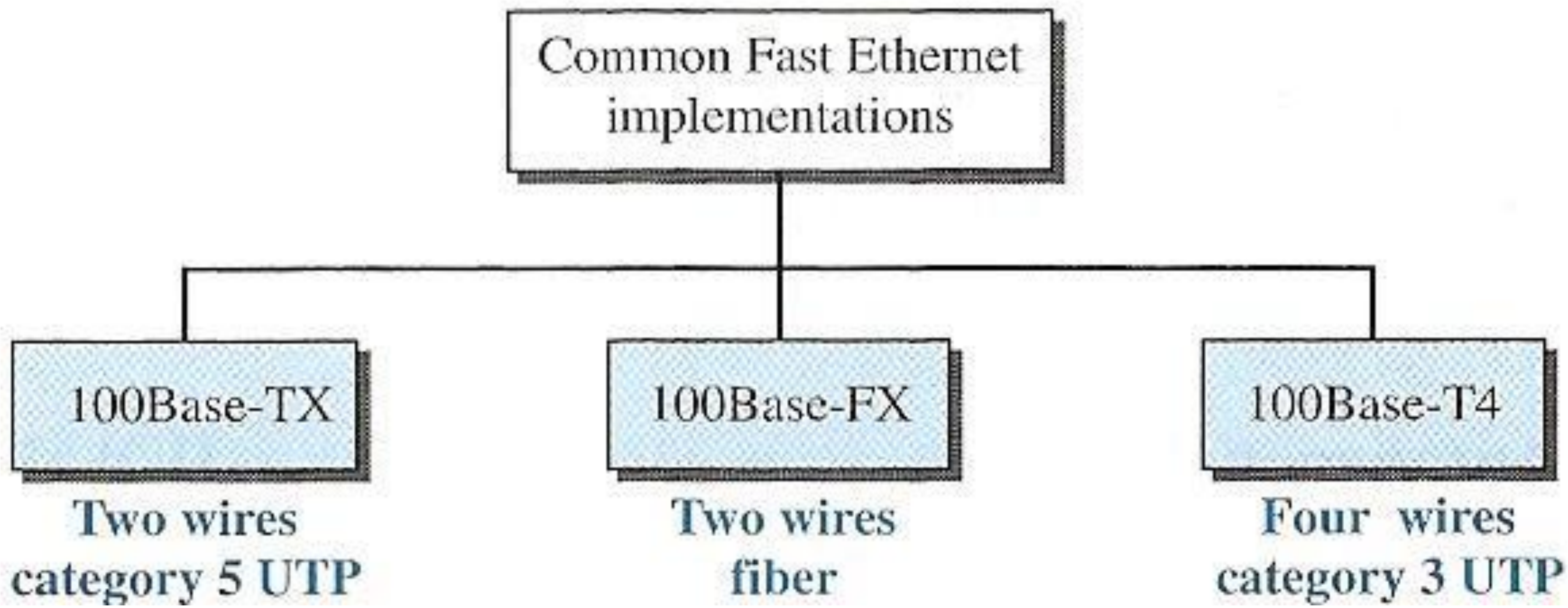
b. Star

Data Link layer

Fast Ethernet: Physical layer

Fast Ethernet implementation at the physical layer can be categorized as either two-wire or four-wire implementation.

- Two-wire: category 5 UTP (100Base-TX), fiber-optic cable (100Base-FX).
- Four-wire: category 3 UTP (100Base-T4).



(the higher the category number the better the shielding and quality, and thus the higher possible speed)

Data Link layer

Fast Ethernet: Encoding

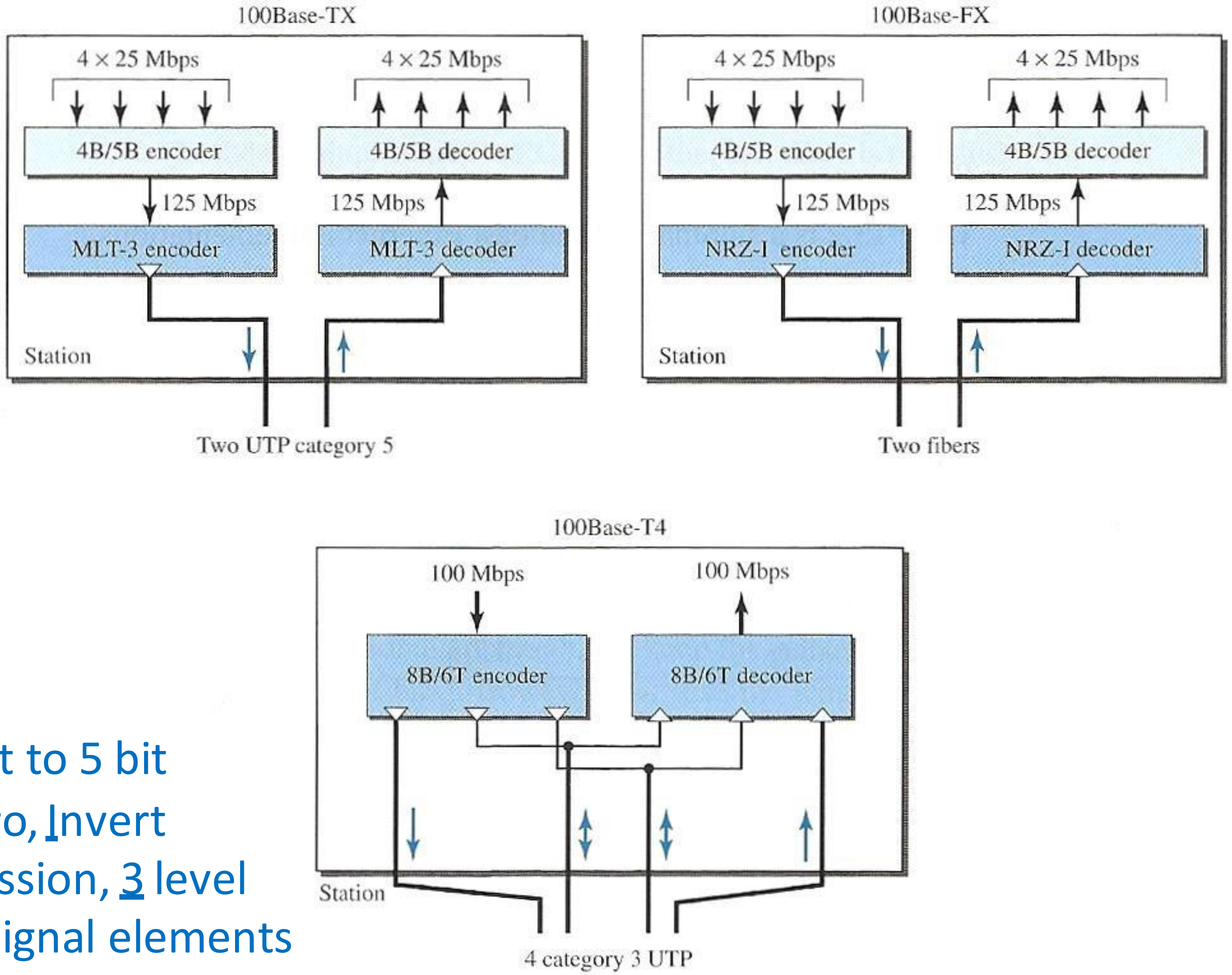
If you want to do Manchester coding for data speed of 100Mbps, then it requires a bandwidth of 200 Mbaud.

This makes Manchester coding unusable for twisted-pair cables, which do not have such high bandwidth.

Fast Ethernet designers sought some alternative encoding/decoding scheme. Three different encoding schemes were chosen for three different implementations.

Data Link layer

Fast Ethernet: Encoding 3 methods



4B/5B: Block encoder 4 bit to 5 bit

NRZ-I: Non Return to Zero, Invert

MLT-3: Multi Line Transmission, 3 level

8B6T: 8 data bits and 6 signal elements

Data Link layer

Fast Ethernet: Summary

Characteristics	100Base-TX	100Base-FX	100Base-T4
Medium	category 5 UTP or STP	fiber	category 3 UTP
Number of wires	2	2	4
Max. length	100 m	100 m	100 m
Block coding	4B/5B	4B/5B	none
Line coding	MLT-3	NRZ-I	8B6T

Data Link layer

Gigabit Ethernet

The need for even faster data speeds led to the design of the Gigabit Ethernet protocol. IEEE has given it the name **standard 802.3z**.

The following Gigabit Ethernet targets can be summarized:

1. Upgrade the speed to 1 Gbps.
2. Make it compatible with Standard and Fast Ethernet.
3. use the same 48-bit MAC address.
4. Keep the same frame format.
5. Maintain the same minimum and maximum lengths for Frames.
6. Support autonegotiation as defined in Fast Ethernet.

Data Link layer

Gigabit Ethernet: MAC sublayer

One of the main considerations in the development of Gigabit Ethernet was to keep the MAC sublayer untouched.

But this was no longer possible if one wanted to achieve 1Gbps.

Gigabit Ethernet has two distinctive approaches for medium access:

- Half-duplex.
- Full-duplex.

Data Link layer

Gigabit Ethernet: MAC sublayer – Full-Duplex mode

- In Full-duplex, there is a central switch, which is connected to all stations or switches.
- Here, each switch has a buffer in all input ports, which holds data until it is sent.
- Since the switch divides the collision domain into N domains, there are no collisions, therefore CDMA/CD is not used.
- This means that the length of the cables is determined by the attenuation of the cables, and not by the collision detection algorithm (CD).

Data Link layer

Gigabit Ethernet: MAC sublayer – Half-Duplex mode (rarely used only)

3 methods are defined:

- Traditional
- Carrier Extention
- Frame Bursting.

Traditional: here the same minimum length is used on the frame as in traditional Ethernet (512bit). But since the length of a bit is 1/100 shorter in Gigabit Ethernet than in traditional Ethernet (10Mbps), the slot time is reduced to 0.512μs, which means that collision is detected 100 times earlier, which in turn means that the cable length can only be 25 m.

Data Link layer

Gigabit Ethernet: MAC sublayer – Half-Duplex mode (only rarely used)

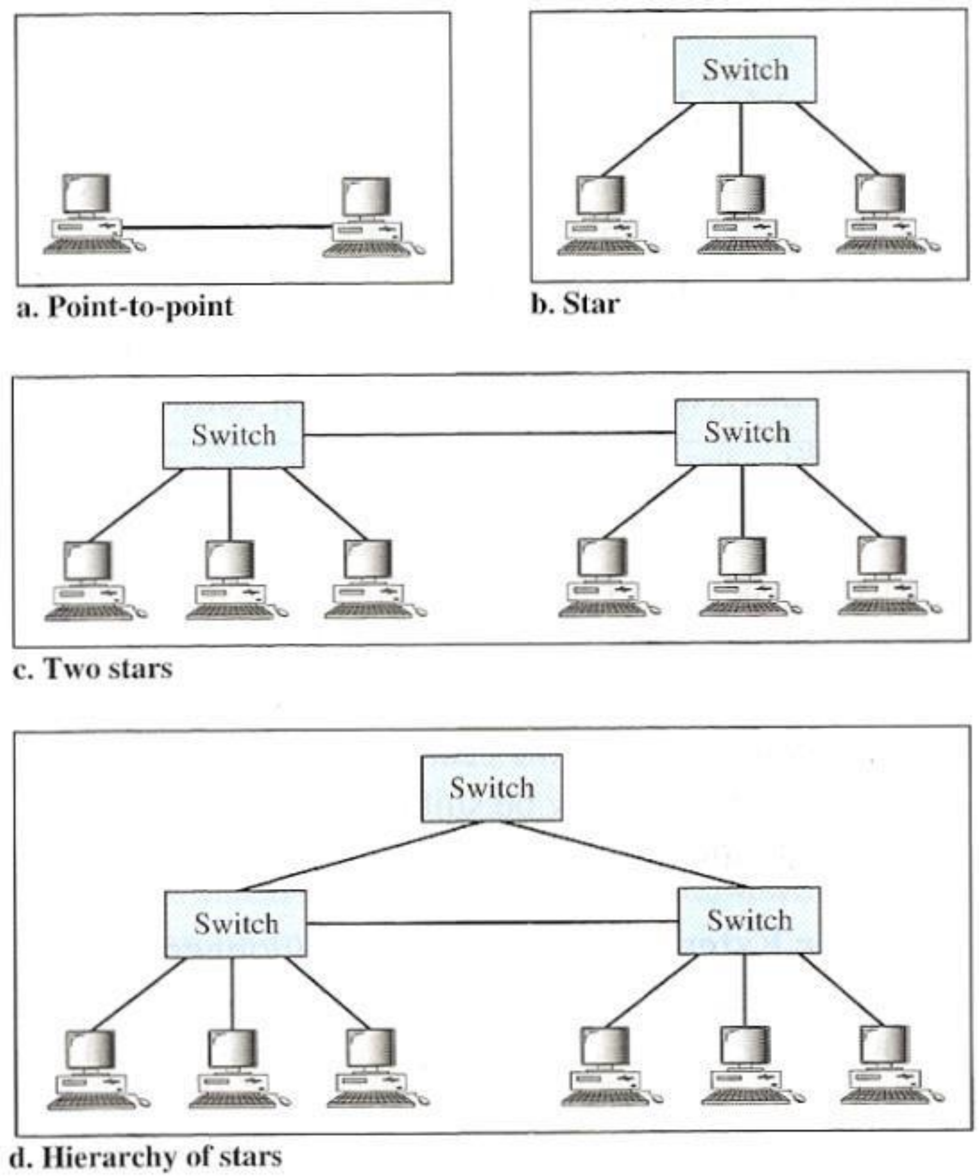
Carrier Extention: to allow a longer (larger) network, we increase the minimum length of a frame. Here, the minimum frame length is defined as 512 bytes = 4096 bit. This means that the minimum length is increased 8 times. This also increases the cable length 8 times to 200 m (100 m from station to hub).
<u>If less than 4096 bit is to be transmitted, bit padding is used</u>.

Frame Bursting: Carrier Extension is very inefficient if only short messages (bit padding and redundant bits) are sent.
Instead of adding extension to each frame, more frames are sent.
But to make these multiple frames look like a frame, <u>bit-padding is added in between the frames</u>.
This makes the many frames look like one, and since the medium is not idle between the frames, other stations are deceived into thinking that only a very large frame has been transmitted.

Data Link layer

Gigabit Ethernet: Physical layer

Two stations can be connected in **Point-To-Point**.
Three or more stations are connected in **star**, with a switch or hub in the center.

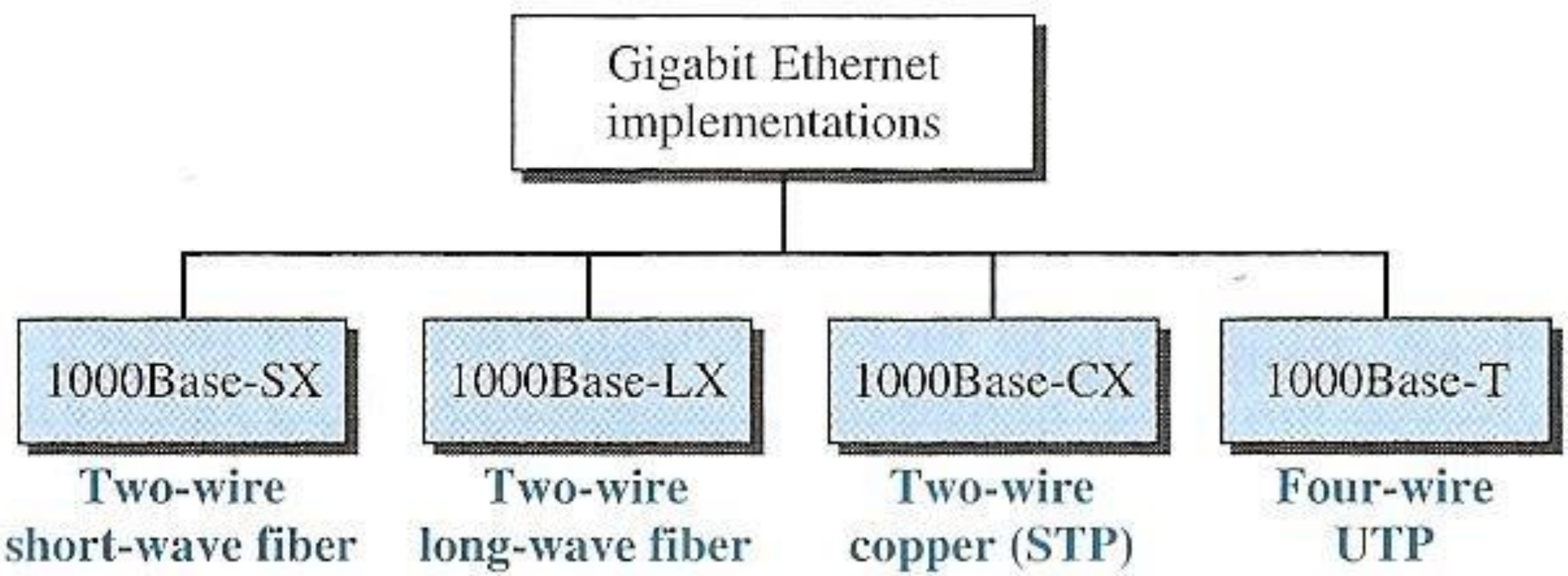


Data Link layer

Gigabit Ethernet: Physical layer

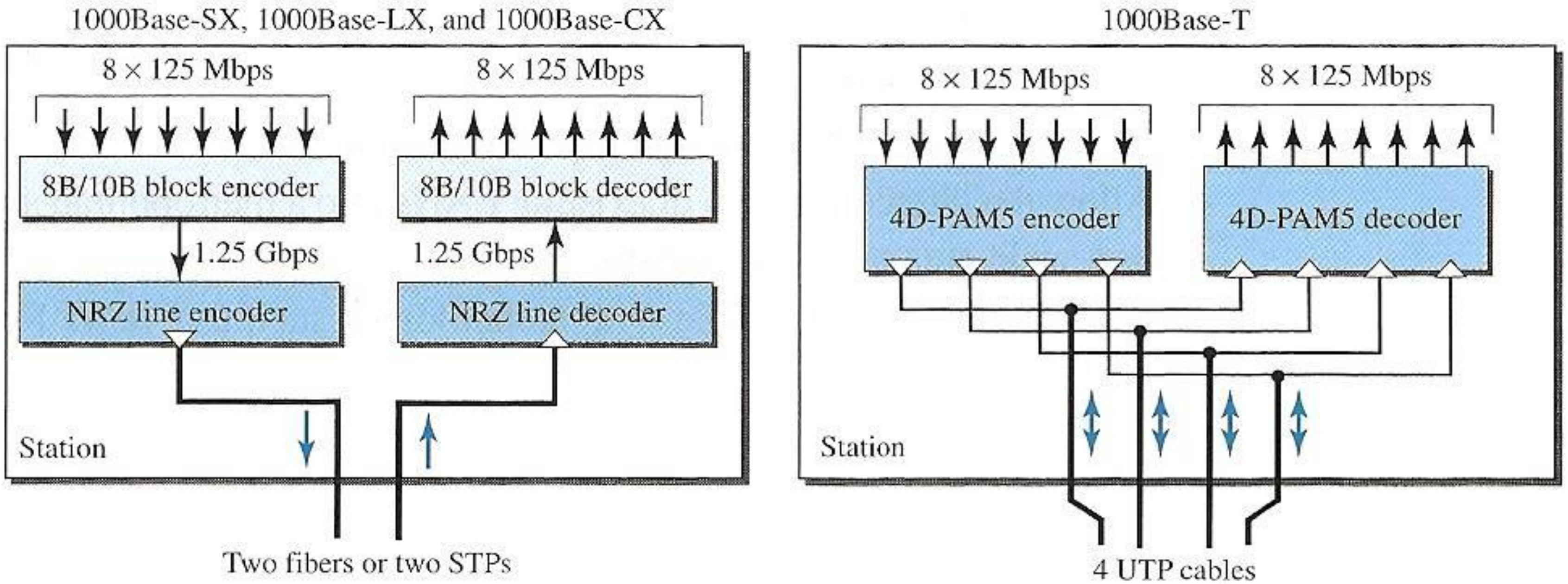
Gigabit Ethernet can be categorized as either two-wire or four-wire implementation.

- Two-wire: Fiber-optic cable: 1000Base-SX (short-wave), 1000Base-LX (long-wave), copper cable: 1000Base-CX (STP).
- Four-wire: 1000Base-T (Category 5 UTP)



Data Link layer

Gigabit Ethernet: Encoding



NRZ: Non Return to Zero
8B/10B: Block coding 8bit to 10 bit
4D-PAM5: Four-Dimentional Five-level Pulse Amplitude Modulation

Data Link layer

Gigabit Ethernet: Summary

Characteristics	1000Base-SX	1000Base-LX	1000Base-CX	1000Base-T
Medium	Fiber (short wave)	Fiber (long wave)	STP	Category 5 UTP
Number of wires	2	2	2	4
Max. length	550 m	5000 m	25 m	100 m
Block coding	8B/10B	8B/10B	8B/10B	none
Line coding	NRZ	NRZ	NRZ	4D-PAM5