

Introduction to Computer Networks



IEEE 802.3 Ethernet

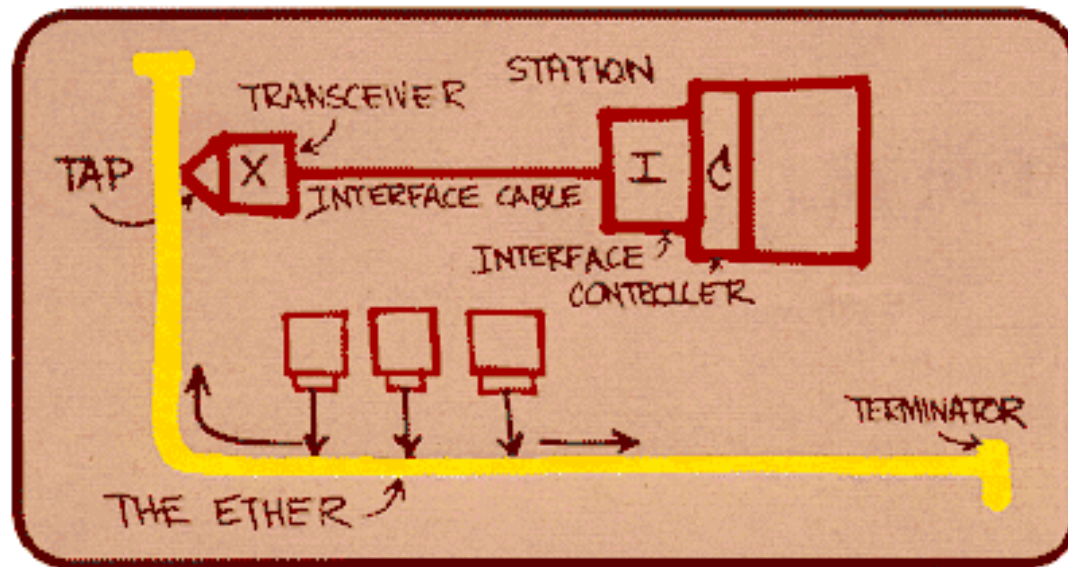
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Outline

- **Introduction**
- **Ethernet Topologies**
- **Ethernet Frame Format**
- **Ethernet MAC Protocol -- CSMA/CD**
- **802.3 Ethernet Standards**

Ethernet

- Most successful local area networking technology of last 30 years.
- First widely used LAN technology
- kept up with speed race: 10 Mbps – 100 Gbps



Metcalfe's Ethernet sketch

Ethernet

- Developed in the mid-1970s by researchers at the Xerox Palo Alto Research Centers (PARC).
- DEC and Intel joined Xerox to define a **10-Mbps Ethernet** standard in 1978.
- This standard formed the basis for **IEEE standard 802.3**
- More recently 802.3 has been extended to include
 - 100-Mbps version called **Fast Ethernet**,
 - 1000-Mbps version called **Gigabit Ethernet**,
 - **10 Gigabit Ethernet**, and also
 - 100 Gigabit Ethernet

Ethernet: Unreliable, Connectionless

- **Connectionless:** No handshaking between sending and receiving NICs
- **Unreliable:** receiving NIC doesn't send ACKs or NACKs to sending NIC
- Ethernet's MAC protocol: **Carrier Sense Multiple Access with Collision Detection (CSMA/CD)**

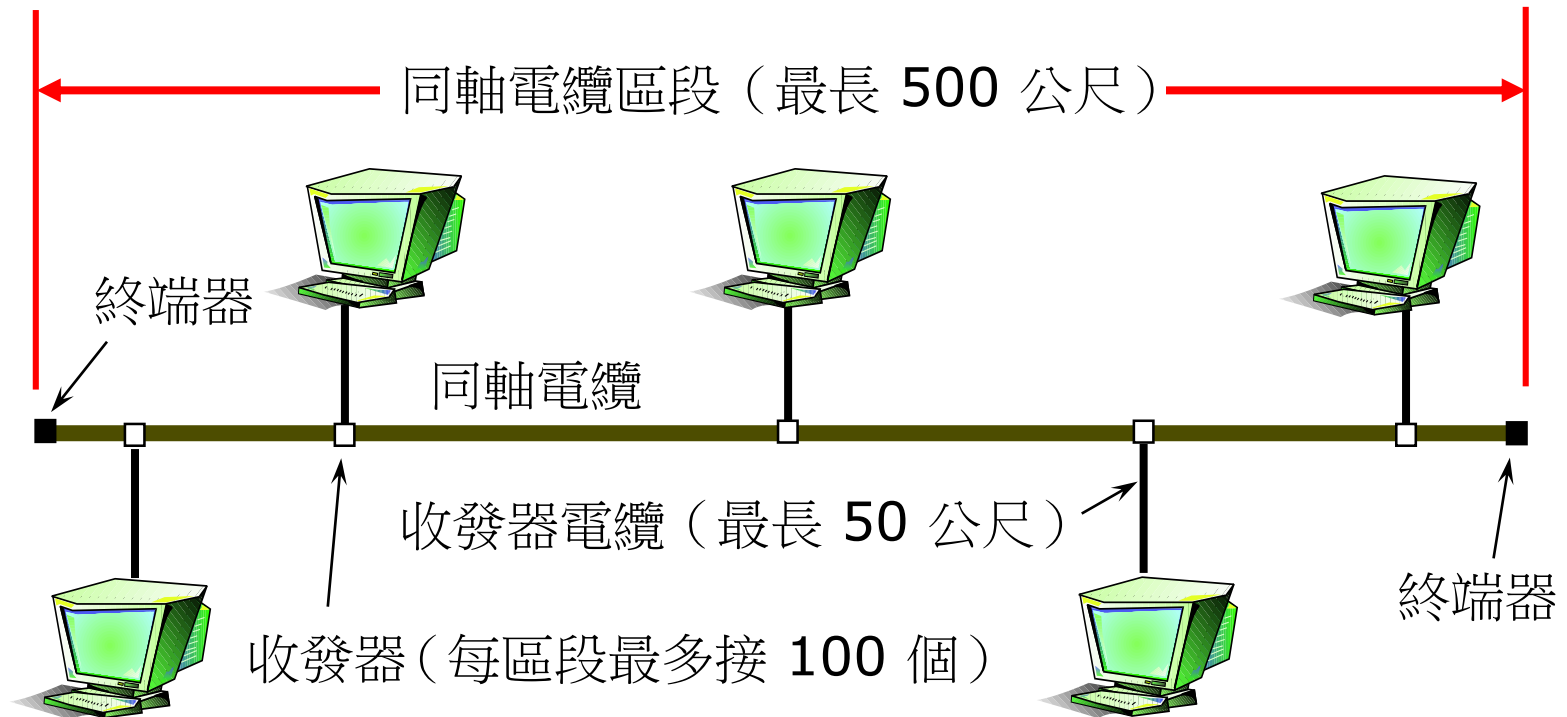
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Bus Topology

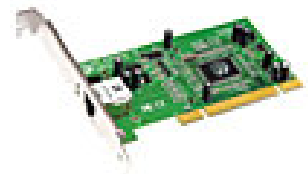
■ Bus topology popular through mid 90s

- all nodes in same collision domain (can collide with each other)

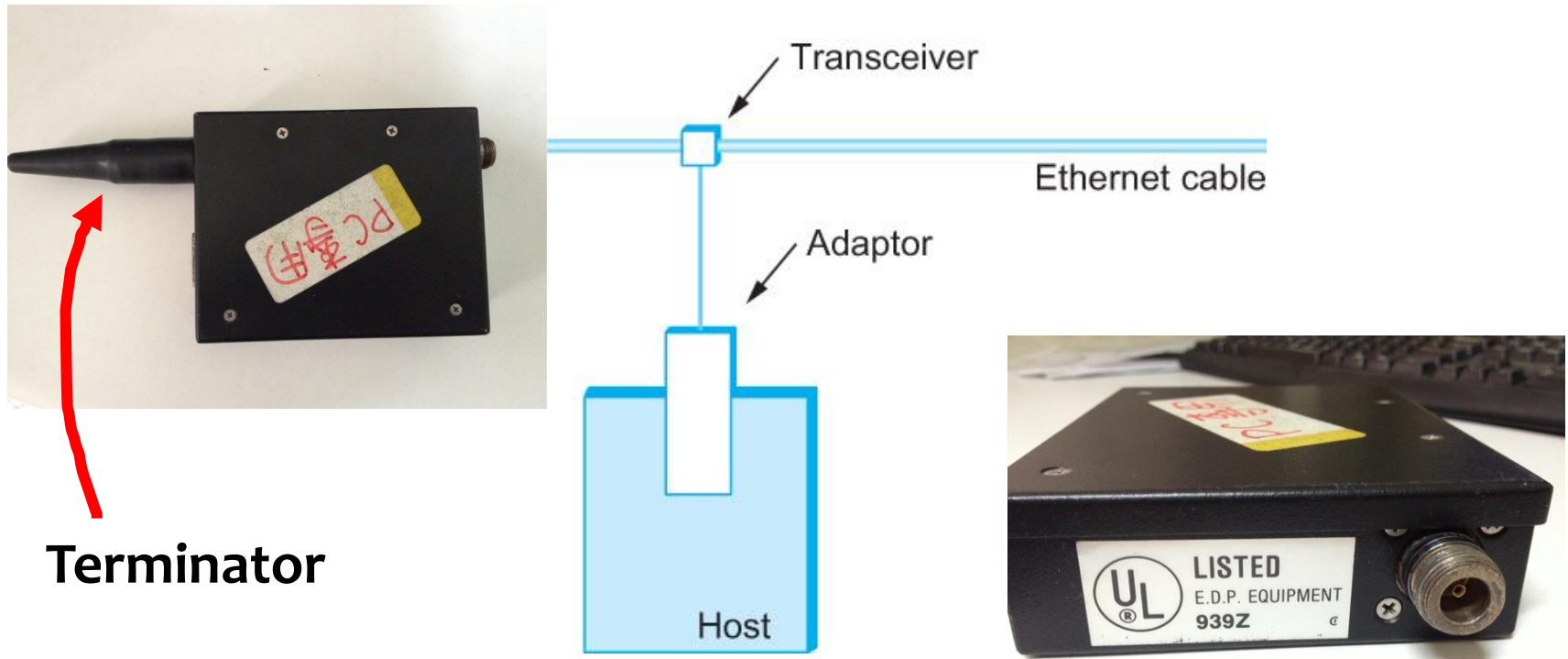


Ethernet (10Base5)

- An Ethernet segment is implemented on a coaxial cable of up to **500 m**.
- Hosts connect to an Ethernet segment by tapping into it.
- A **transceiver** (a small device directly attached to the tap) detects when the line is idle and drives signal when the host is transmitting.
- The transceiver also receives incoming signal.
- The transceiver is connected to an **Ethernet adaptor** which is plugged into the host. But now most are built in into the computers.
- The protocol is implemented on the adaptor.



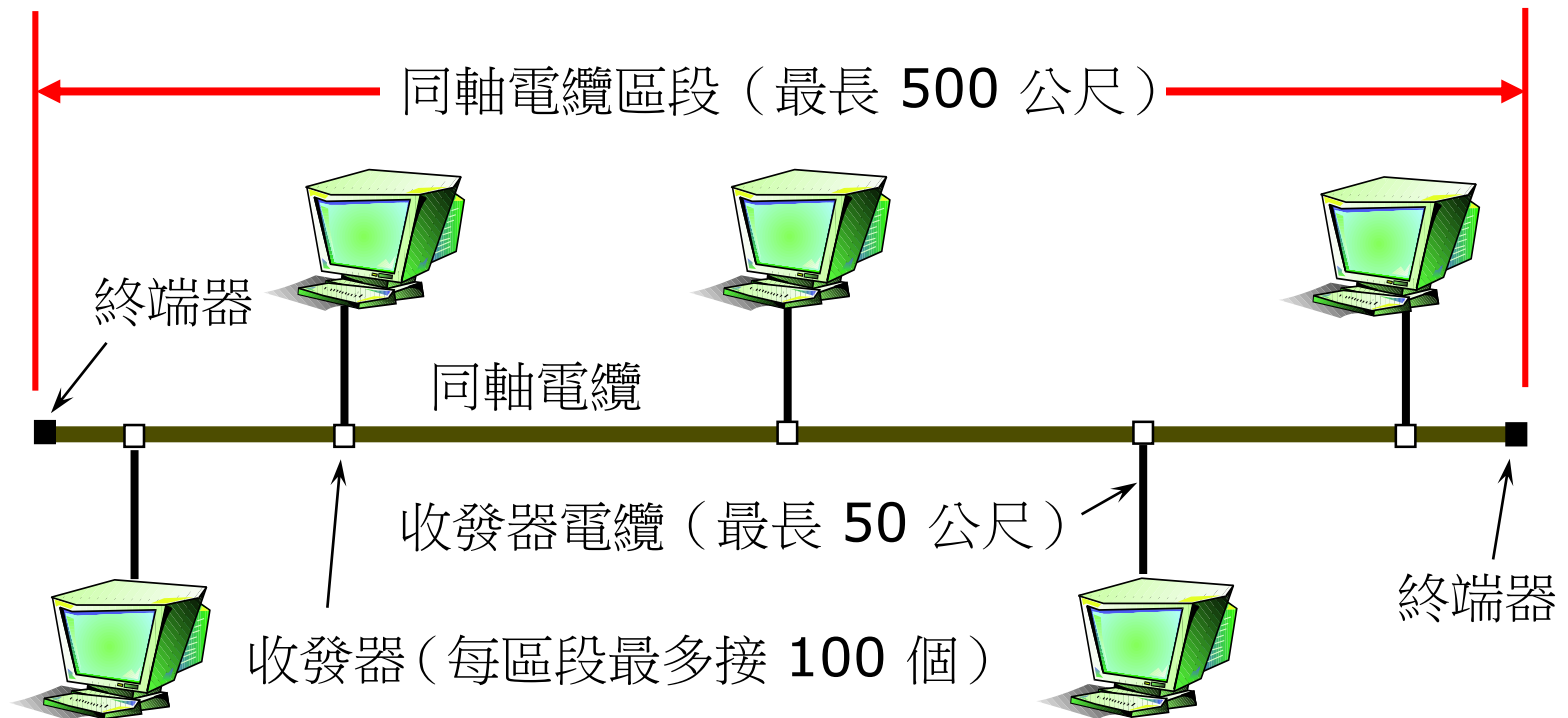
Ethernet (10Base5)



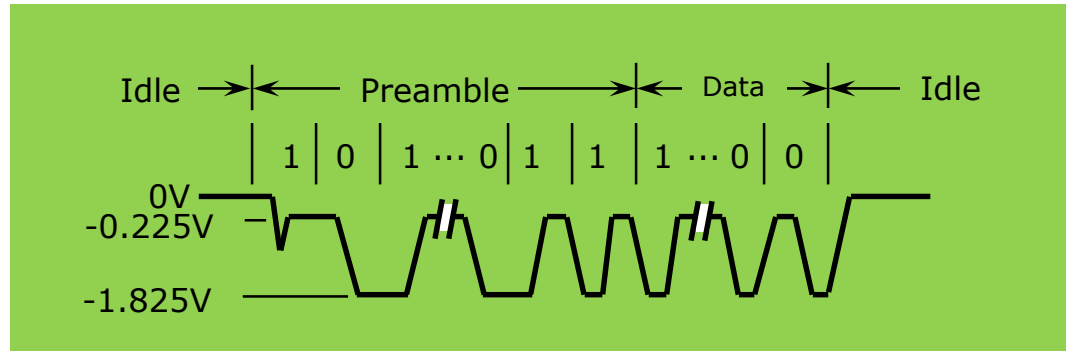
Ethernet transceiver, adaptor, and terminator

Network Configuration Example 1

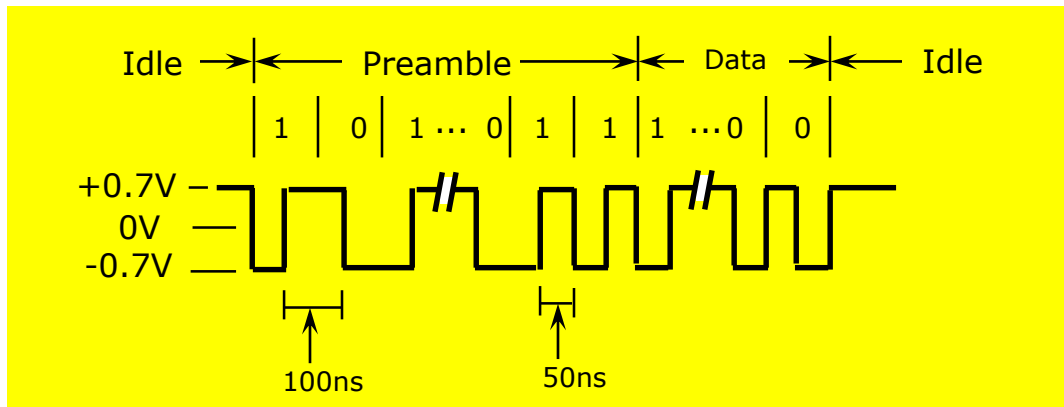
(Single segment)



Cable Signaling (Manchester Encoding)



Coaxial Cable



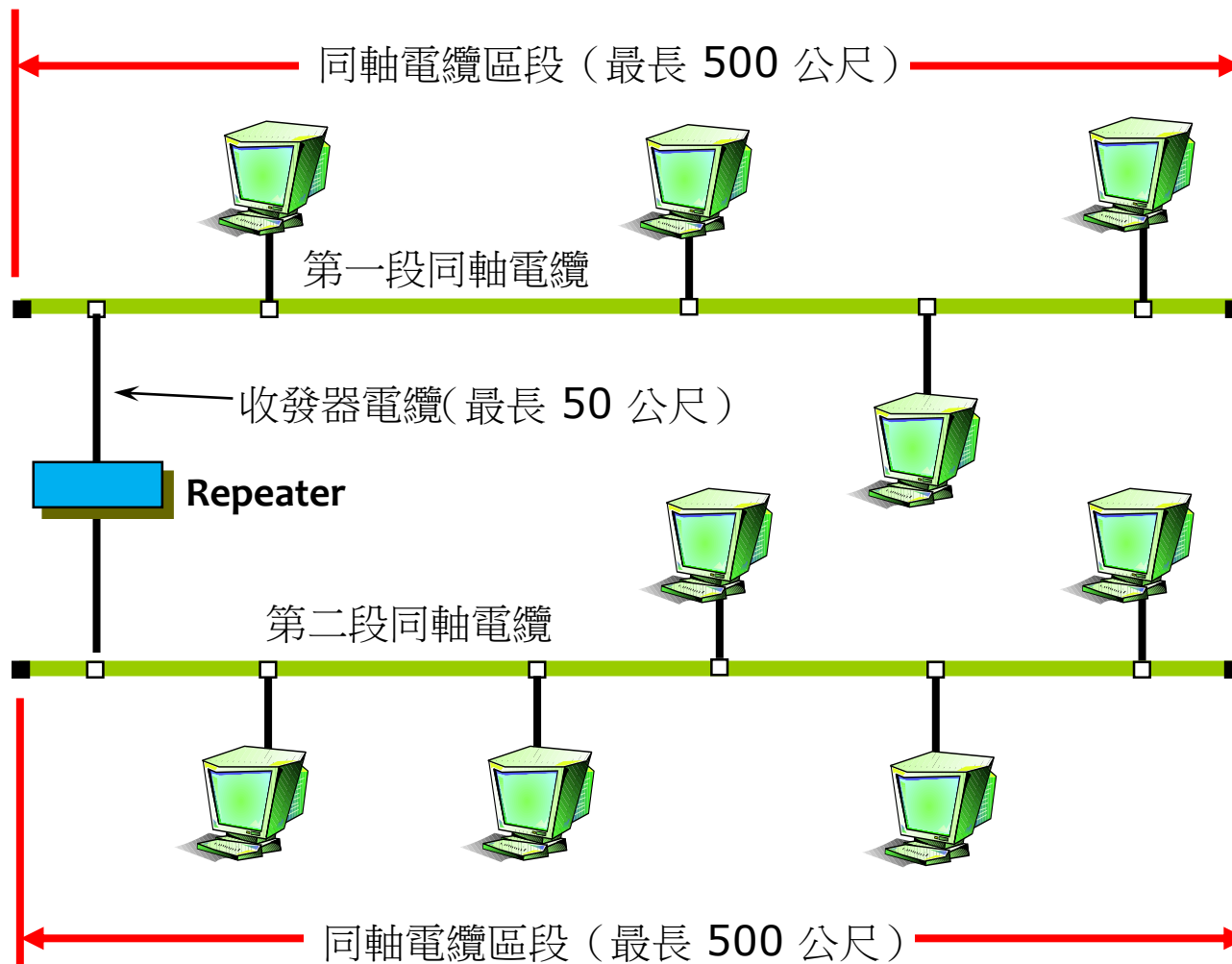
Transceiver Cable

- Each bit has a transition
- Allows clocks in sending and receiving nodes to synchronize to each other

Ethernet (10Base5)

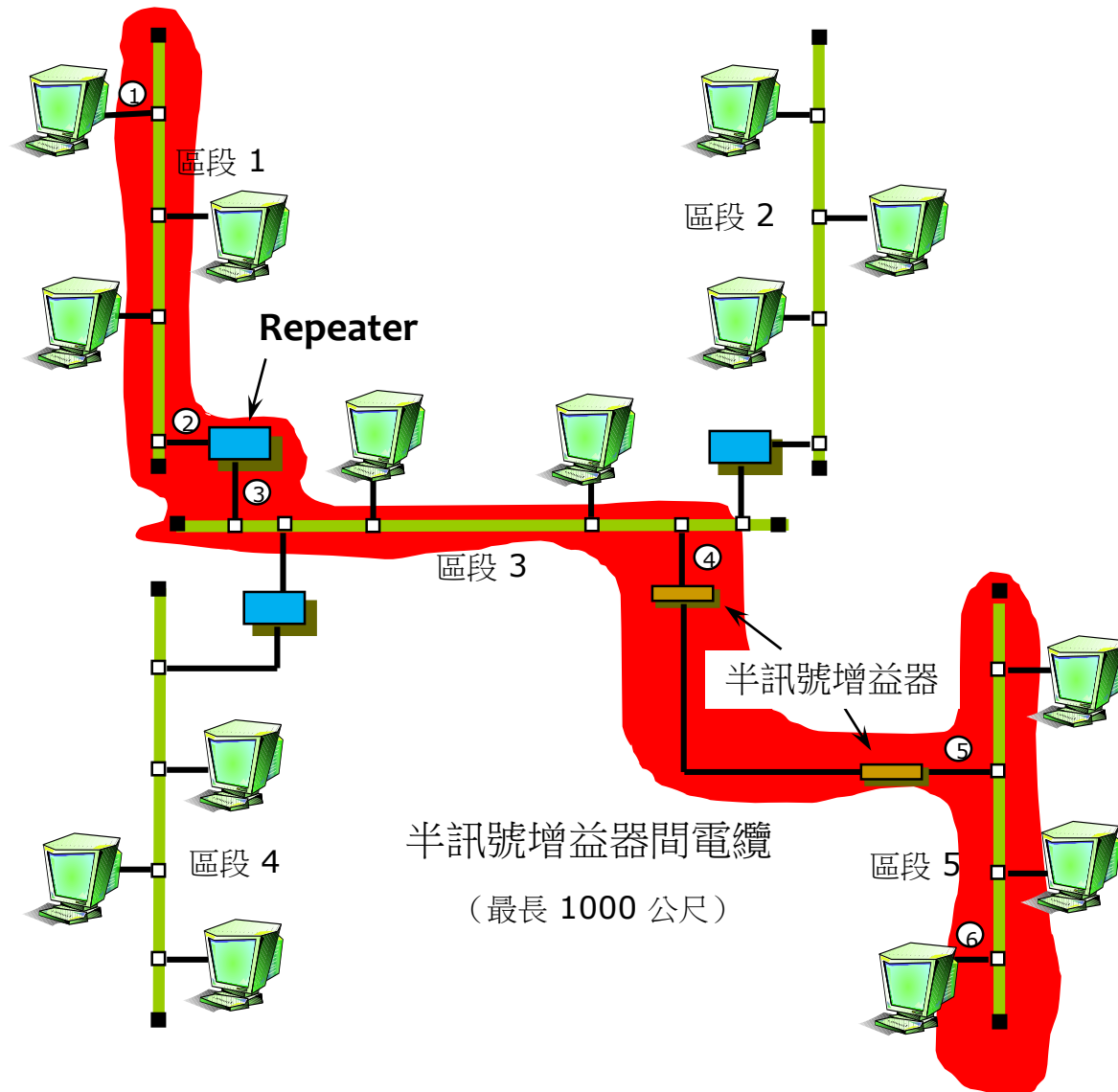
- Multiple Ethernet segments can be joined together by *repeaters*.
- A *repeater* is a device that forwards **digital signals**.
- No more than **four repeaters** may be positioned between any pair of hosts.
 - An Ethernet has a total reach of only 2500 m.

Network Configuration Example 2 (Two segments)



Network Configuration Example 3

(Five segments, maximum)



Ethernet (10Base2)

■ New Technologies in Ethernet

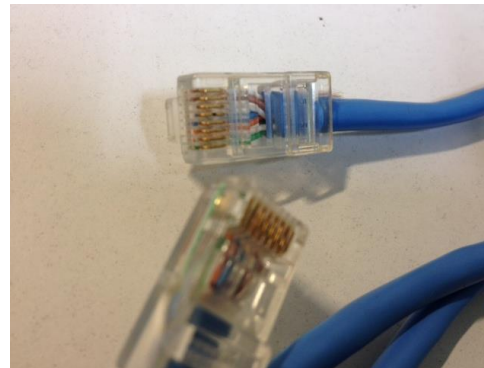
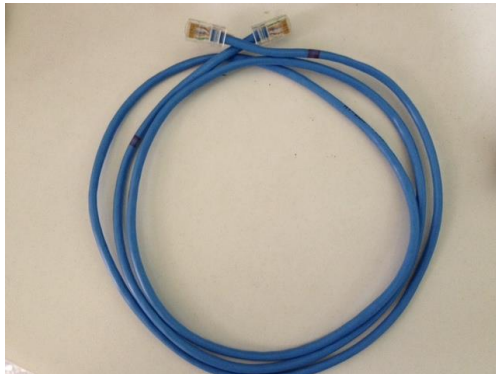
- Instead of using coax cable, an Ethernet can be constructed from **a thinner cable** known as **10Base2** (the original was 10Base5)
 - ▶ **10** means the network operates at 10 Mbps
 - ▶ **Base** means the cable is used in a baseband system
 - ▶ **2** means that a given segment can be no longer than 200 m



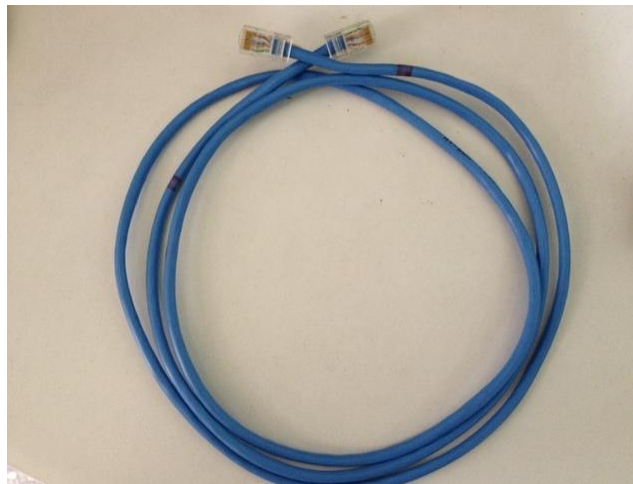
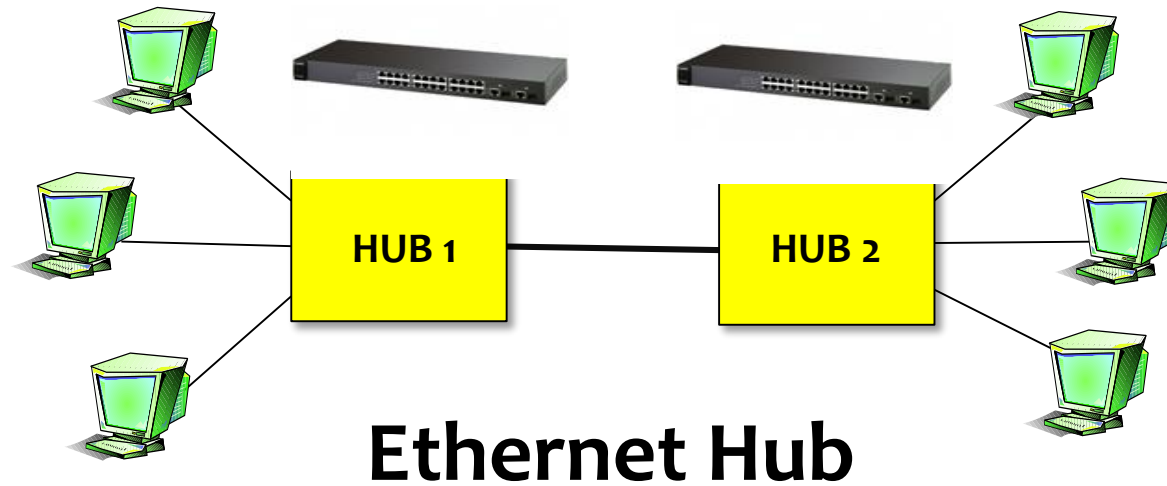
Ethernet (10BaseT)

■ New Technologies in Ethernet

- Another cable technology is 10BaseT
 - ▶ **T** stands for twisted pair
 - ▶ Limited to 100 m in length
- With 10BaseT, the common configuration is to have several **point to point segments** coming out of a multiway repeater, called **Hub**



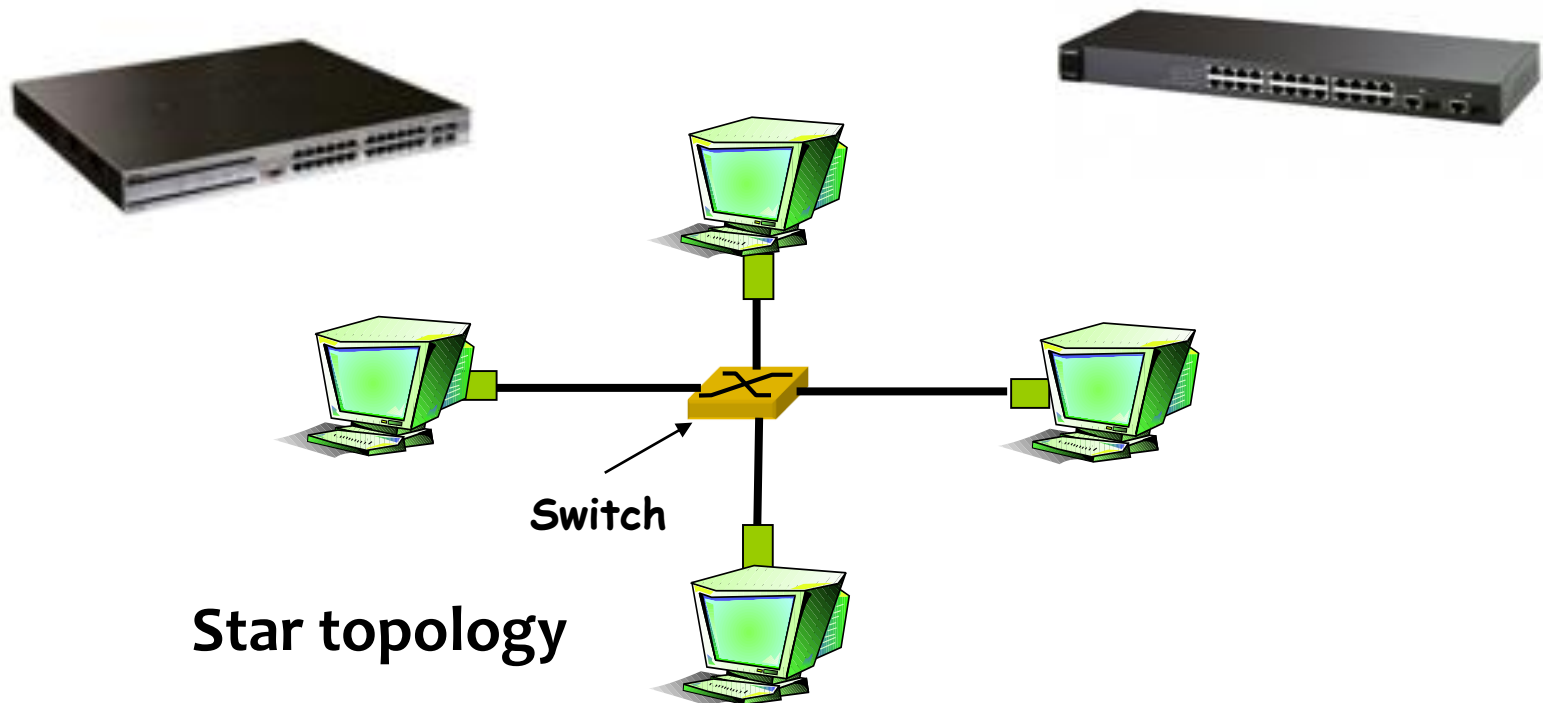
Ethernet



Star Topology

■ Today: **Star topology** prevails

- active **switch** in center
- each “spoke” runs a (separate) Ethernet protocol (nodes do not collide with each other)

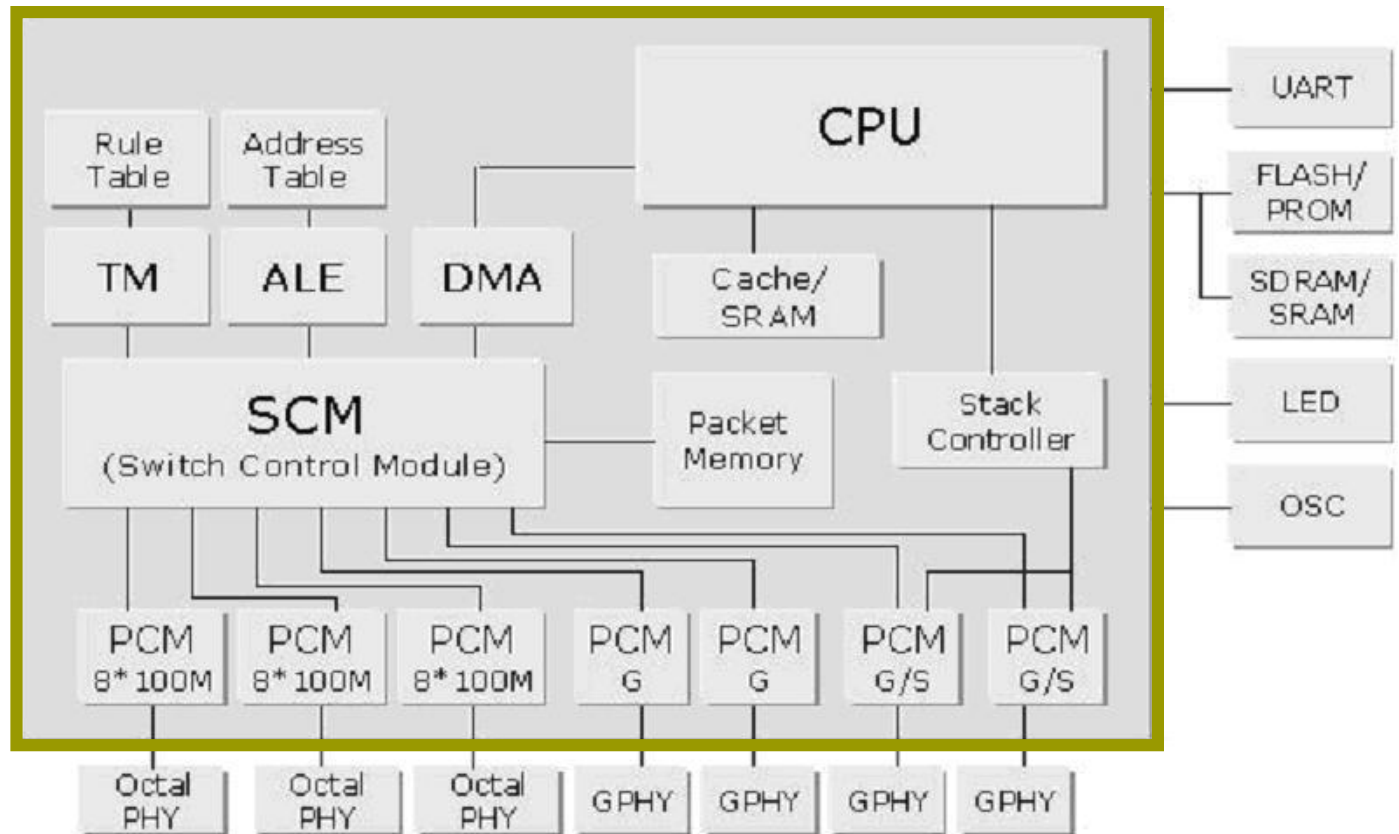


Ethernet-Switch

- To speed up the transmission rate of Ethernet Hub without changing the interface cards on stations.
- Ether-Switch Architecture
- Each Ethernet port can have a transmission simultaneously.



Ethernet Switch ASIC example



Block Diagram

Acute Leo AQ6628 24+4 Ethernet Switch ASIC

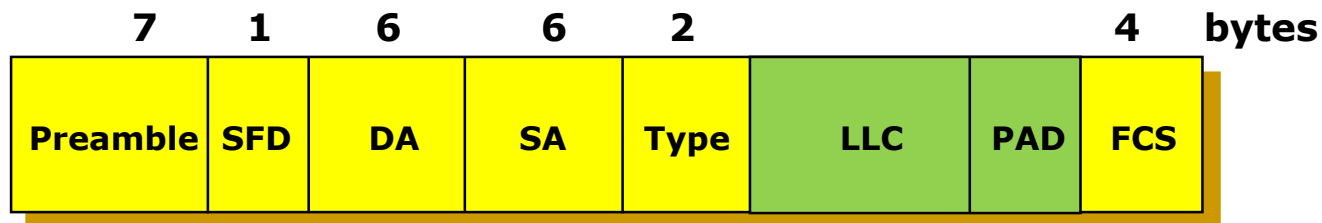
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- Ethernet Topologies
- **Ethernet Frame Format**
- Ethernet MAC Protocol -- CSMA/CD
- 802.3 Ethernet Standards

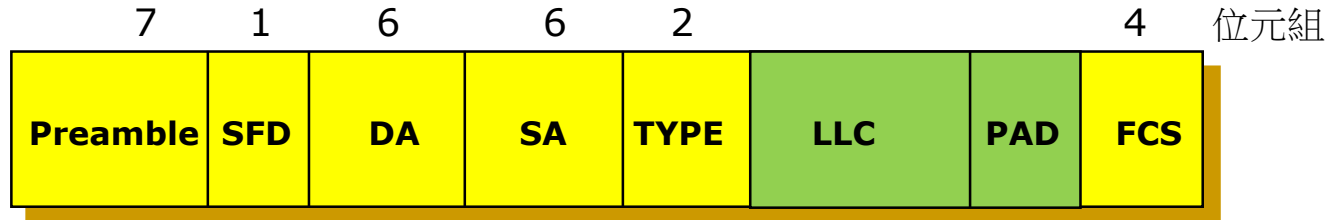
Ethernet Frame Format

■ Frame format

- Preamble (64bits): allows the receiver to synchronize with the signal (sequence of alternating 0s and 1s).
- Source and Destination MAC Addresses (48bits each).
- Packet type (16bits): acts as demux key to identify the higher level protocol.
- Data (up to 1500 bytes)
 - ▶ Minimally a frame must contain at least 46 bytes of data.
 - ▶ Frame must be long enough to detect collision.
- FCS: CRC (32bit)



Ethernet Frame Format



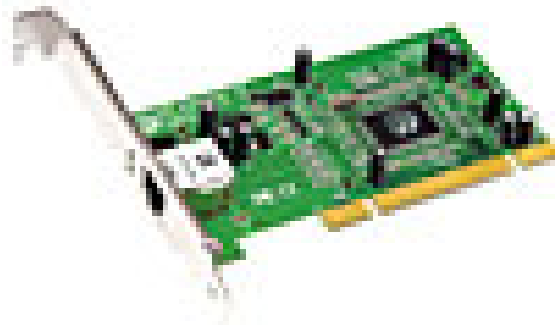
- Preamble: (101010...1010) for Synchronization
- SFD: Start Frame Delimiter (10101011)
- DA: Destination MAC Address
- SA: Source MAC Address
- Packet type (16bits): acts as demux key to identify the higher level protocol.
- LLC-Frame: Up to 1500 bytes
- PAD: Padding when LLC-Frame < 46 bytes
- FCS: Frame Check Sequence (CRC-32)
- MAC-frame size -- from DA to FCS
 - Min 64 bytes to distinguish from collision
 - Max 1518 bytes to prevent dominating bandwidth

Ethernet Addresses

- Each host on an Ethernet (in fact, every Ethernet host in the world) has a **unique Ethernet Address**.
- The address belongs to the adaptor, not the host.
 - It is usually burnt into ROM.
- Ethernet addresses are typically printed in a human readable format
 - As a sequence of six numbers separated by colons.
 - Each number corresponds to 1 byte of the **6 byte address** and is given by a pair of hexadecimal digits, one for each of the 4-bit nibbles in the byte
 - Leading 0s are dropped.
 - For example, **8:0:2b:e4:b1:2** is
 - ▶ 00001000 00000000 00101011 11100100 10110001 00000010

Ethernet Addresses

- To ensure that every adaptor gets a unique address, each manufacturer of Ethernet devices is allocated a **different prefix** that must be prepended to the address on every adaptor they build
 - ▶ AMD has been assigned the 24bit prefix **8:0:20**



Ethernet Addresses

- Each frame transmitted on an Ethernet is received by **every adaptor** connected to that Ethernet.
- Each adaptor recognizes those frames addressed to its address and passes only those frames on to the host.
- In addition to **unicast address**, an Ethernet address consisting of all 1s is treated as a **broadcast address**.
 - All adaptors pass frames addressed to the *broadcast* address up to the host.
- Similarly, an address that has the first bit set to 1 but is not the *broadcast* address is called a **multicast address**.
 - A given host can program its adaptor to accept some set of *multicast* addresses.

Ethernet Addresses

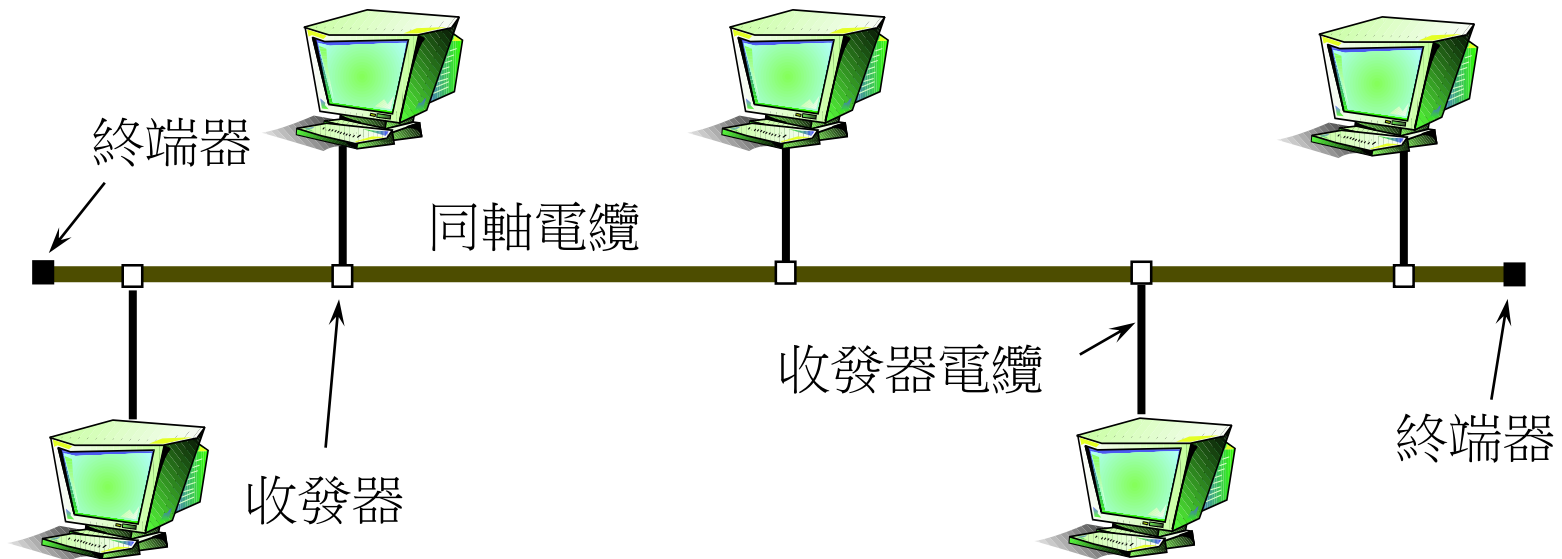
- To summarize, an Ethernet adaptor **receives all frames** and accepts
 - Frames addressed to its own address
 - Frames addressed to the broadcast address
 - Frames addressed to a multicast address if it has been instructed

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Ethernet MAC protocol

- Any signal placed on the Ethernet by a host is **broadcast over the entire network**
 - Signal is propagated in both directions.
 - Repeaters forward the signal on all outgoing segments.
 - **Terminators** attached to the end of each segment absorb the signal.



CSMA (Carrier Sense Multiple Access)

CSMA: listen before transmit:

If channel sensed idle: transmit entire frame

■ If channel sensed busy, defer transmission

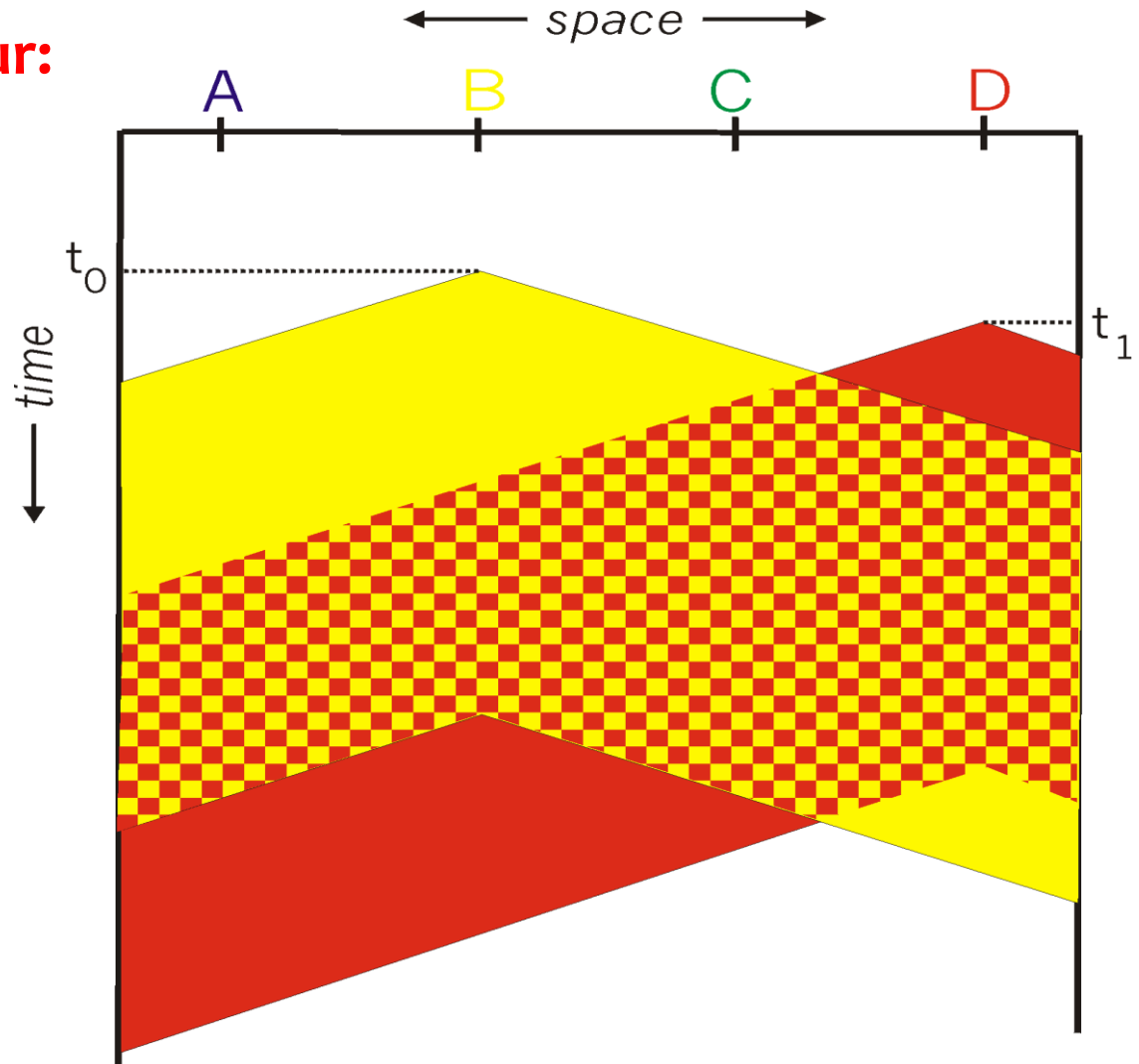
CSMA collisions

collisions can still occur:

propagation delay means
two nodes may not hear
each other's transmission

collision:

entire packet transmission
time wasted



CSMA/CD (Collision Detection)

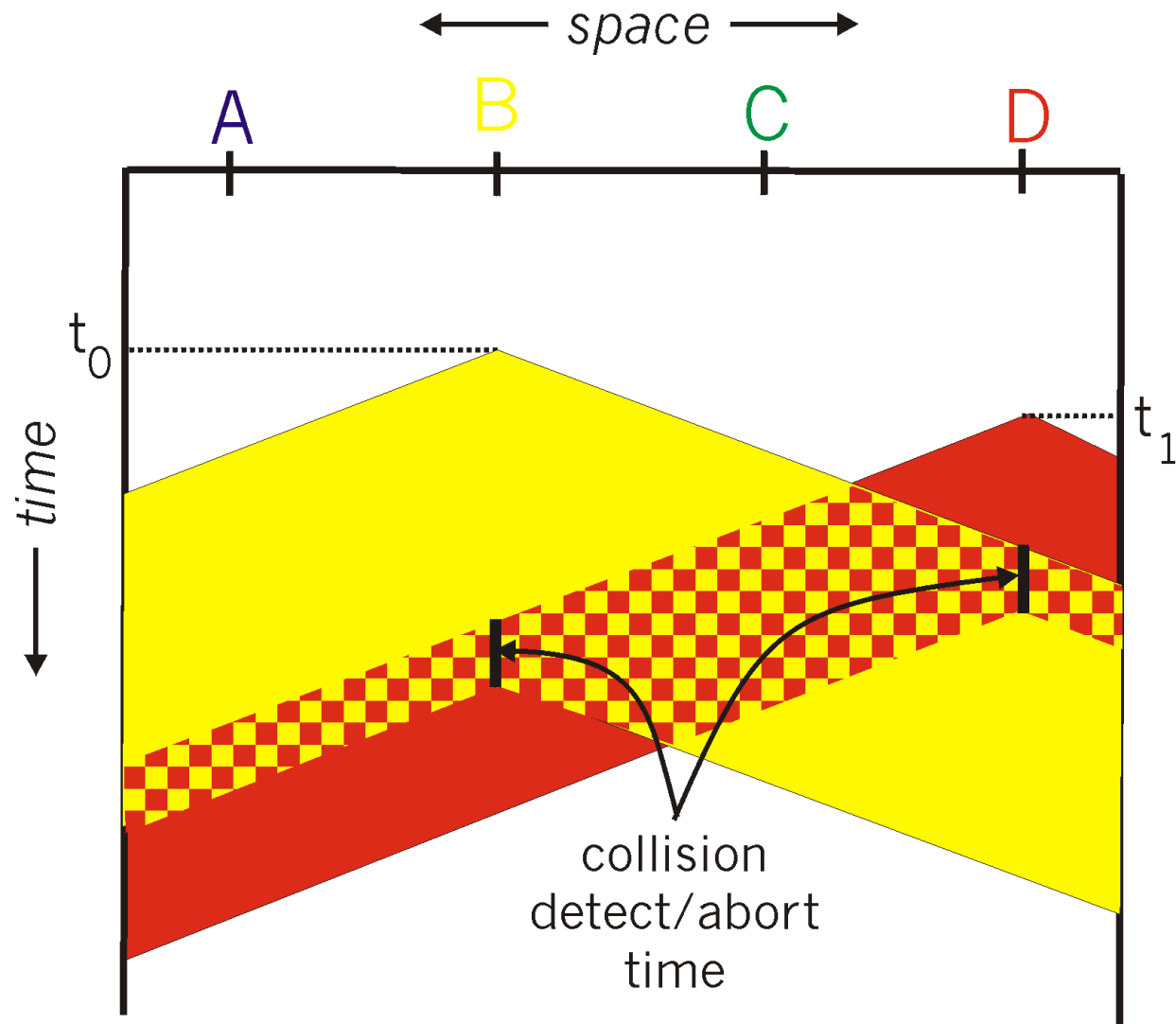
CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- **colliding transmissions aborted**, reducing channel wastage

■ Collision detection:

- Measure signal strengths, compare transmitted, received signals

CSMA/CD collision detection



CSMA/CD

- Carrier Sense Multiple Access with Collision Detection (**CSMA/CD**).
 - A set of nodes send and receive frames over a shared link.
 - **Carrier sense** means that all nodes can distinguish between an **idle** and a **busy** link.
 - **Collision detection** means that a node listens as it transmits and can therefore detect when a frame it is transmitting has collided with a frame transmitted by another node.

CSMA/CD

- When the adaptor has a frame to send and the **line is idle**, it transmits the frame immediately.
- When the adaptor has a frame to send and the **line is busy**, it waits for the line to go idle and then transmits immediately.
- The Ethernet is said to be **1-persistent protocol** because an adaptor with a frame to send transmits with **probability 1** whenever a busy line goes idle.

CSMA/CD

- Since there is no centralized control it is possible for two (or more) adaptors to begin transmitting at the same time,
 - Either because both found the line to be idle,
 - Or, both had been waiting for a busy line to become idle.
- When this happens, the two (or more) frames are said to be *collide* on the network.

CSMA/CD

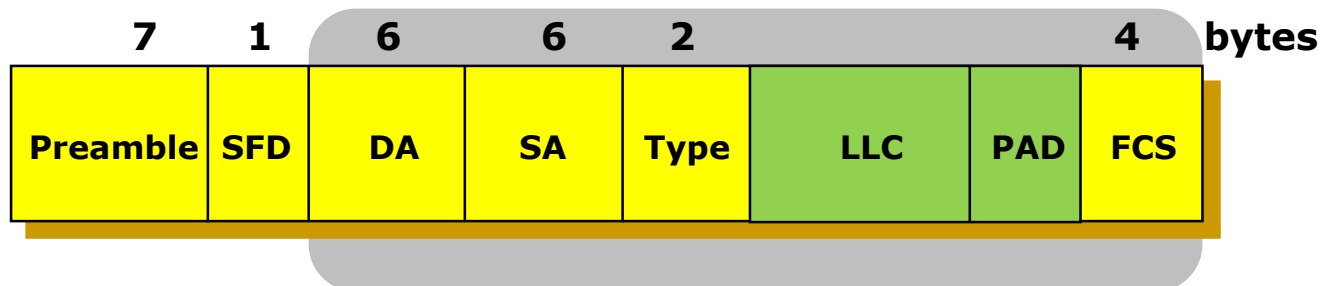
- Since Ethernet supports **collision detection**, each sender is able to determine that a collision is in progress.
- At the moment an adaptor detects that its frame is colliding with another, it first makes sure to transmit a **32-bit jamming sequence** and then stops transmission.
 - Thus, a transmitter will minimally send 96 bits in the case of collision
 - ▶ 64-bit preamble + 32-bit jamming sequence

CSMA/CD

- One way that an adaptor will send only **96 bits** (called a **runt frame**) is if the two hosts are **close to each other**.
- In case the two hosts are farther apart, they would have had to transmit longer, and thus send more bits, before detecting the collision.

Collision Window

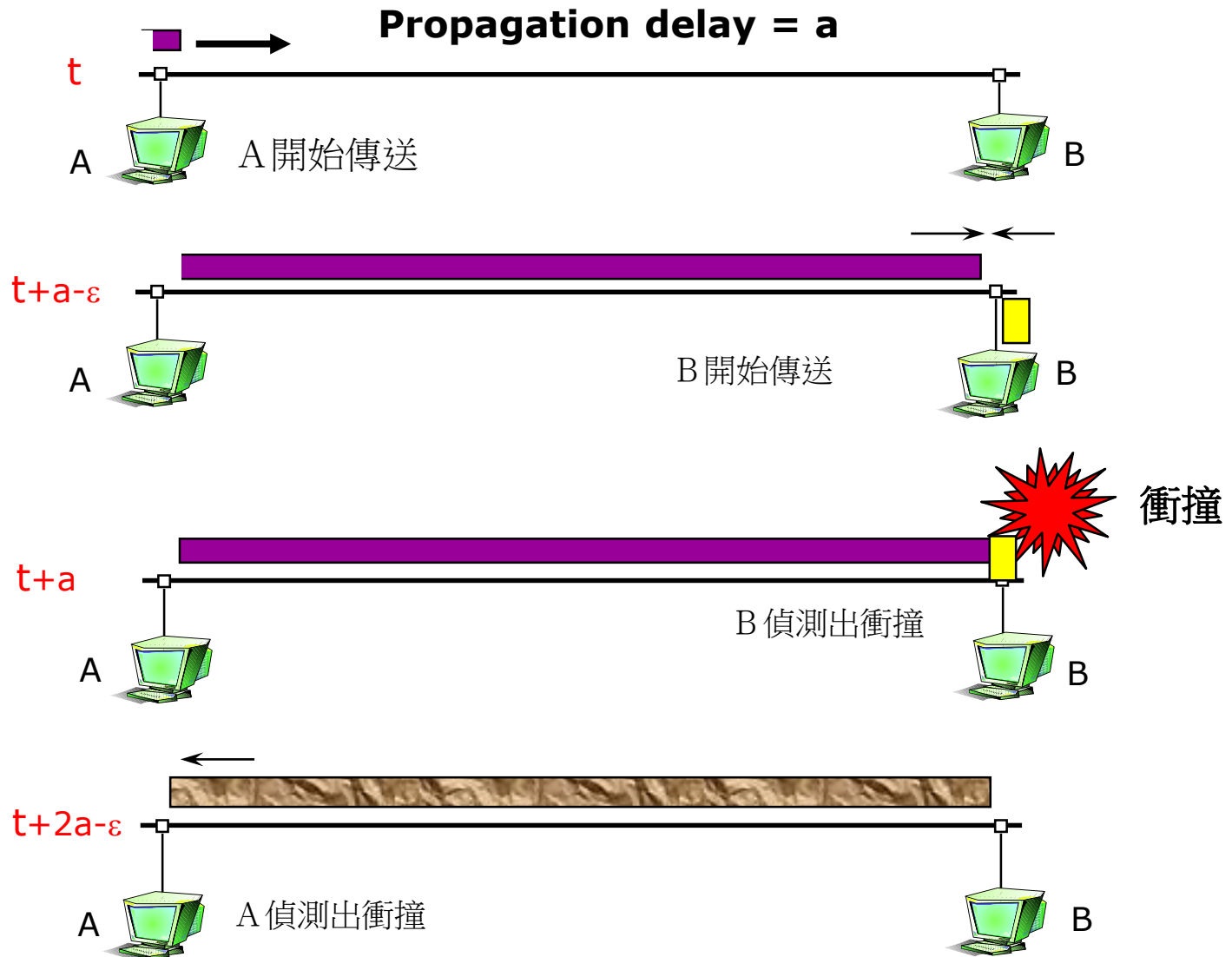
- The worst case scenario happens when the two hosts are **at opposite ends of the Ethernet**.
- To know for sure that the frame its just sent did not collide with another frame, the transmitter may need to **send as many as 512 bits**.
 - Every Ethernet frame must be **at least 512 bits (64 bytes) long**.
 - ▶ 14 bytes of header + 46 bytes of data + 4 bytes of CRC



Collision Window

- **Why 512 bits (64 bytes) ?**
 - Why is its length limited to 2500 m?
- **Collision Window = round-trip delay ($2a$)**
- **The farther apart two nodes are, the longer it takes for a frame sent by one to reach the other, and the network is vulnerable to collision during this time**

Collision Detection Window for CSMA/CD (=2a)



Collision Window

- A begins transmitting a frame at time t
- a denotes the one link latency
- The first bit of A's frame arrives at B at time $t + a$
- Suppose an instant before host A's frame arrives, host B begins to transmit its own frame
- B's frame will immediately collide with A's frame and this collision will be detected by host B
- Host B will send the 32-bit jamming sequence
- Host A will not know that the collision occurred until B's frame reaches it, which will happen at $t + 2a$
- Host A must continue to transmit until this time in order to detect the collision
 - Host **A must transmit for $2a$** to be sure that it detects all possible collisions

Collision Window

- Consider that a maximally configured Ethernet is 2500 m long, and there may be up to four repeaters between any two hosts, the **round trip delay has been determined to be 51.2 μ s**
 - Which on **10 Mbps** Ethernet corresponds to 512 bits
 - **$10 \text{ Mbps} \times 51.2 \mu\text{s} = 512 \text{ bits}$**
- The other way to look at this situation,
 - We need to limit the Ethernet's maximum latency to a fairly small value (51.2 μ s) for the access algorithm to work
 - ▶ Hence the maximum length for the Ethernet is on the order of 2500 m.

Exponential Backoff Algorithm

- Once an adaptor has detected a collision, and stopped its transmission, it **waits a certain amount of time and tries again.**
- Each time the adaptor tries to transmit but fails, it **doubles the amount of time it waits** before trying again. double 的时间
- This strategy of doubling the delay interval between each retransmission attempt is known as ***Exponential Backoff***.

Exponential Backoff Algorithm

- The adaptor first delays either 0 or 51.2 μs , selected at random.
- If this effort fails, it then waits 0, 51.2, 102.4, 153.6 μs (selected randomly) before trying again;
 - This is $k * 51.2$ for $k = 0, 1, 2, 3$
- After the third collision, it waits $k * 51.2$ for $k = 0 \dots 2^3 - 1$ (again selected at random).
- In general, the algorithm randomly selects a k between 0 and $2^n - 1$ and waits for $k * 51.2 \mu\text{s}$, where n is the number of collisions experienced so far.

第 n 次冲突的话，从1-2的 n 次方中选择一个时间， n 最大为16次（0-1023）中的一个，不然这个数太大，即连续16次冲突，那就放弃了

CSMA/CD Protocol

- Carrier Sense before transmission
- Carrier Sense while transmission
- Collision: Two or more stations transmitting simultaneously
- Backoff: Random delay after collision
- Deference: Defers transmission if channel is sensed busy
- Collision Window (Slot time): Round-trip propagation delay time plus some carrier sense time. In IEEE 802.3, this value is defined to be 51.2 us.

CSMA/CD Collision Handling

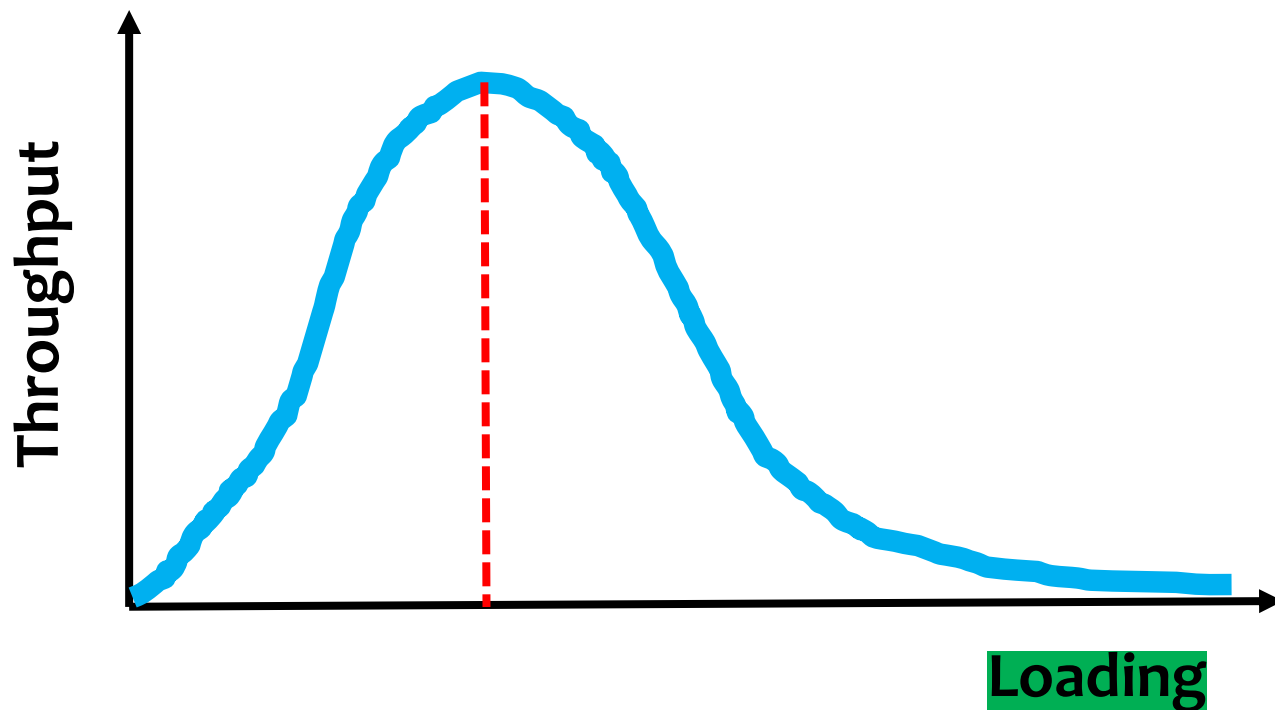
- Collision Signal is generated by Physical layer.
- **Jam signal (collision enforcement)**: To make sure that all stations involved in the collision will detect collision. A pattern of **32 bits**.
- Collision backoff and retransmission method (**Truncated Binary Exponential Backoff Algorithm, BEBA**):
 - n : number of collisions experienced ($n \leq 16$)
 - **$k : \text{Min}(n, 10)$ -- Truncation**
 - r : Random delay time (unit: slot time), $0 \leq r < 2^k$

CSMA/CD Collision Handling

- Slot time = 51.2 us.
- Disadvantage of BEBA: 最后进来的，反而先送到，因为k比较小
 - **Last-in-First-out effect:** Stations with no or few collisions will have a better chance to transmit before stations that have waited longer.

Ethernet Performance

- Ethernets work best under **lightly loaded** conditions.
- Under **heavy loads**, too much of the network's capacity is **wasted by collisions**.

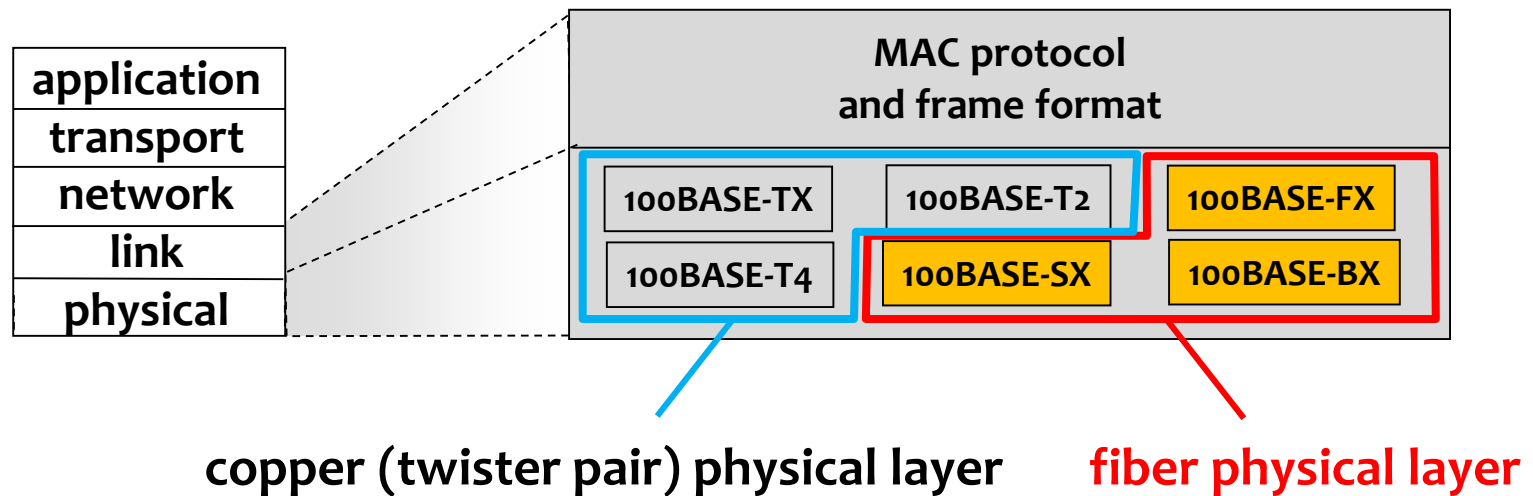


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802.3 Ethernet Standards: Link & Physical Layers

- **Many** different Ethernet standards
 - common MAC protocol (CSMA/CD) and frame format
 - different speeds: 2 Mbps, 10 Mbps, 100 Mbps, 1Gbps, 10Gbps, 100Gbps
 - different physical layer media: fiber, cable



Summary

- MAC Protocol -- CSMA/CD
- Connection less, unreliable transmission
- Topology from **Bus** to **Star (switches)**
- Half-duplex transmission in Bus topology
 - Work best under **lightly loaded** conditions
 - Too much collision under **heavy load**
- Full-duplex transmission in Switch topology (point-to-point)
 - No more collisions !!
 - Excellent performance (wired speed)