Introduction to Computer Networks

IEEE 802.3 Ethernet

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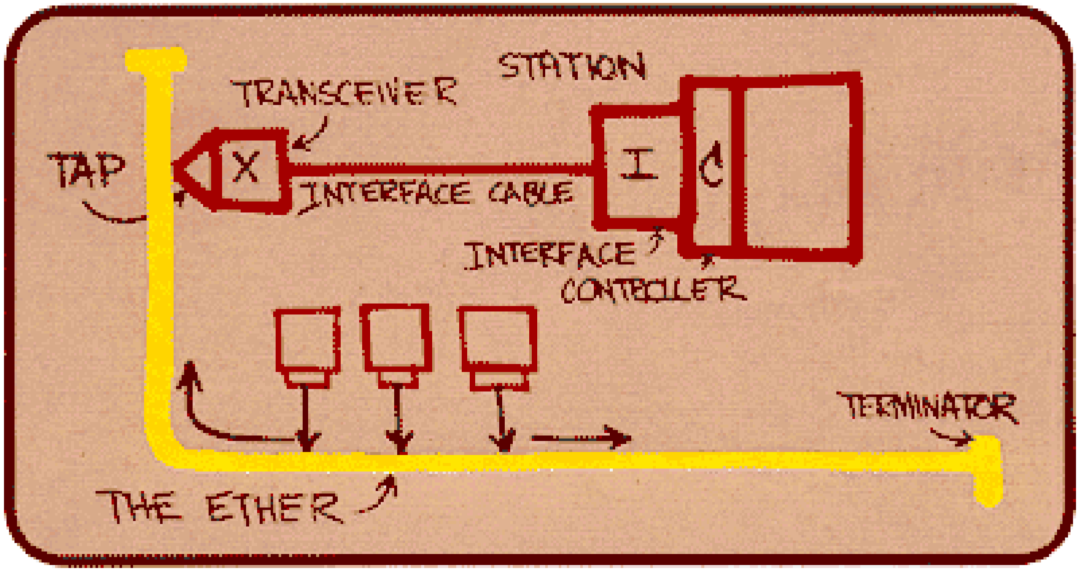
Outline

- 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


STATION
TRANSCEIVER
TAP
X
I
C
INTERFACE CABLE
INTERFACE
CONTROLLER
TERMINATOR
THE ETHER

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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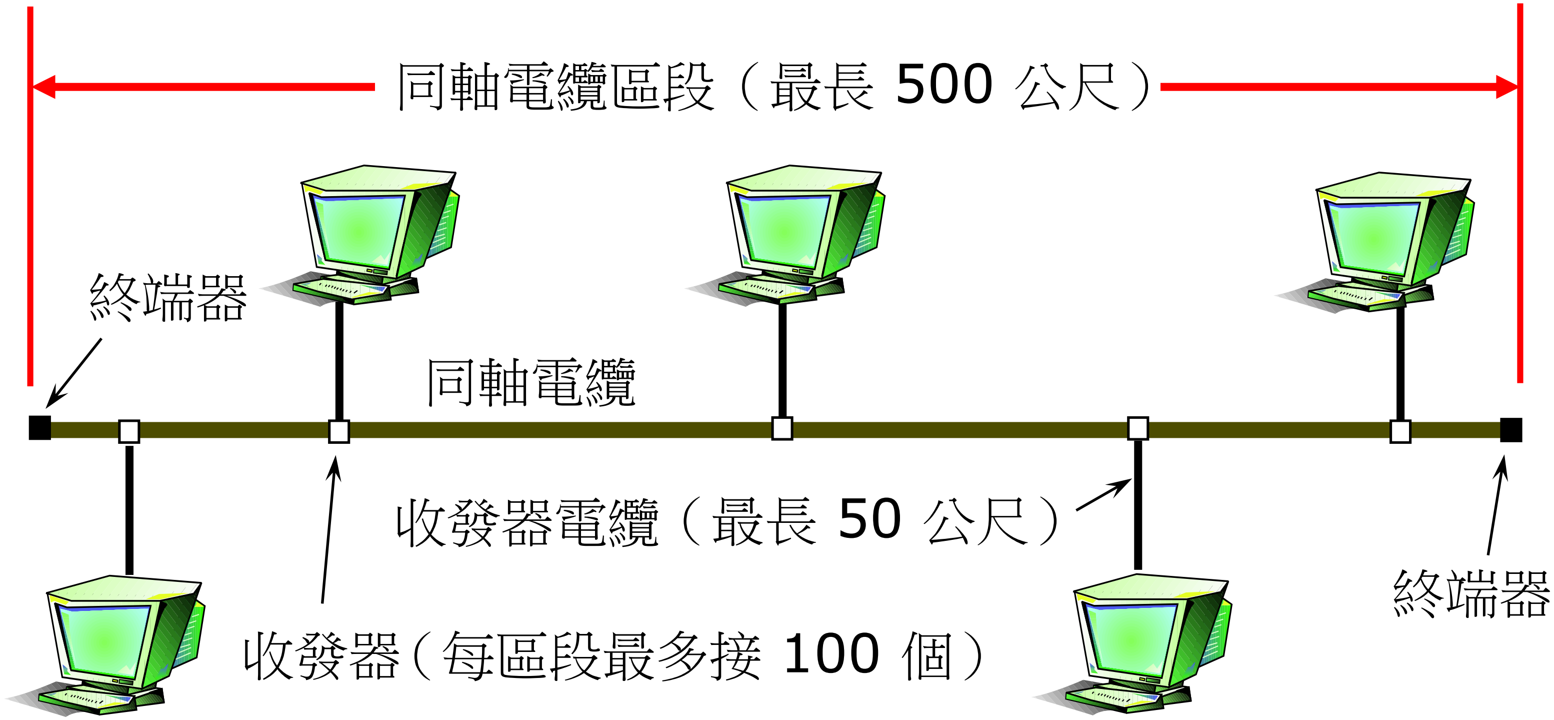
Bus Topology

- **Bus topology** popular through mid 90s
  - all nodes in same collision domain (can collide with each other)



同軸電纜區段（最長 500 公尺）

終端器

同軸電纜

收發器電纜（最長 50 公尺）

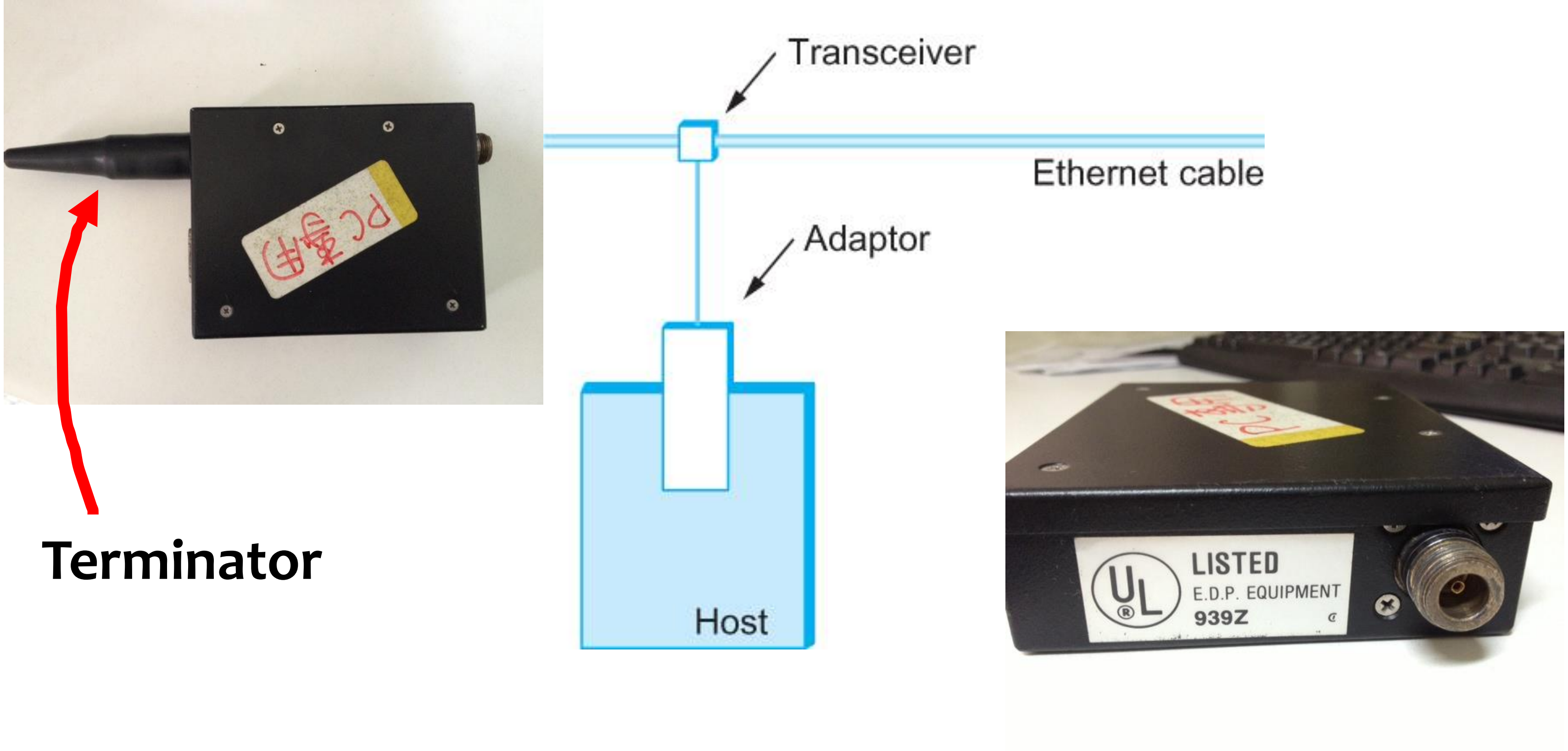
收發器（每區段最多接 100 個）

終端器

Ethernet (10Base5)

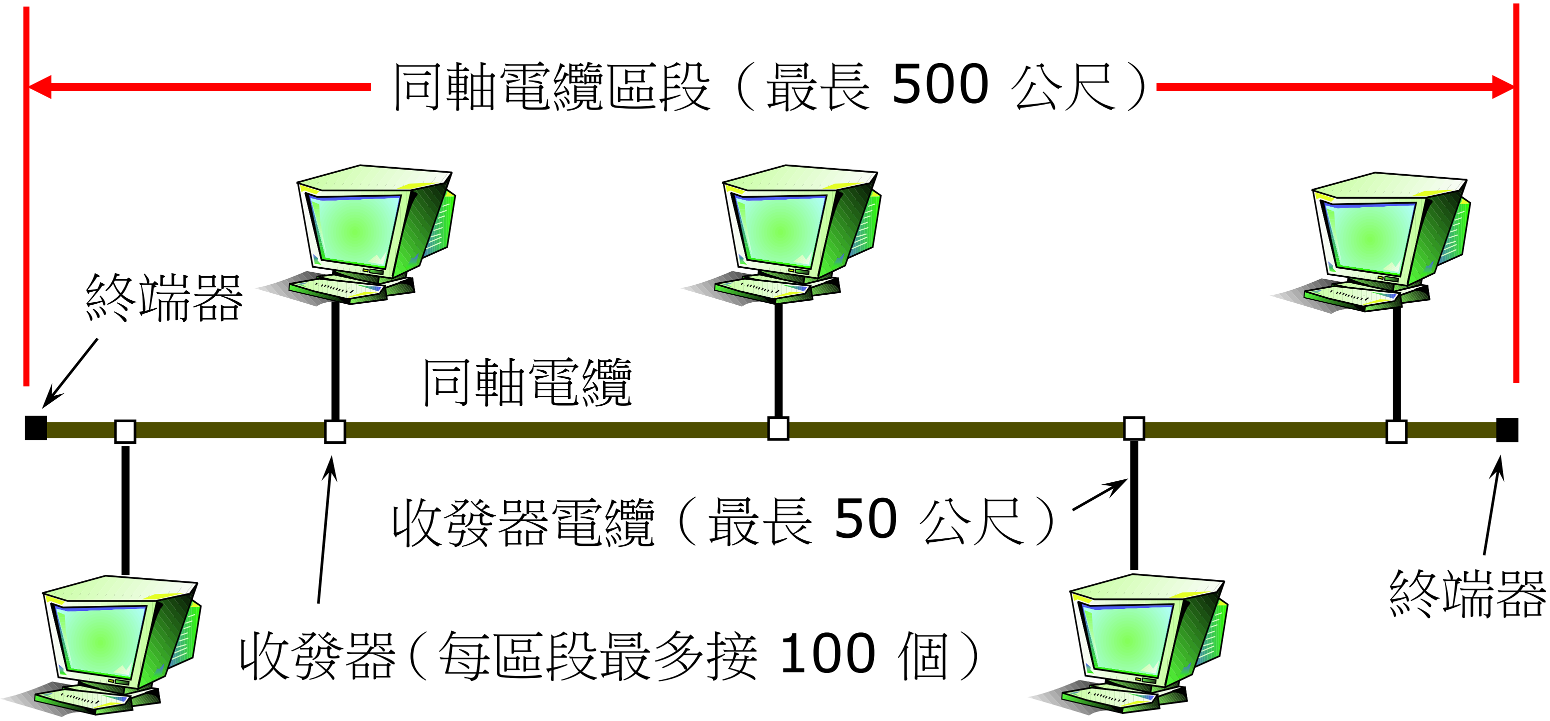
- An Ethernet segment is implemented on a coaxial cable of up to 500 m.
- Hosts connect to an Ethernet segment by tapping into it.
- A transceiver (a small device directly attached to the tap) detects when the line is idle and drives signal when the host is transmitting.
- The transceiver also receives 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)

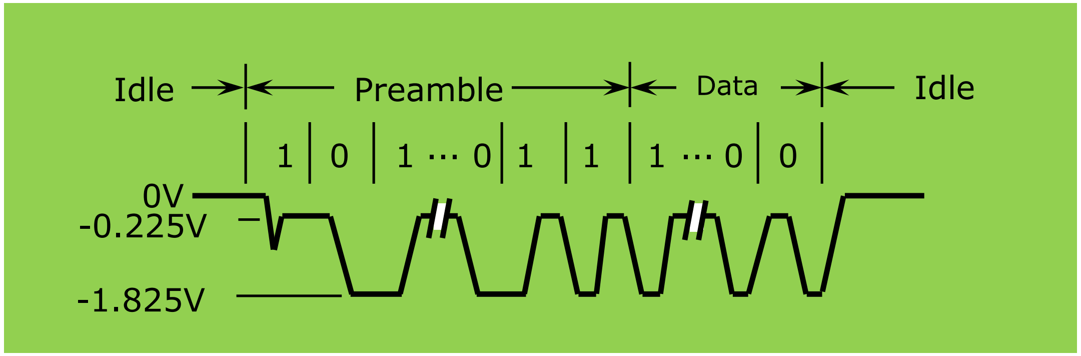

Transceiver
Ethernet cable
Adaptor
Host
Terminator
PC専用
LISTED
E.D.P. EQUIPMENT
939Z

Ethernet transceiver, adaptor, and terminator

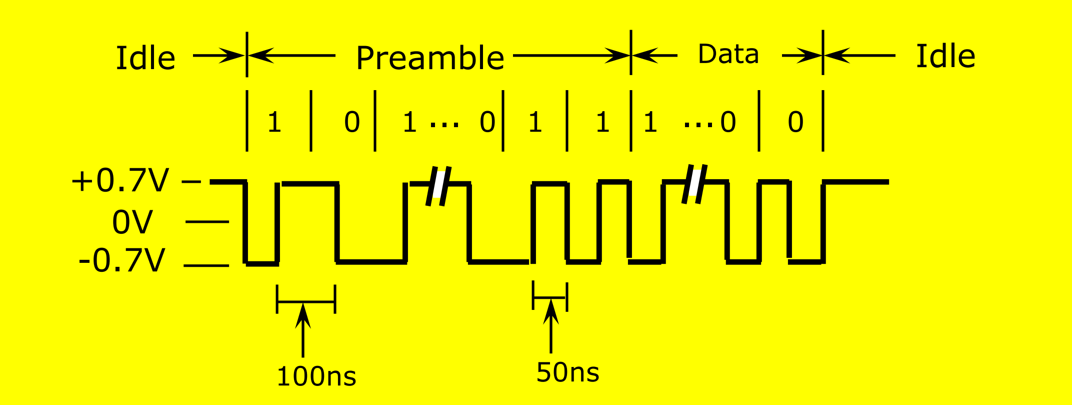
Network Configuration Example 1
(Single segment)


同軸電纜區段（最長 500 公尺）
終端器
同軸電纜
收發器電纜（最長 50 公尺）
收發器(每區段最多接 100 個）
終端器

Cable Signaling (Manchester Encoding)


Idle
Preamble
Data
Idle
1 | 0 | 1 … 0 | 1 | 1 | 1 … 0 | 0
0V
-0.225V
-1.825V

Coaxial Cable


Idle
Preamble
Data
Idle
1 | 0 | 1 … 0 | 1 | 1 | 1 … 0 | 0
+0.7V
0V
-0.7V
100ns
50ns

Transceiver Cable

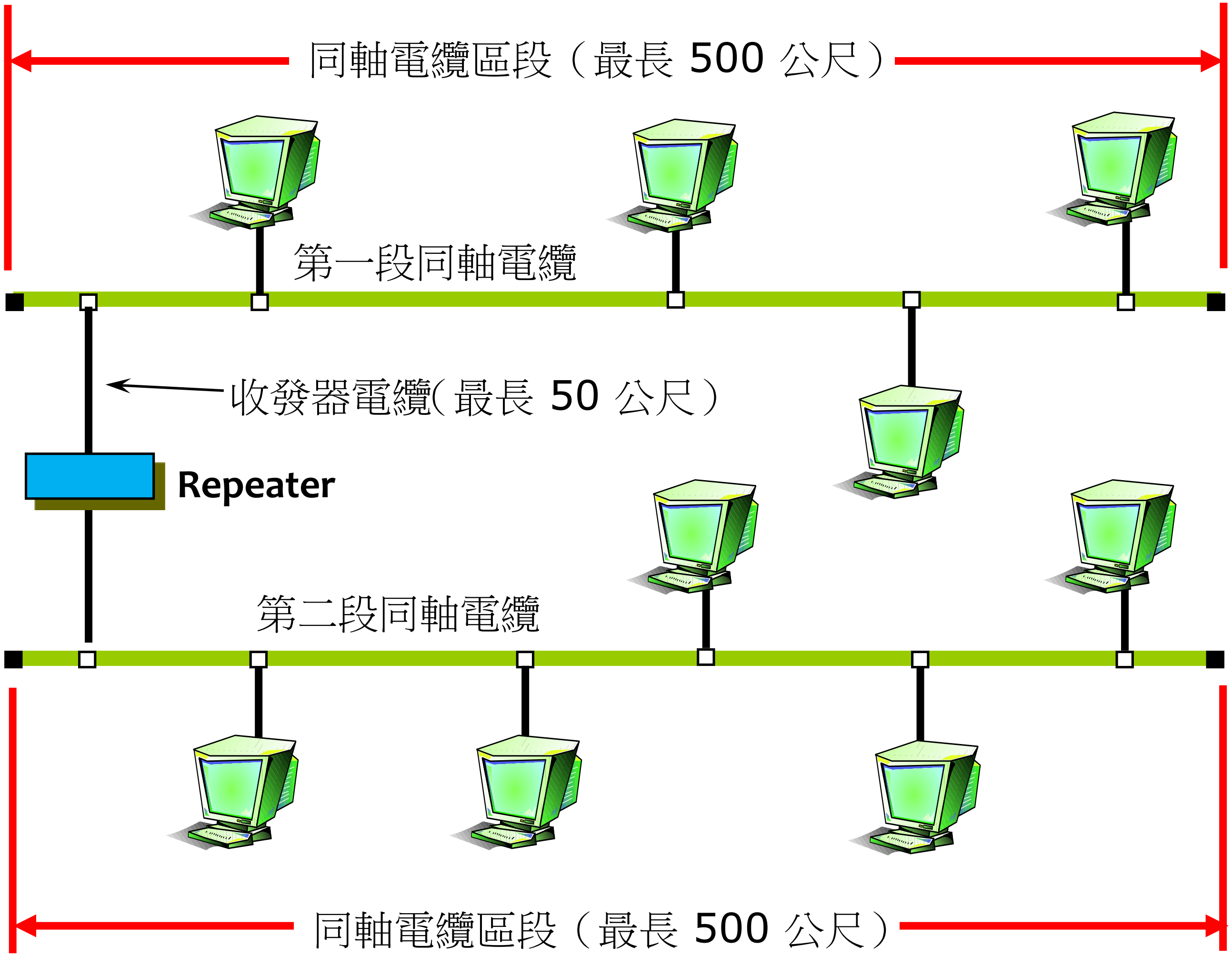
- Each bit has a transition
- Allows clocks in sending and receiving nodes to synchronize to each other

Ethernet (10Base5)

10Mbps baseband 500m

- **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)



同軸電纜區段（最長 500 公尺）

第一段同軸電纜

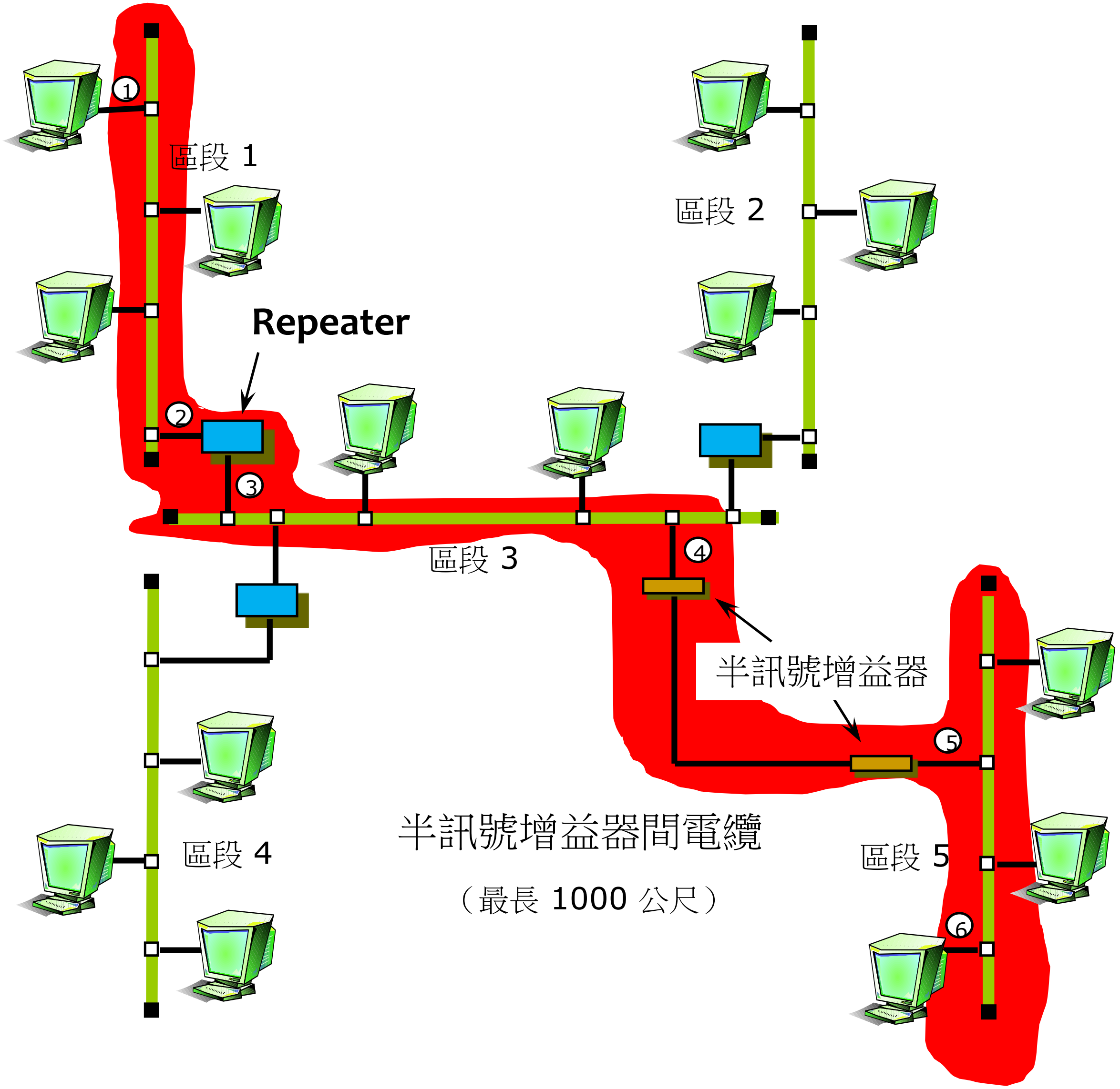
收發器電纜(最長 50 公尺)

Repeater

第二段同軸電纜

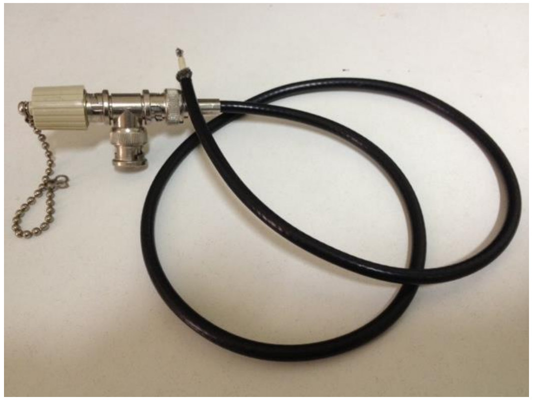
同軸電纜區段（最長 500 公尺）

Network Configuration Example 3
(Five segments, maximum)


①
區段 1
區段 2
Repeater
②
③
區段 3
④
半訊號增益器
⑤
半訊號增益器間電纜
（最長 1000 公尺）
區段 4
區段 5
⑥

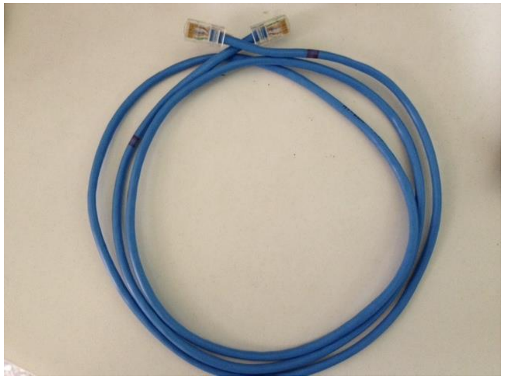
Ethernet (10Base2)

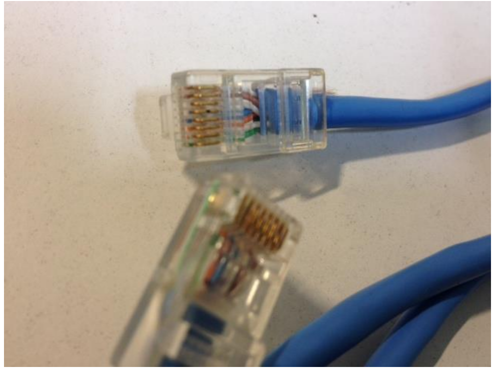
- **New Technologies in Ethernet**
  - **Instead of using coax cable, an Ethernet can be constructed from a thinner cable known as 10Base2 (the original was 10Base5)**
    - **10 means the network operates at 10 Mbps**
    - **Base means the cable is used in a baseband system**
    - **2 means that a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



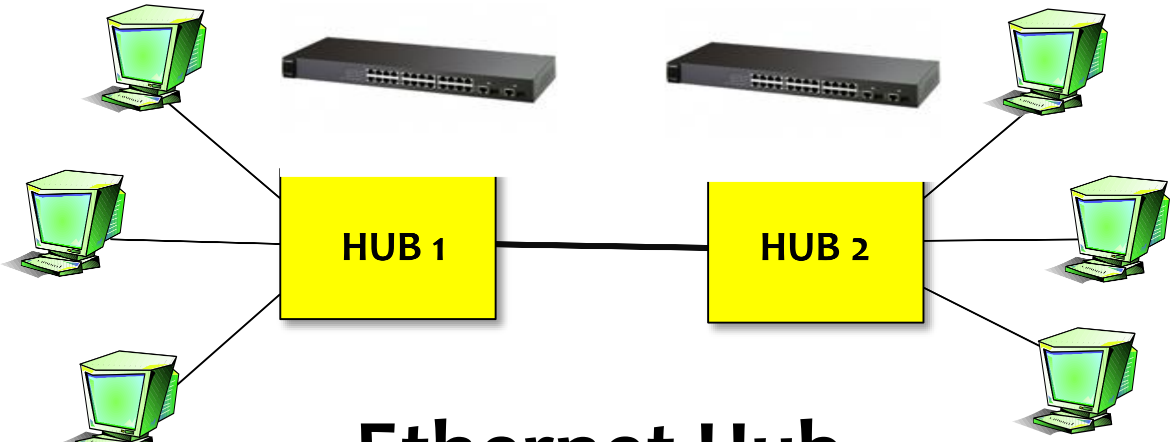
Ethernet (10BaseT)

- 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*

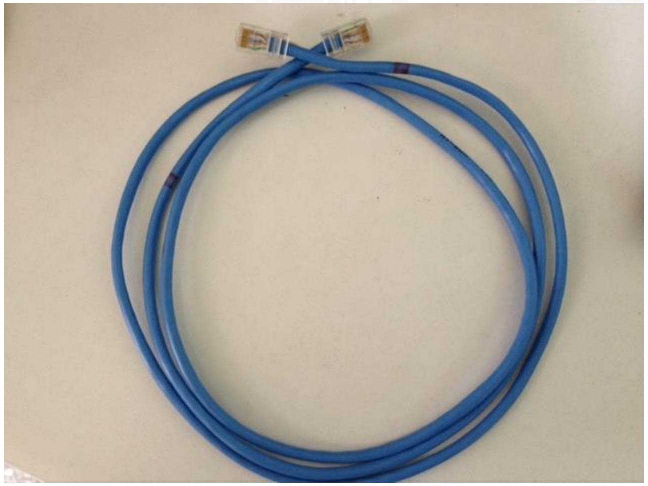




Ethernet

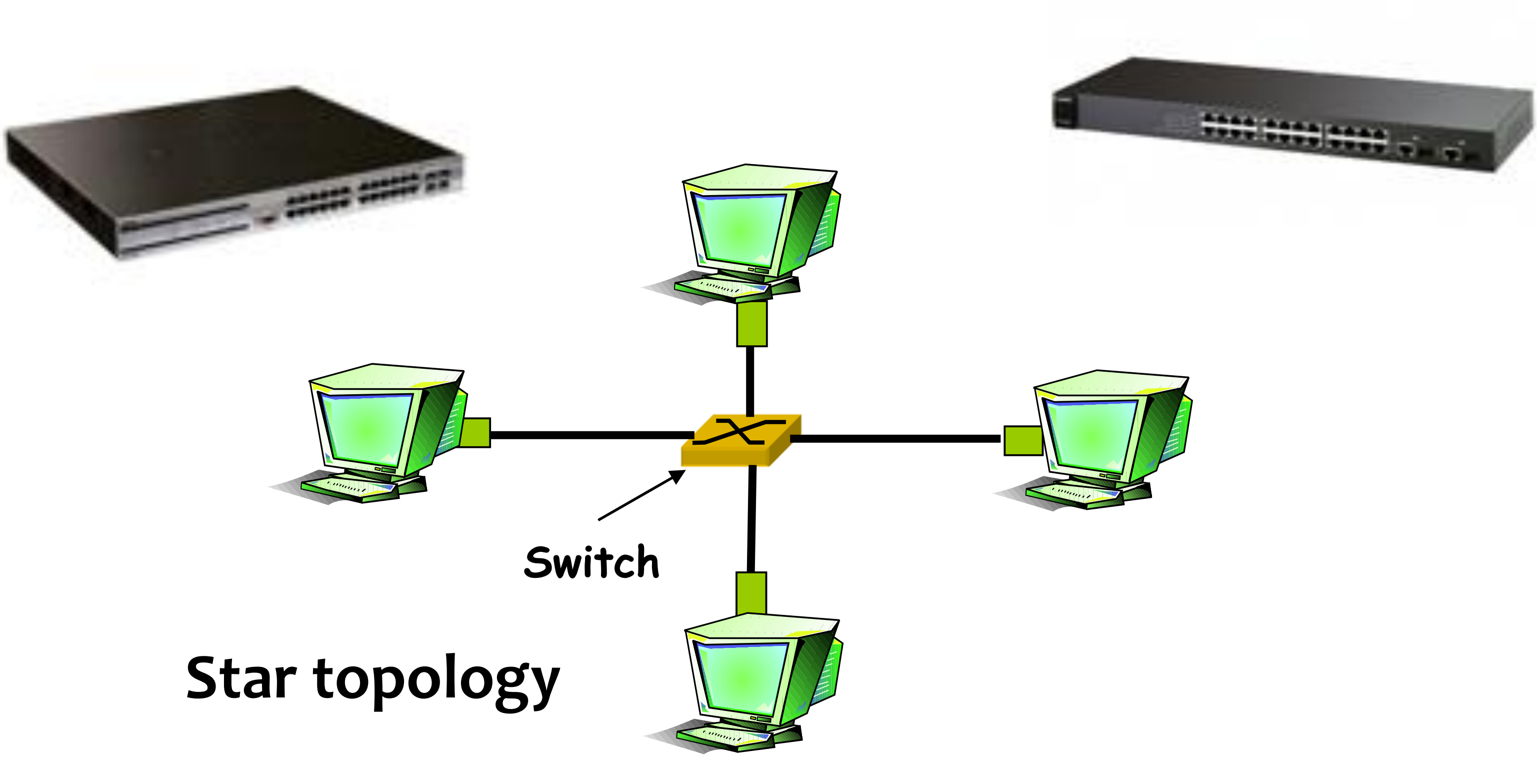


Ethernet Hub



Star Topology

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



Star topology

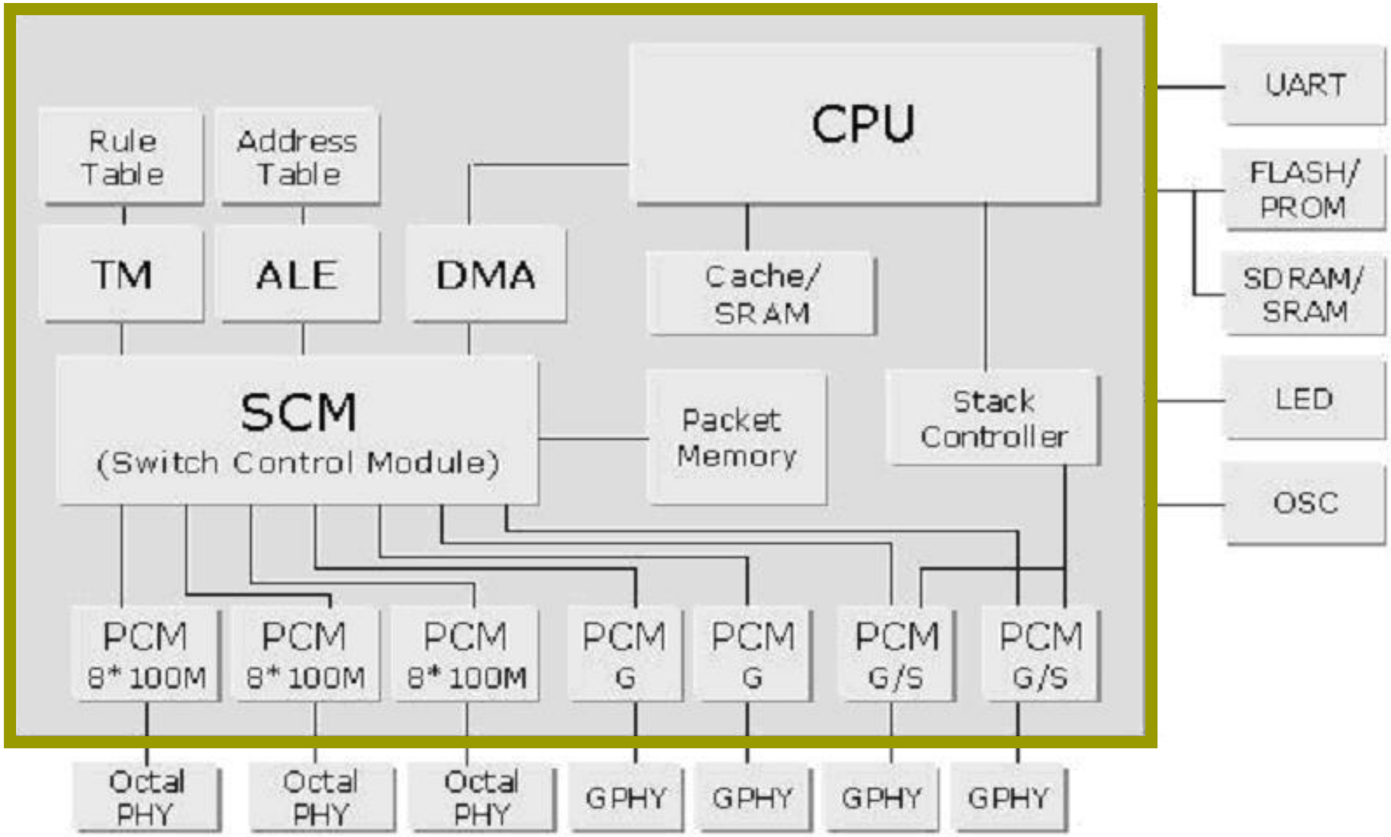
Ethernet-Switch

- 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.

KINGNET
KN-S1024G

Ethernet Switch ASIC example

ACUTE
AQ6628


CPU
Rule Table
Address Table
TM
ALE
DMA
Cache/ SRAM
SCM (Switch Control Module)
Packet Memory
Stack Controller
PCM 8*100M
PCM 8*100M
PCM 8*100M
PCM G
PCM G
PCM G/S
PCM G/S
Octal PHY
Octal PHY
Octal PHY
GPHY
GPHY
GPHY
GPHY
UART
FLASH/ PROM
SDRAM/ SRAM
LED
OSC

Block Diagram

Acute Leo AQ6628 24+4 Ethernet Switch ASIC

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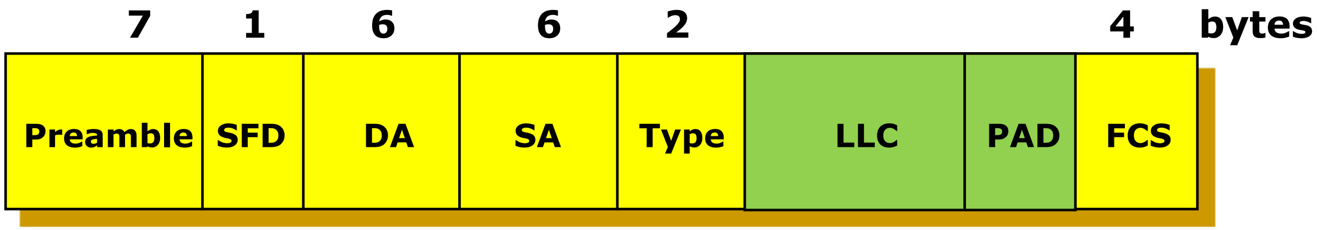
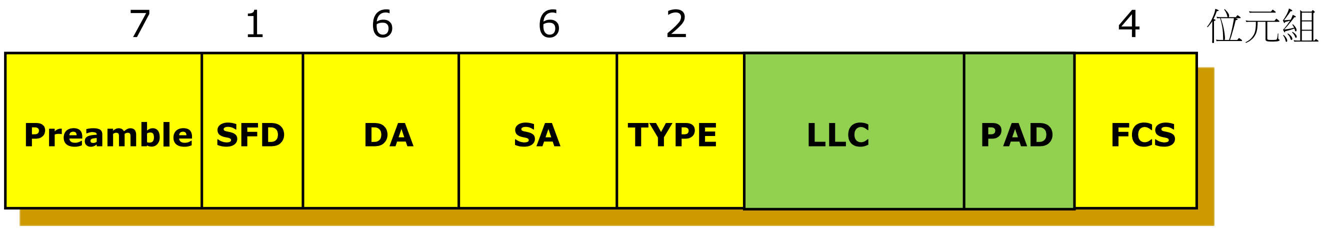
Ethernet Frame Format

- **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)



7	1	6	6	2			4	bytes
Preamble	**SFD**	**DA**	**SA**	**Type**	**LLC**	**PAD**	**FCS**	

Ethernet Frame Format



7	1	6	6	2			4	位元組
Preamble	SFD	DA	SA	TYPE	LLC	PAD	FCS	

- 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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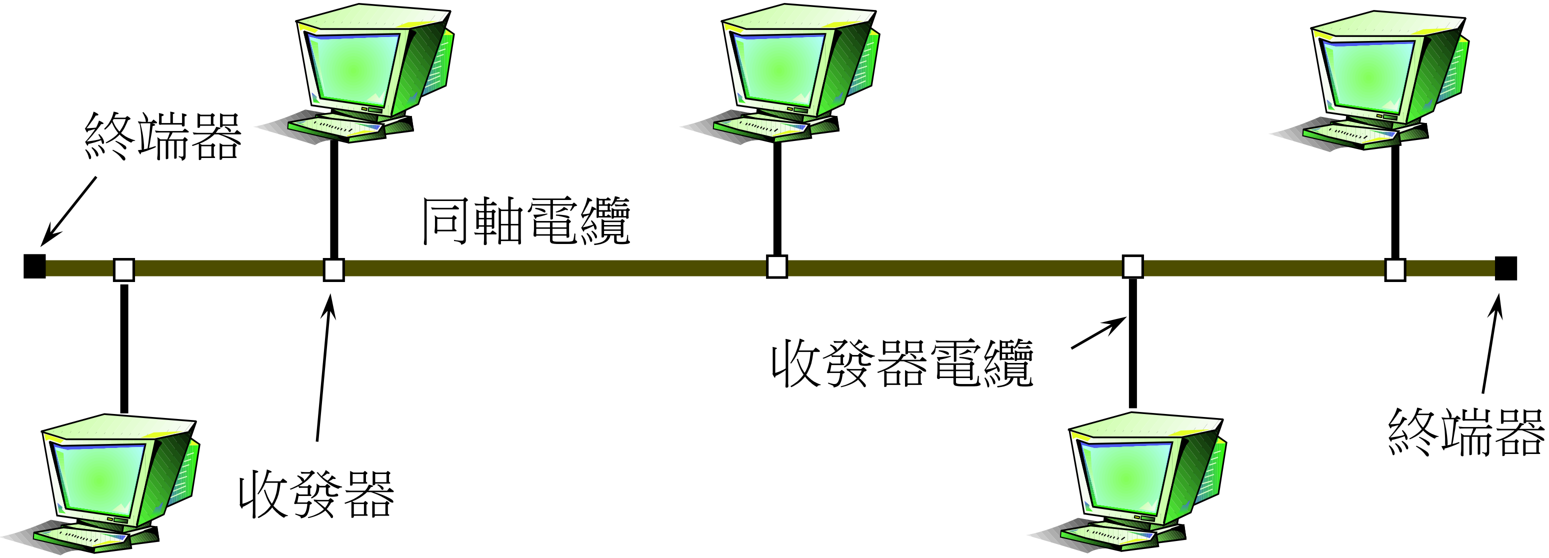
Ethernet MAC protocol

- 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

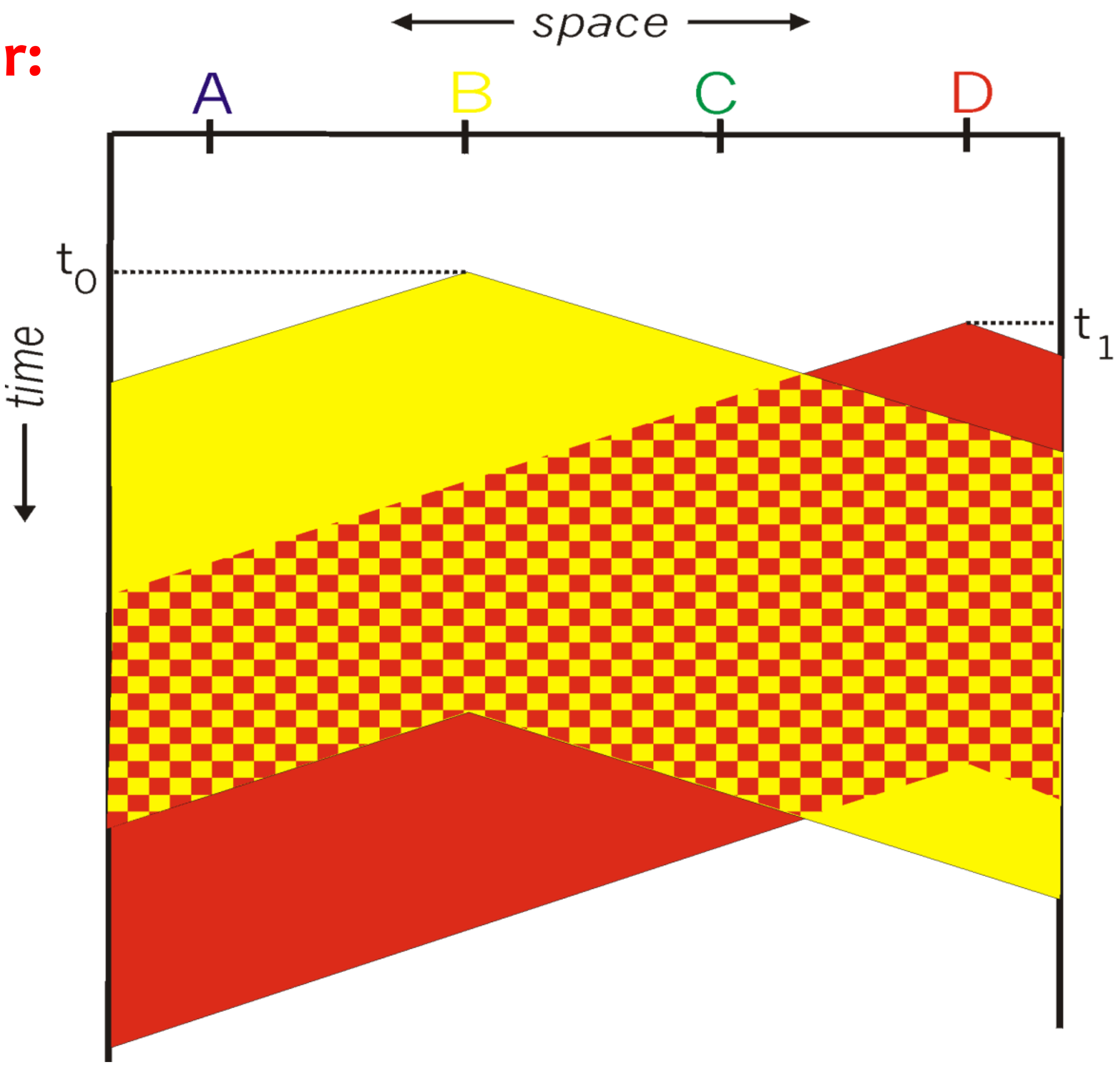
CSMA collisions

collisions can still occur:

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

collision:

entire packet transmission time wasted


space
A
B
C
D
time
t_0
t_1

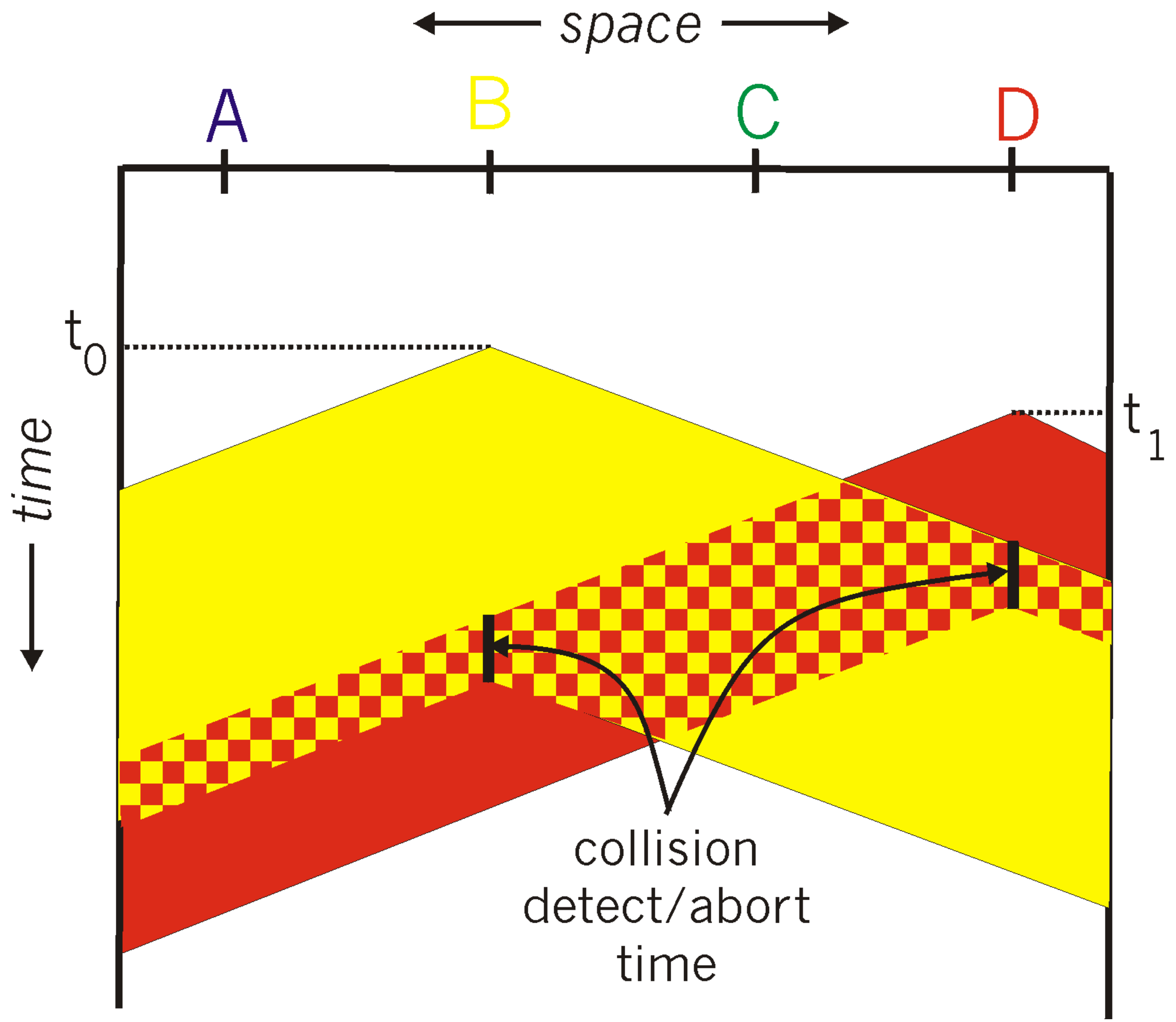
CSMA/CD (Collision Detection)

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


space
A
B
C
D
t_0
t_1
time
collision detect/abort time

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

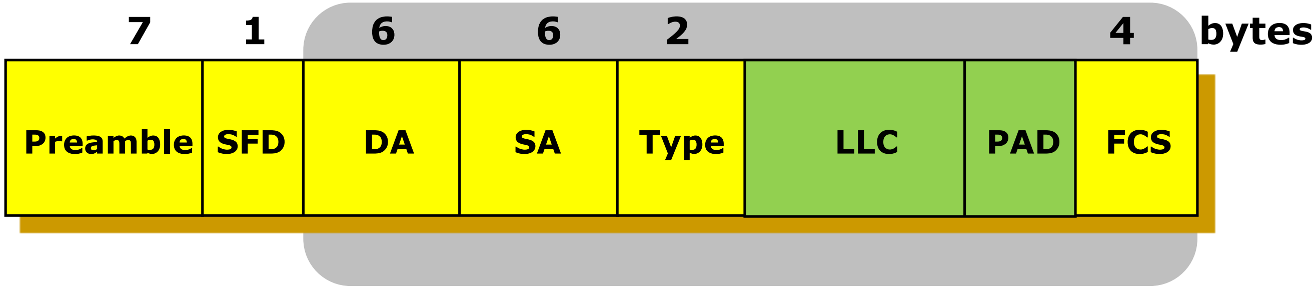
- Since Ethernet supports collision detection, each sender is able to determine that a collision is in progress.
- At the moment an adaptor detects that its frame is colliding with another, it first makes sure to transmit a 32-bit jamming sequence and then stops transmission.
  - Thus, a transmitter 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



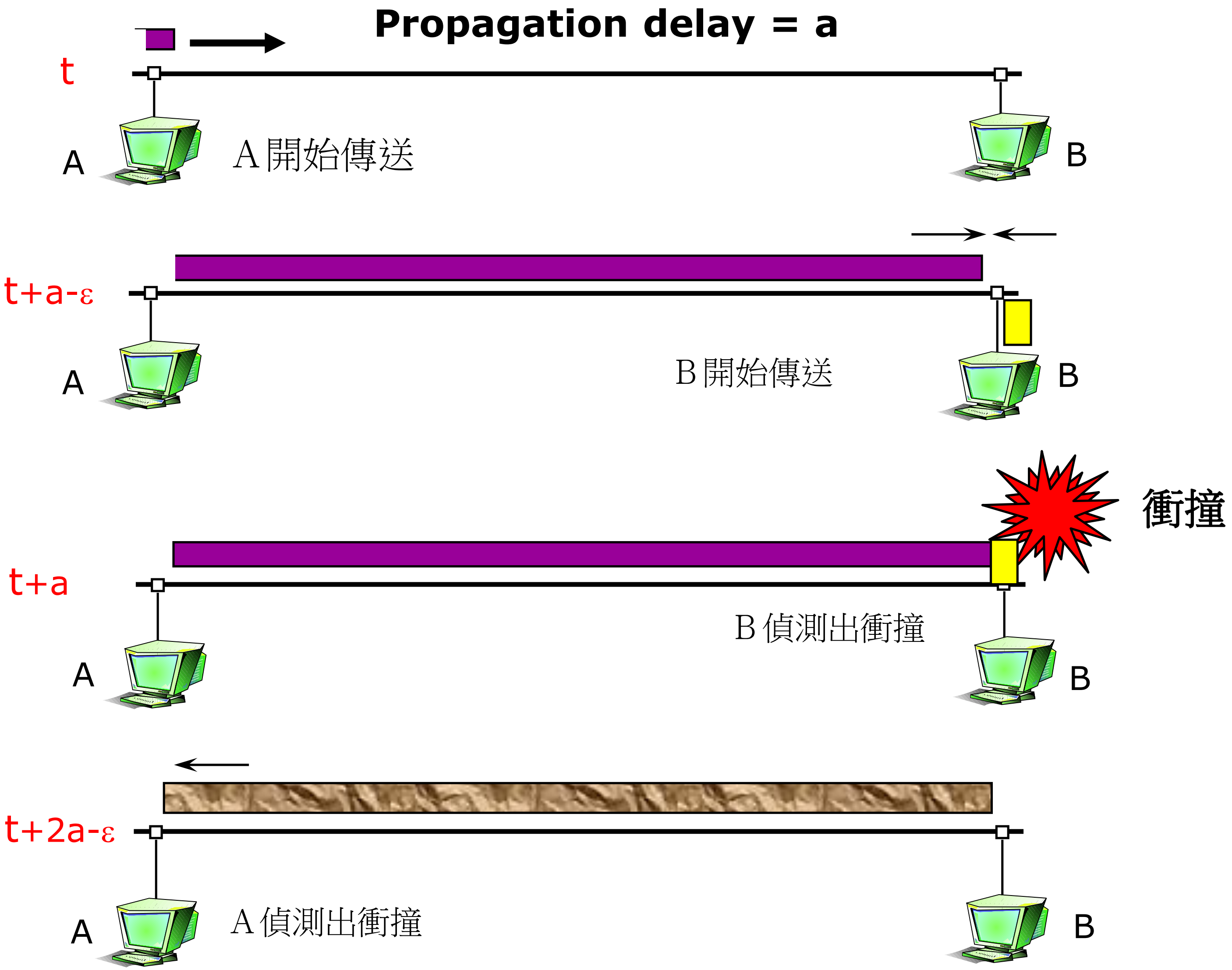
Preamble	SFD	DA	SA	Type	LLC	PAD	FCS	
7	1	6	6	2			4	bytes

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)


Propagation delay = a
t
A
A開始傳送
B
t+a-ε
A
B開始傳送
B
衝撞
t+a
A
B偵測出衝撞
B
t+2a-ε
A
A偵測出衝撞
B

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 µs
  - Which on 10 Mbps Ethernet corresponds to 512 bits
  - 10 Mbps x 51.2 µs = 512 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 µs) 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.
- 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… $2^3 - 1$ (again selected at random).
- In general, the algorithm randomly selects a *k* between 0 and $2^n - 1$ and waits for *k* * 51.2 μs, where *n* is the number of collisions experienced so far.

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

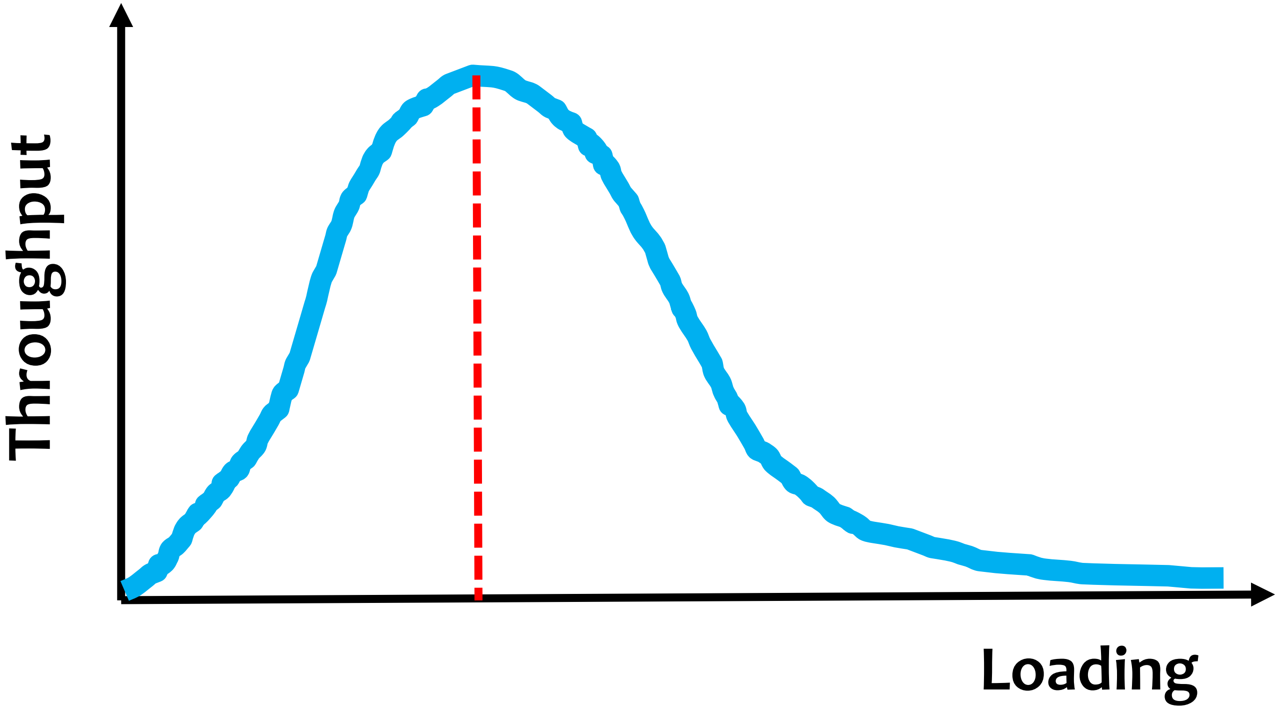
- Collision Signal is generated by Physical layer.
- Jam signal (collision enforcement): To make sure that all stations involved in the collision will detect collision. A pattern of 32 bits.
- Collision backoff and retransmission method (Truncated Binary Exponential Backoff Algorithm, BEBA):
  - n :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

CSMA/CD Collision Handling

- Slot time = 51.2 us.
- Disadvantage of BEBA:
  - 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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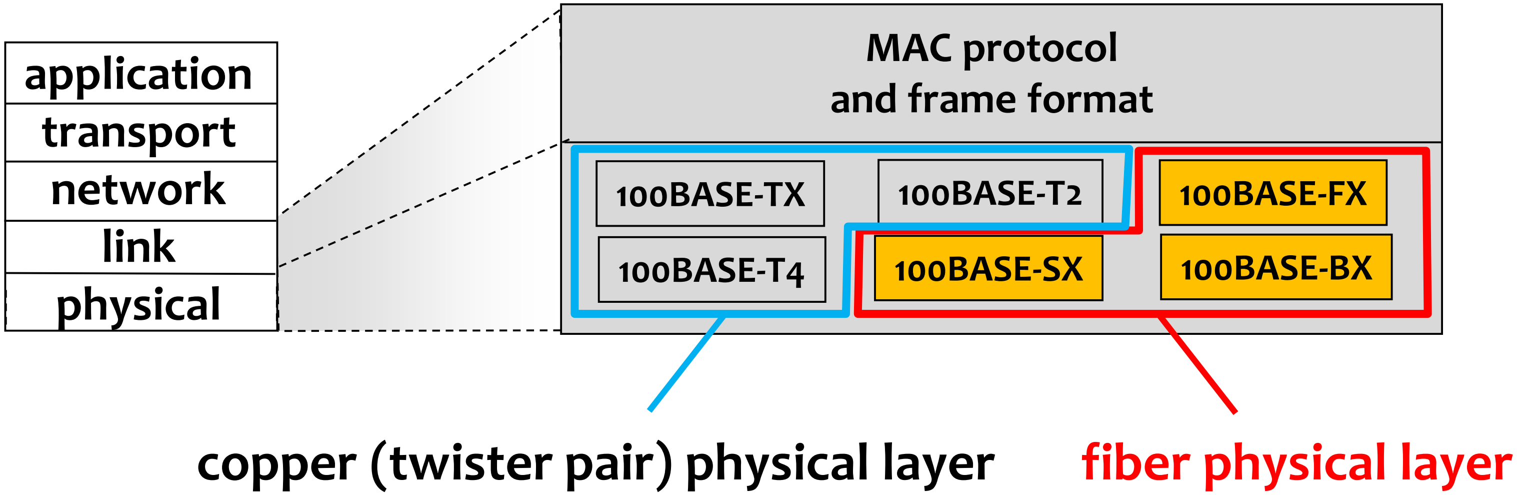
802.3 Ethernet Standards: Link & Physical Layers

- *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


application
transport
network
link
physical
MAC protocol
and frame format
100BASE-TX
100BASE-T2
100BASE-FX
100BASE-T4
100BASE-SX
100BASE-BX
copper (twister pair) physical layer
fiber physical layer

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)