Chapter 4
The Medium Access Control Sublayer

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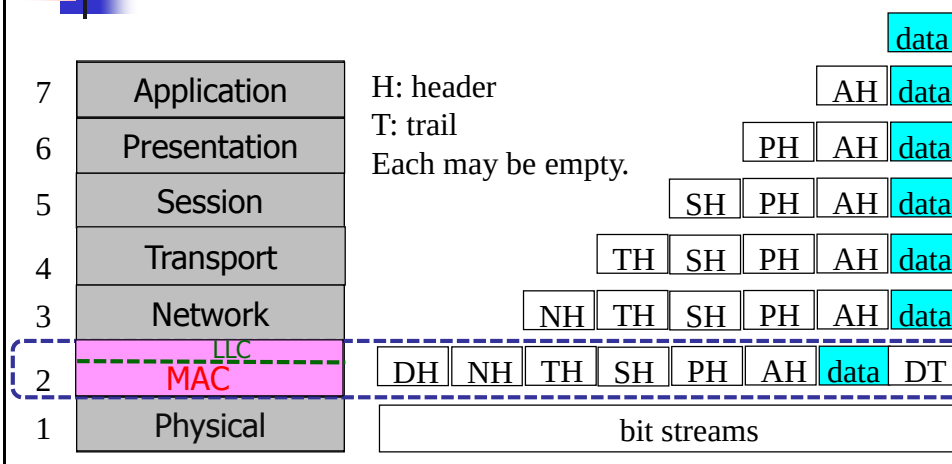
Adapted from Computer Networks,
Andrew S. Tanenbaum, Vrije University, Netherlands
& Computer Networking: A Top Down Approach,
Jim Kurose, Keith Ross

The Medium Access Control Sublayer

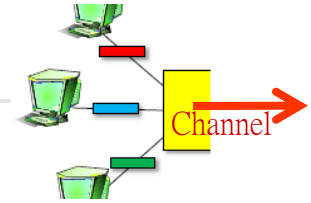


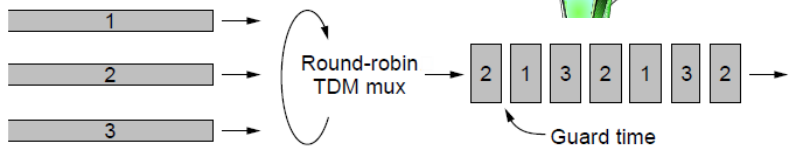
OSI Reference Model

The Channel Allocation Problem

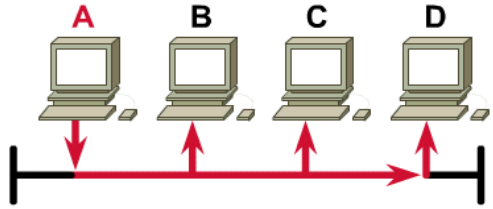
- Static Channel Allocation

e.g., static TDM





- Dynamic Channel Allocation



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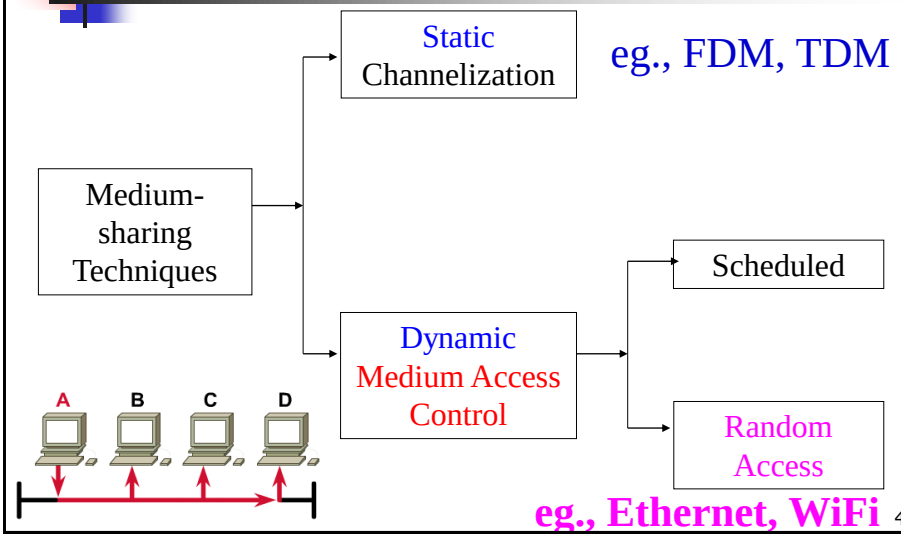
The Channel Allocation Problem



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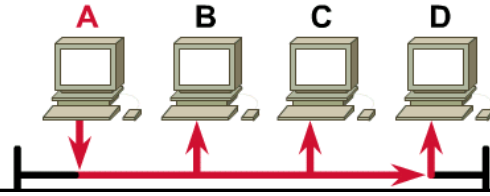
Assumptions for Dynamic Channel Allocation

1. Independent traffic: *N* independent stations (terminals, nodes)
2. Single channel (link)
3. Observable Collisions
4. Continuous or slotted time
5. Carrier sense or no carrier sense



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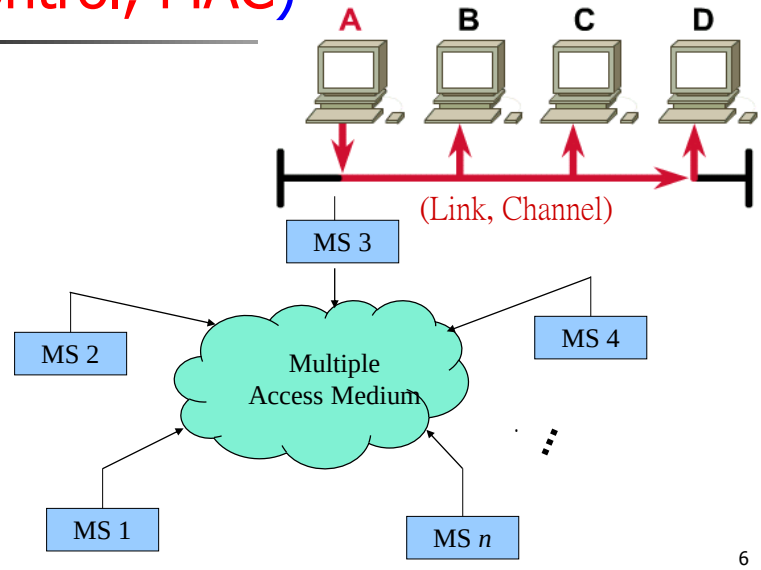
Multiple access (Medium Access Control, MAC)



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Why do we need MAC?

Contention and Collision Avoidance !

Why Do We Need MAC?

Fairness !!!

Multiple Access Protocols (Random Access)

- ALOHA
- Carrier Sense Multiple Access
- Collision-free protocols
- Limited-contention protocols
- Wireless LAN protocols

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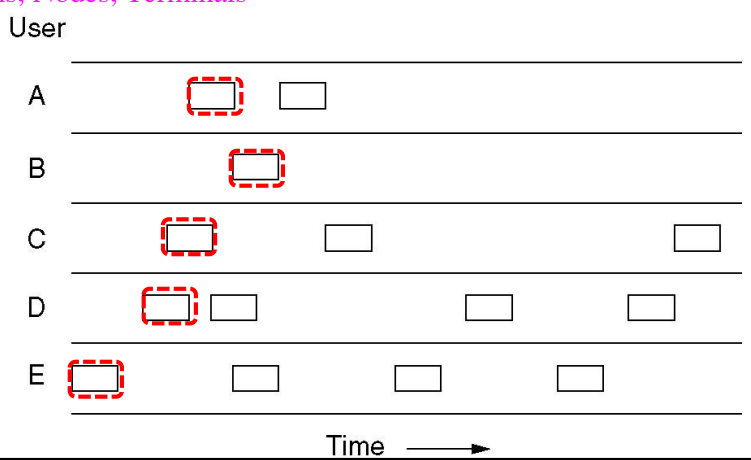
ALOHA (in the 1970s)

In pure ALOHA, frames are transmitted at completely arbitrary times.

Stations, Nodes, Terminals



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Hawaii

- Honolulu

http://www.punjabigraphics.com/images/155/Aloha-Colorful-Flowers-Picture.jpg

http://a.abcnews.com/images/Travel/GTY_hawaii_kab_140620_12x5_1600.jpg

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The **ALOHA** packet radio system

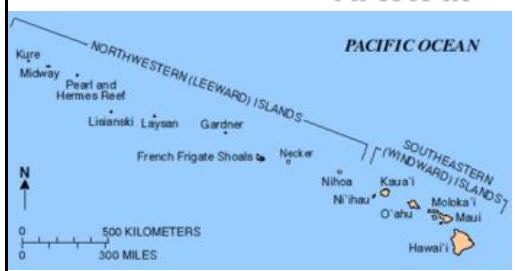
Kauai

Oahu

檀香山(Honolulu)

Maui

HAWAII



Hawaii

https://www.technologyuk.net/telecommunications/networks/images/aloha.gif

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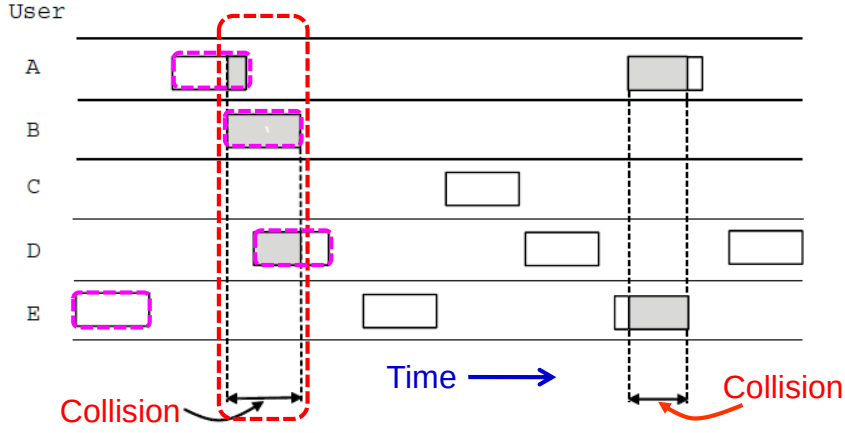
ALOHA (1)

Stations, Nodes, Terminals



In pure ALOHA, frames are transmitted at completely arbitrary times

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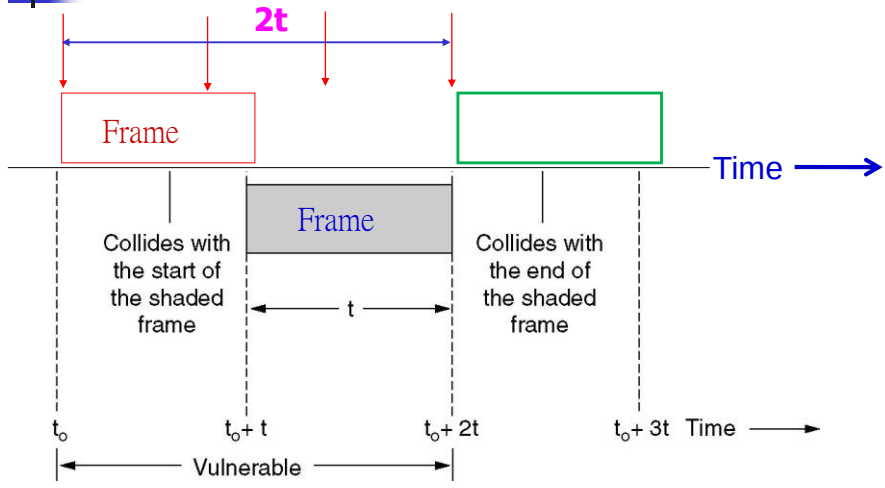
ALOHA (2): Performance

Vulnerable period (**2t**) for the shaded frame



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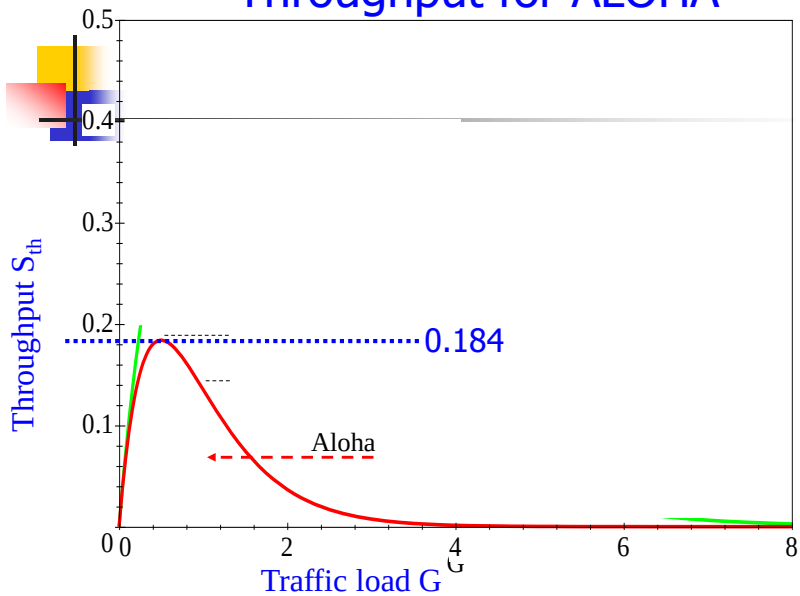
Throughput for ALOHA



- Max. throughput for ALOHA S_{th} = 0.184 at G = ½

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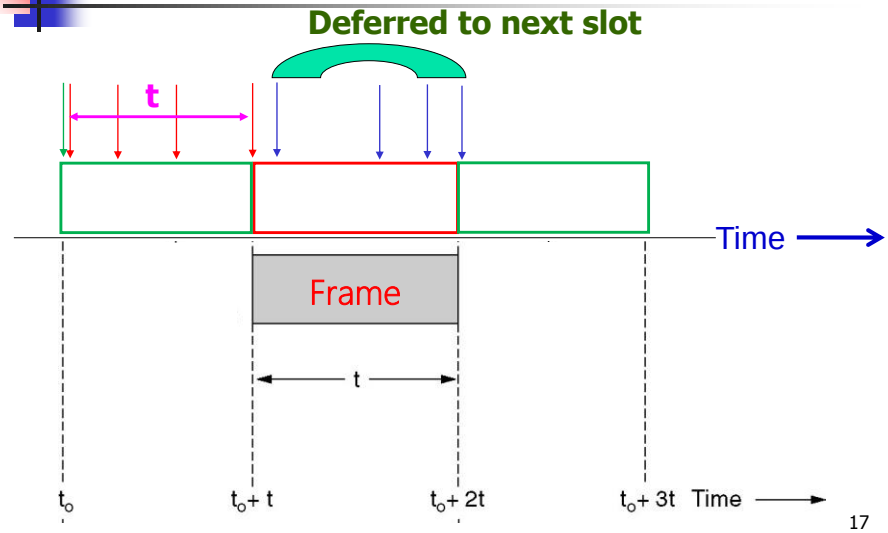
Slotted ALOHA: Performance

Vulnerable period (**t**) for the shaded frame.



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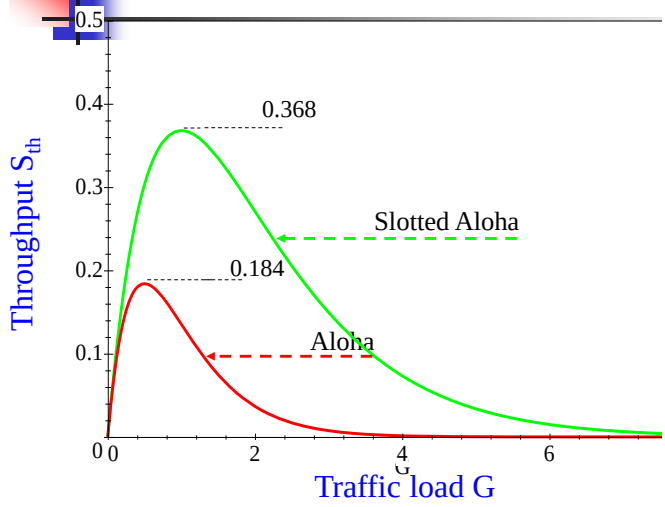
Comparison of Throughputs for ALOHA and Slotted ALOHA



- Max. throughput for ALOHA (A) S_{th} = 0.184 at G = ½
- Max. throughput for Slotted ALOHA (SA) S_{th} = 0.368 at G = 1
- Notice that S_{th} for SA is exactly 2 x bigger than S_{th} for A
  - Hypothesis: bec. max. duration of a collision for SA (=2T) is 2 x smaller than for A (=T)

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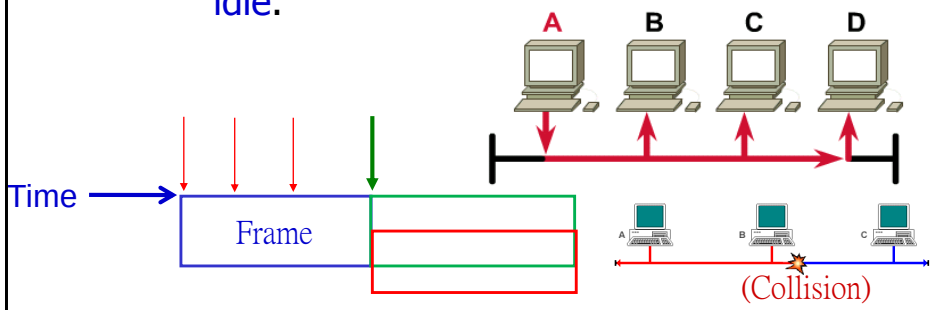
Carrier Sense Multiple Access (CSMA)

- 1-persistent CSMA
  - Listen before transmit: If the channel is busy, the station waits until it becomes idle.



  - If channel sensed idle: transmit entire frame

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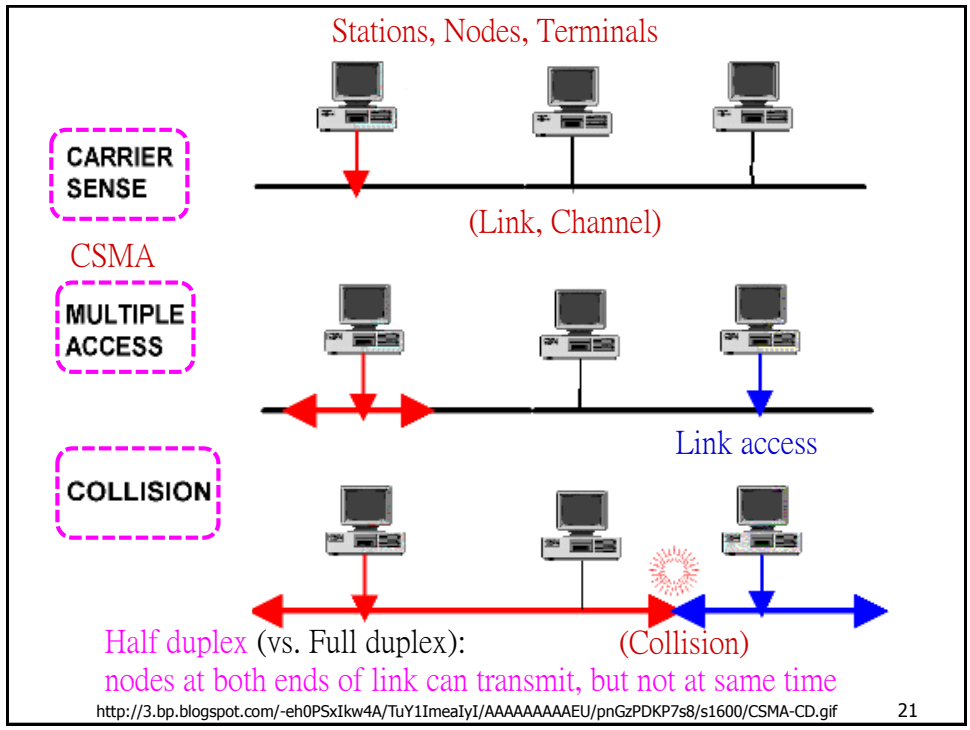
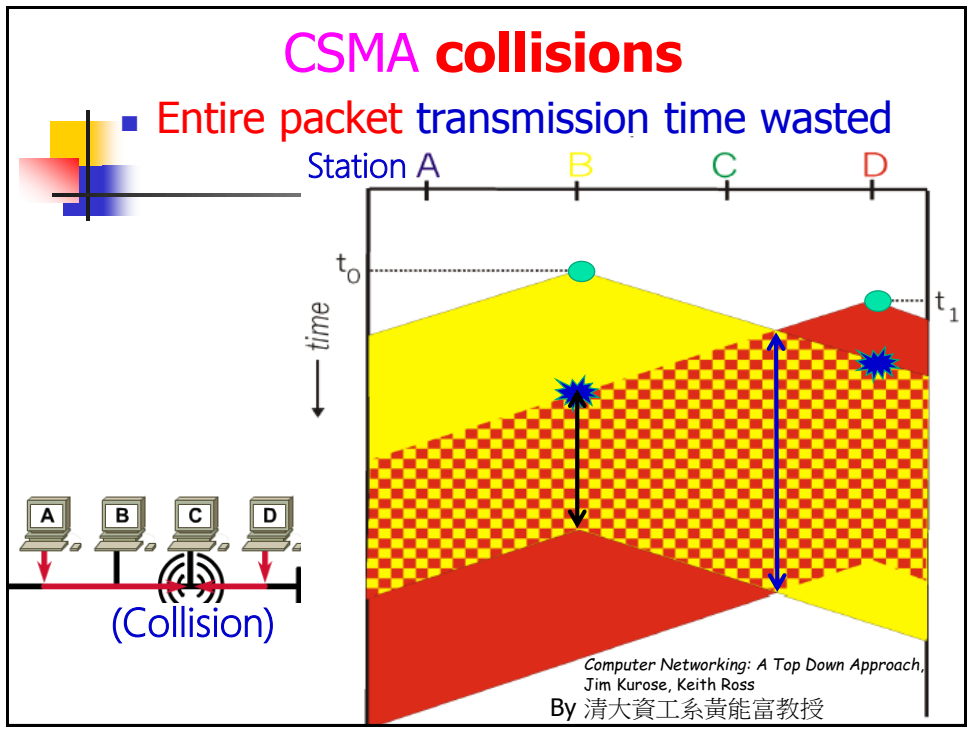
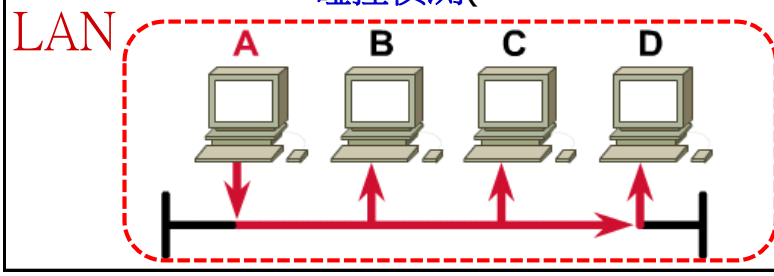

Stations, Nodes, Terminals
CARRIER SENSE
(Link, Channel)
CSMA
MULTIPLE ACCESS
Link access
COLLISION
Half duplex (vs. Full duplex):
(Collision)
nodes at both ends of link can transmit, but not at same time
http://3.bp.blogspot.com/-eh0PSxIkw4A/TuY1ImeaIyI/AAAAAAAAAEU/pnGzPDKP7s8/s1600/CSMA-CD.gif
21


CSMA collisions
Entire packet transmission time wasted
Station A
B
C
D
t_0
t_1
time
A
B
C
D
(Collision)
Computer Networking: A Top Down Approach,
Jim Kurose, Keith Ross
By 清大資工系黃能富教授

Ethernet MAC Sublayer Protocol (2)

- Ethernet(乙太網路): LAN
  - 廣播式傳輸(Broadcasting) Half duplex
  - No centralized control
    - distributed algorithm
  - 採用CSMA/CD技術：
    - 載波感測(Carrier Sense)
    - 碰撞偵測(Collision Detection)



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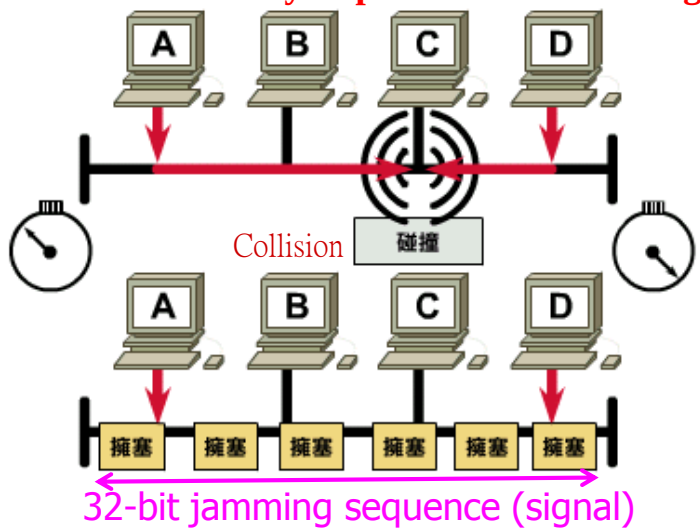
Ethernet MAC Sublayer Protocol (3)

- 碰撞(collide)

BEBA:
Binary Exponential Backoff Algorithm



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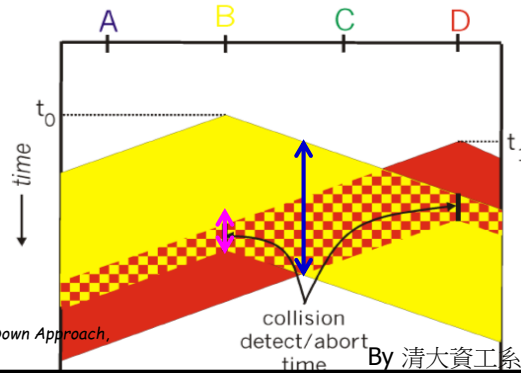
CSMA with Collision Detection (CSMA/CD)

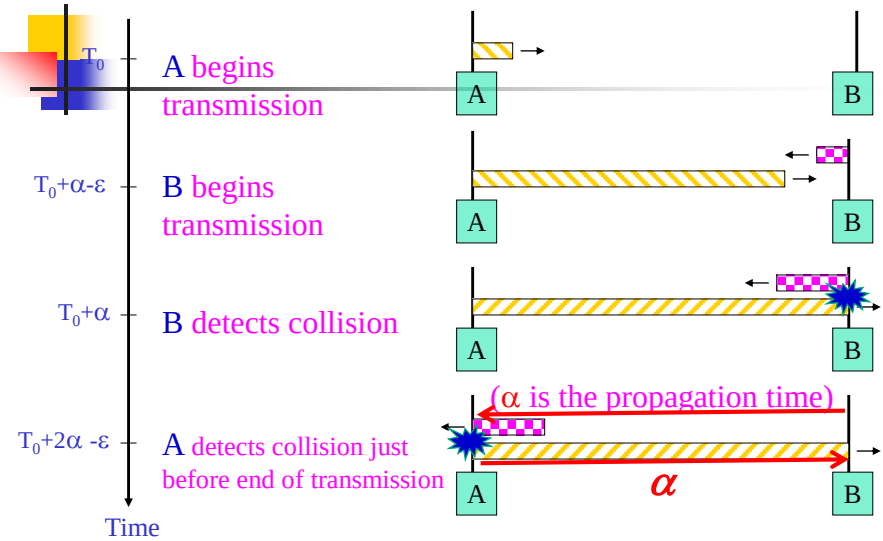
- collisions detected within short time
- colliding transmissions aborted, reducing channel wastage



32-bit Jamming signal

Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross

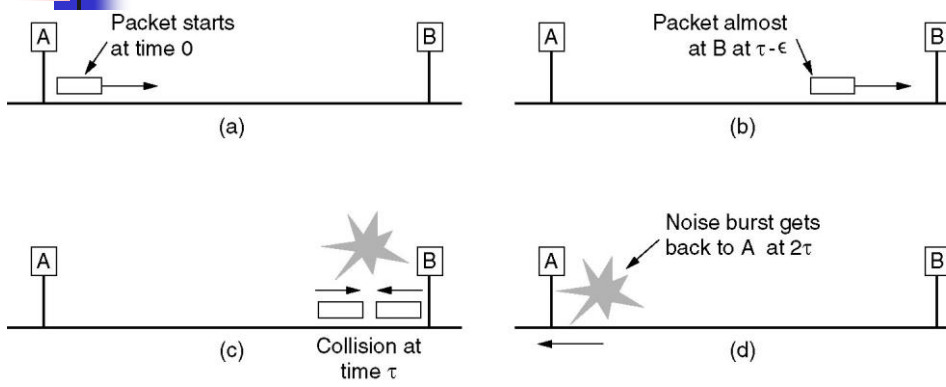
CSMA/CD (Cont'd)



Collision Window = round-trip delay (2α) (2τ)
(Slot time)

Ethernet MAC Sublayer Protocol (4)

The two hosts are at opposite ends of the Ethernet.



Collision detection can take as long as 2τ.

Collision Window = round-trip delay (2α) (2τ)
(Slot time)

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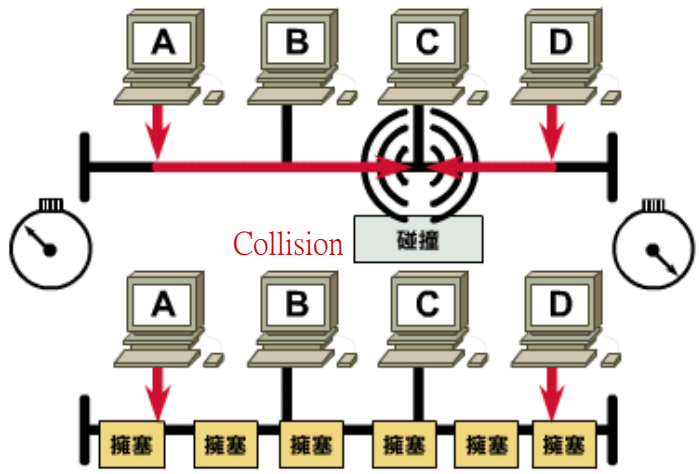
Binary Exponential Backoff Algorithm

BEBA



32-bit jamming sequence (signal)

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Binary Exponential Backoff Algorithm

- First collision: selects either 0 or 1 collision window (2α) at random for delay . (Slot time)
- Second collision: waits 0, 1, 2, or 3 collision windows (selected randomly) before trying again (This is k* (2α) for k= 0, 1, 2, 3 slots)
- …
- 10th collision: randomly selects a k between 0 and $2^{10}-1$ (k = 0, 1, 2, …, 1023 slots)
- …
- 16th collision: randomly selects a k between 0 and $2^{10}-1$ (k = 0, 1, 2, …, 1023 slots)

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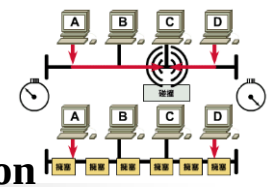
CSMA/CD Protocol



- 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.

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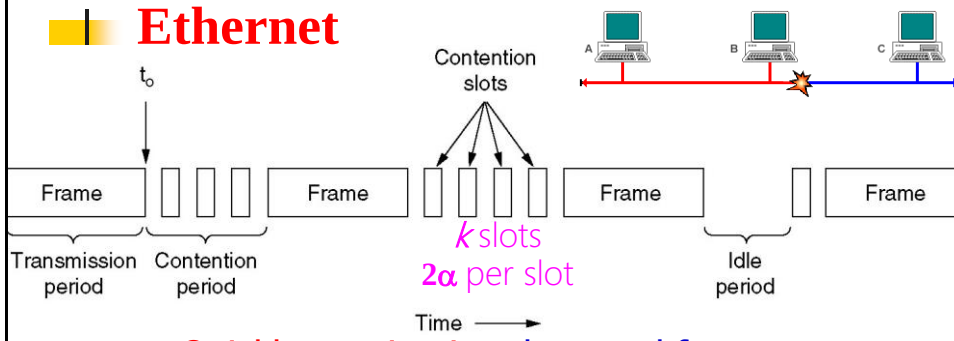
CSMA with Collision Detection

Ethernet



1. Quickly terminating damaged frames saves time and bandwidth.
2. CSMA/CD can be in one of three states: contention, transmission, or idle.
3. Collision window = slot time = 2τ (2α)
4. Half duplex

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Ethernet (IEEE 802.3) (using CSMA/CD)

- Physical layer (Manchester Encoding)
- MAC sublayer protocol
- Ethernet performance
- Fast Ethernet
- Gigabit Ethernet
- 10 Gigabit Ethernet
- IEEE 802.2: Logical Link Control
- Retrospective on Ethernet

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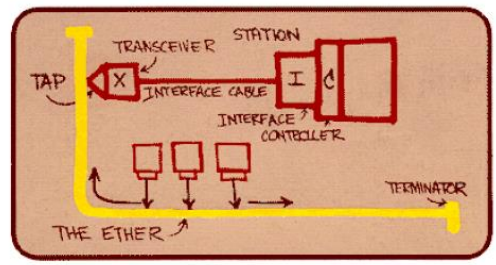
Ethernet (IEEE 802.3)

- 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

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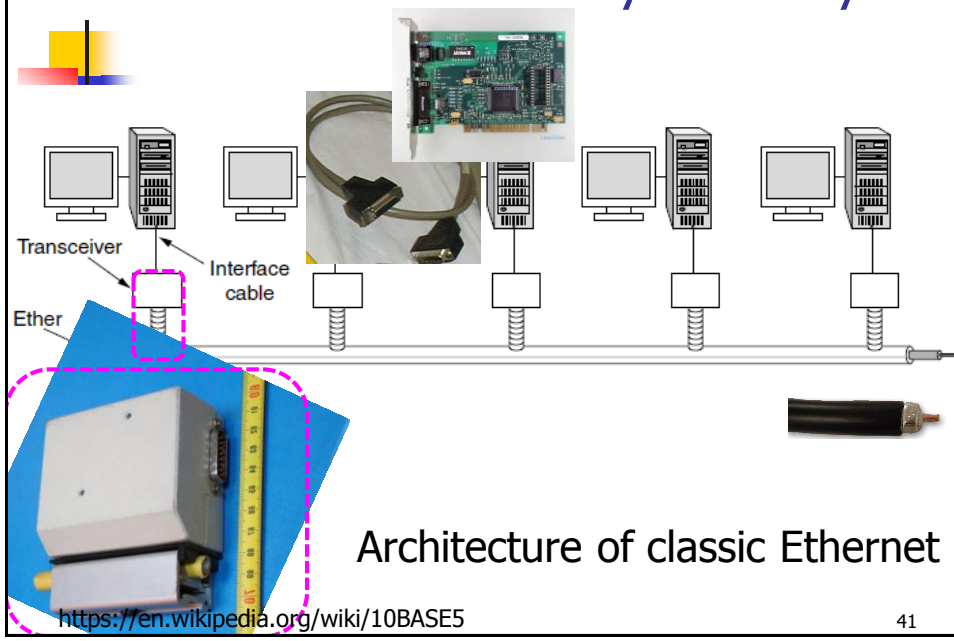
Classic Ethernet Physical Layer



Architecture of classic Ethernet

https://en.wikipedia.org/wiki/10BASE5

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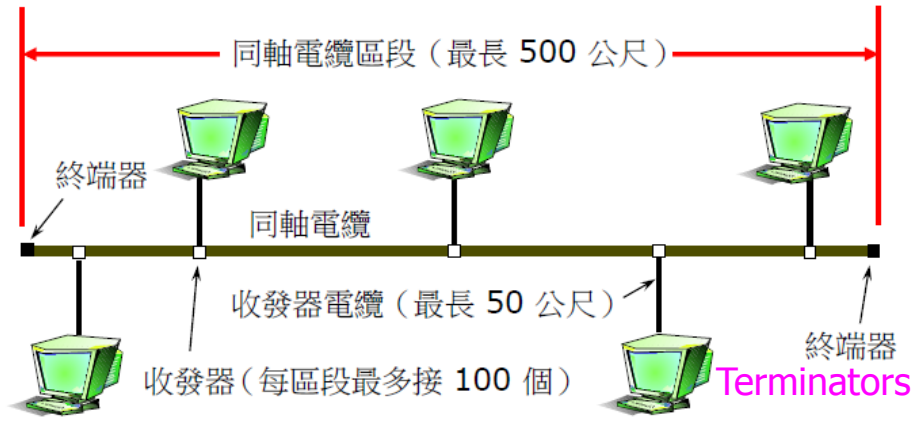
Ethernet (10Base5)

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

Broadcast(廣播)



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Ethernet (IEEE 802.3)

- DEC, Intel, and Xerox (DIX): 10Mbps Ethernet in 1978
- Standard: IEEE 802.3
- 100Mbps version: Fast Ethernet
- 1000Mbps version: Gigabit Ethernet
- 10 Gigabit Ethernet
- 100 Gigabit Ethernet
- Connectionless & Unreliable

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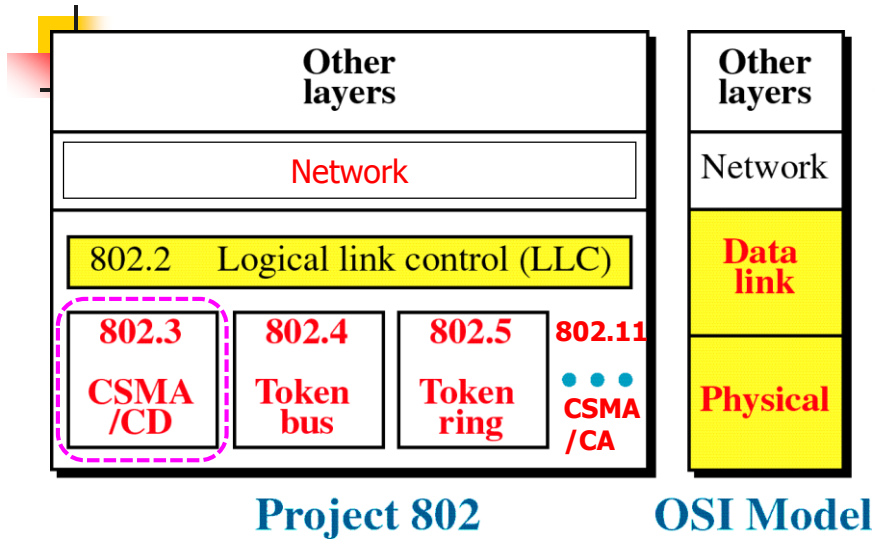
IEEE Project 802



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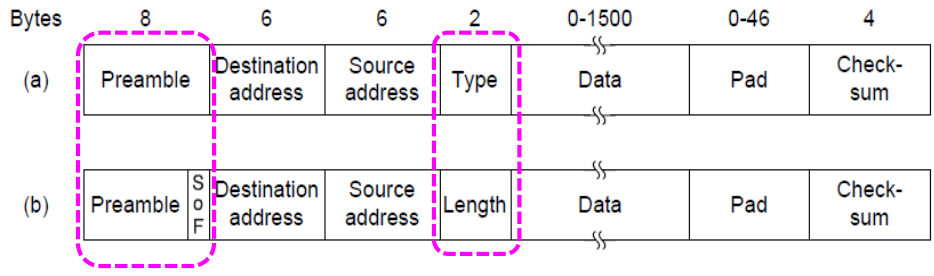
MAC Sublayer Protocol (1)



Frame formats. (a) Ethernet (DIX)
(b) IEEE 802.3

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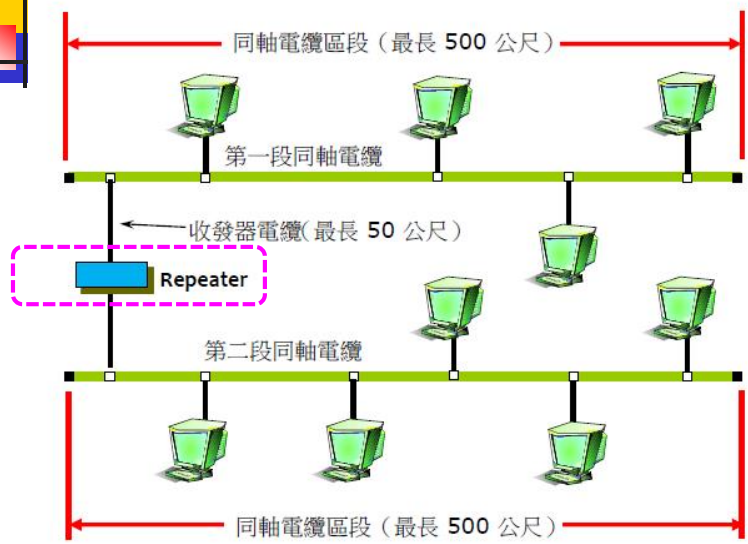
Two segments via a repeater

A *repeater* is a device that forwards digital signals



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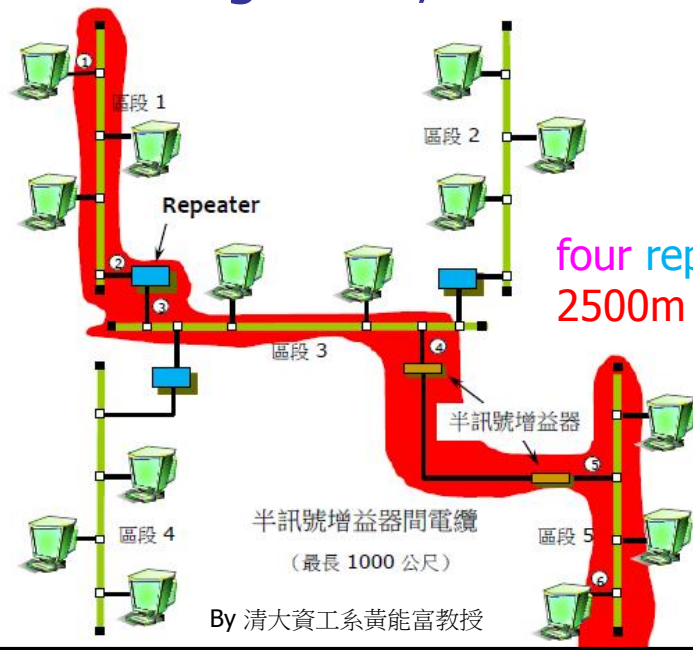
Five segments, maximum



four repeaters
2500m = 2.5km

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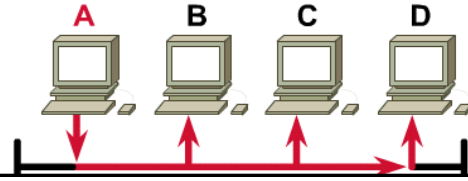
Collision Window

Collision Window = round-trip delay (2α) (2τ)

Consider that a maximally configured 10 Mbps Ethernet is 2500 m long, and there may be up to four repeaters between any two hosts, the round trip delay (2α) has been determined to be 51.2 us (512 bit time)

- **10 Mbps x 51.2 us = 512 bits = 64 bytes**
- **Minimal frame size** = 64 bytes to distinguish from **collision**



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Ethernet MAC Sublayer Protocol (5)

- 偵測碰撞(collision detection) (512 bit time)
  1. RTT(Round Trip Time) < **51.2*us*** (2α)
  2. Frame(訊框)大小 >= 64 bytes
     以10Mbps計算
     $10^7 \times 51.2 \times 10^{-6} = 512$ bits = 64 bytes
  3. Frame(訊框)大小 <= 1518 bytes
     為免某工作站佔用傳輸媒介太久(公平)
  3. 網路最大長度約2500公尺

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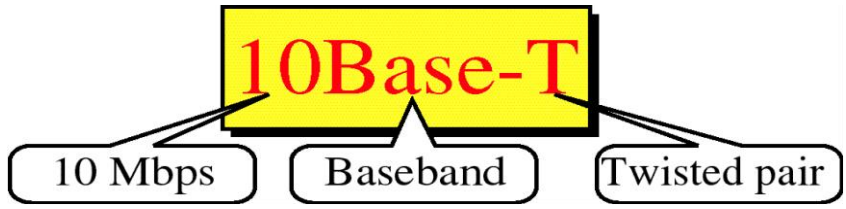
Ethernet Cabling

The most common kinds of Ethernet cabling.

Name	Cable	Max. seg.	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Original cable; now obsolete
10Base2	Thin coax	185 m	30	No hub needed
10Base-T	Twisted pair	100 m	1024	Cheapest system
10Base-F	Fiber optics	2000 m	1024	Best between buildings



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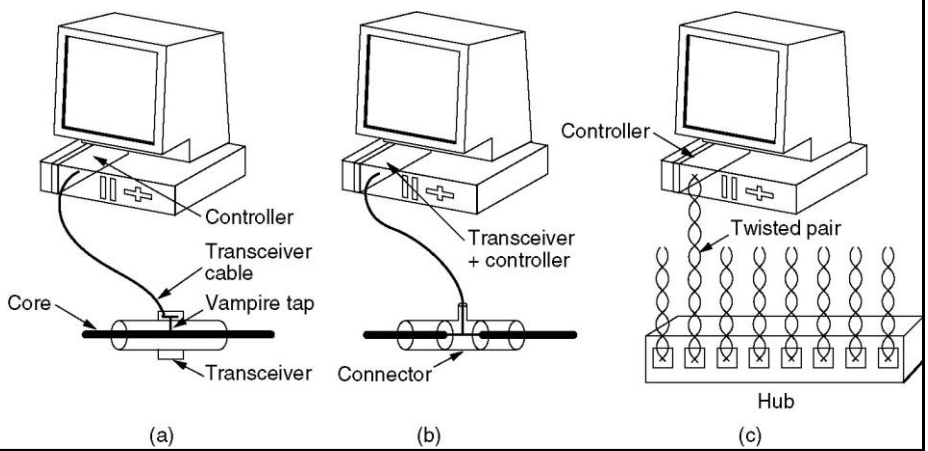
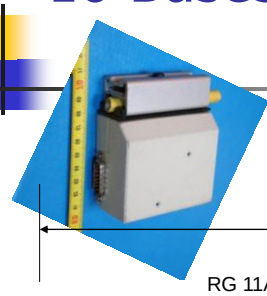
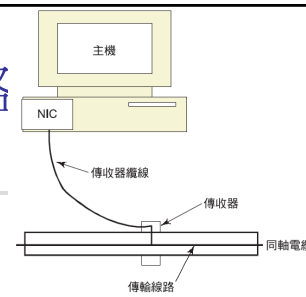
Ethernet Cabling (2)

Three kinds of Ethernet cabling.
(a) 10Base5, (b) 10Base2, (c) 10Base-T.



10 Base5 乙太網路





最長 500 公尺

RG 11A/U 同軸電纜

50 歐姆
終端電阻

收發器
[Transceiver]

收發器
[Transceiver]

收發器
[Transceiver]

50 歐姆
終端電阻

最多 100 部電腦

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10 Base2 Ethernet

最長 185 公尺

Bus Topology(匯流排拓樸)

RG 58A/U 同軸電纜

50 歐姆
終端電阻

50 歐姆
終端電阻

最多 30 部電腦

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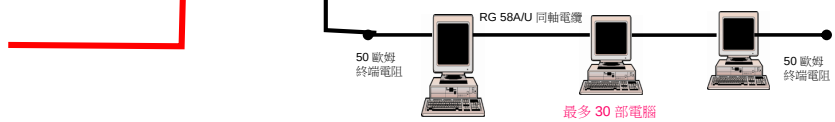
Repeater(中繼器)

A *repeater* is a device that forwards digital signals

這台中繼器正面具有光纖和 BNC 接頭

翻到背面, 則可看到 2 個 RJ-45 接頭



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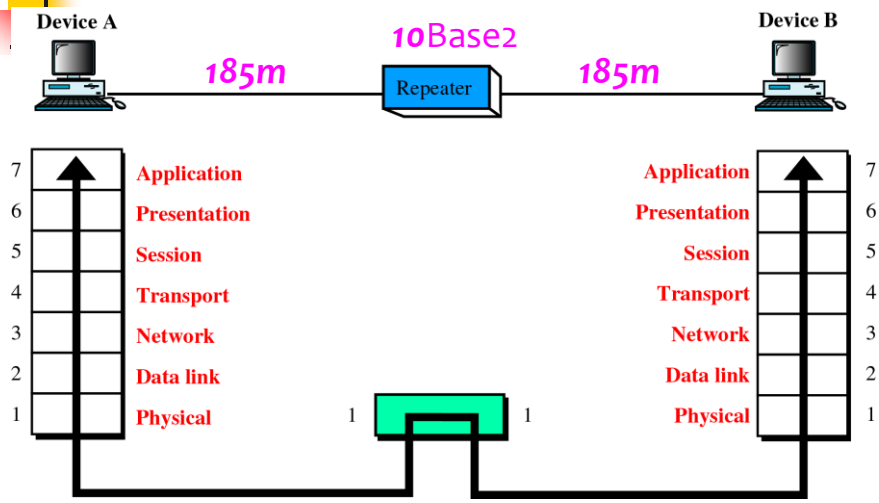
A Repeater: Layer 1 device



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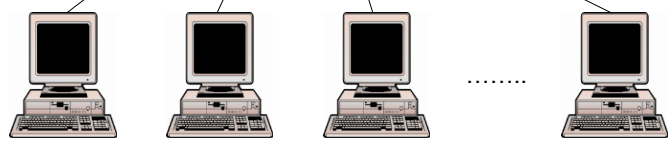
10 BaseT Ethernet

Hub (a multiway repeater)

UTP 線

最長 100 公尺



Star Topology(星狀拓樸)

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集線器(Hub):

- 延長通訊距離
- 多台主機或網路設備之連通
- Layer 1設備，不具MAC位址過濾能力➔本設備所連接網路屬相同碰撞領域(Collision Domain)及相同廣播領域(Broadcast Domain)
- 常見於公司小部門或學校電腦教室之內部網路

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Ethernet MAC Sublayer Protocol (6)

- **碰撞**領域(Collision Domain)
  - 僅由第一層設備所連結之網路屬相同**碰撞**領域。
  - 頻寬由此領域所有節點分享(同一時間只有一個節點會成功傳送資料)
  - 10Mbps Ethernet同一碰撞領域任兩節點距離需<2500公尺, 若所接集線器較多，則距離更應縮短。Hub會有延遲，故以51.2 us為訊號來回時間為考量。
  - 若是100Mbps Fast-Ethernet，同一碰撞領域任兩節點距離需<250公尺

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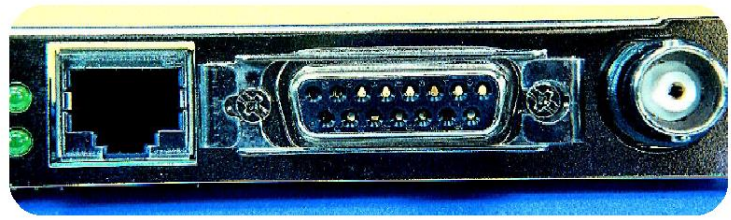
3 合 1 網路卡

- 這種網路卡具有 3 種接頭, 可接 3種纜線, 因此稱為 **3合1** 網路卡。



10BaseT (RJ-45) **10Base5 (AUI)** **10Base2 (BNC)**

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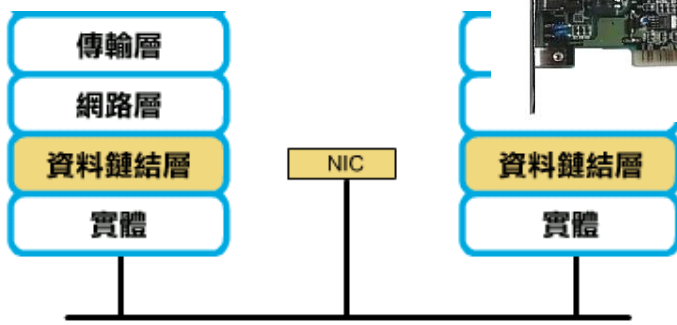
網路介面卡 Adaptor (network interface card, NIC):

- 每張網路卡都有一個唯一的硬體位址，叫做MAC位址



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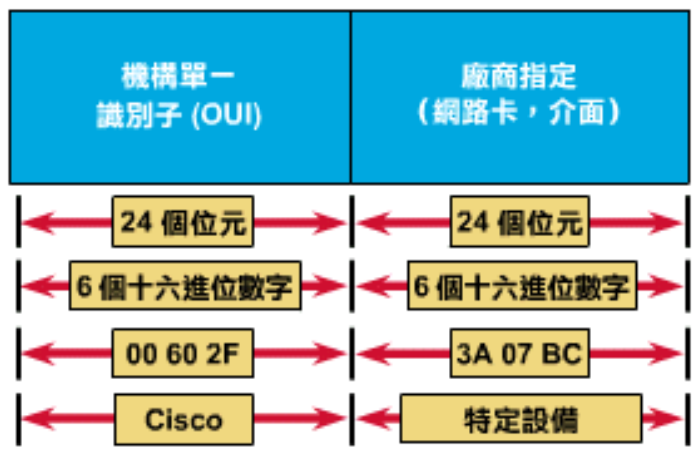
MAC位址格式

- 由IEEE 管制OUI (MAC Prefix)



00:60:2F:3A:07:BC

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My IP/ MAC Address/ DNS

- Win 9x/Me
  - winipcfg.exe
- Win NT/Server/XP/7/8/10
  - ipconfig /all
- Linux
  - ifconfig -a
- Solaris
  - Arp
  - Netstat -p

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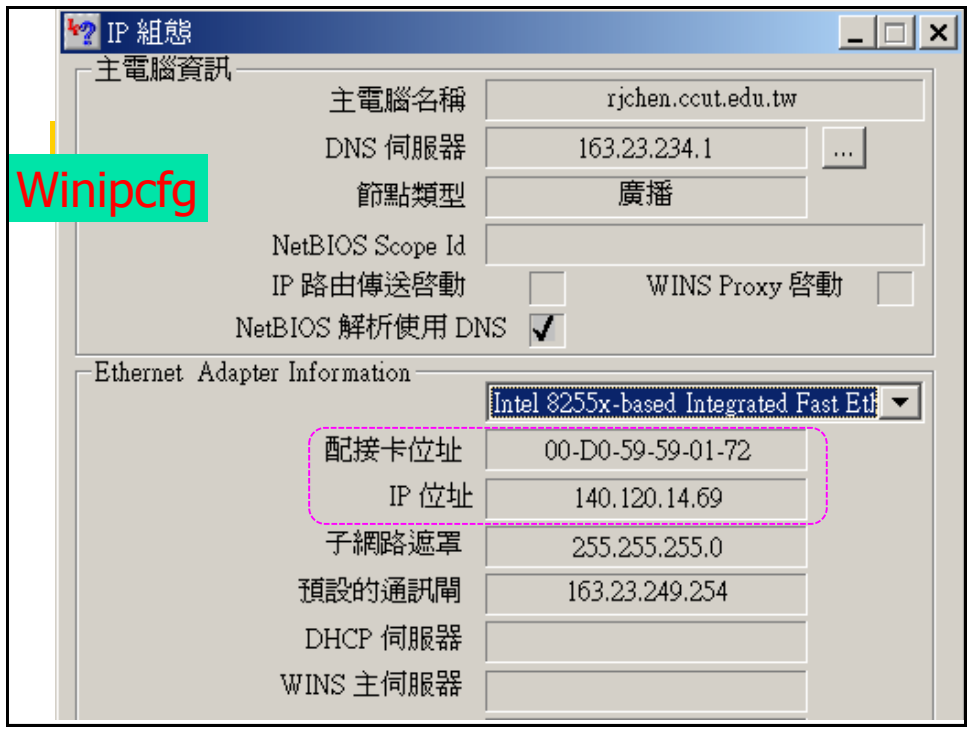

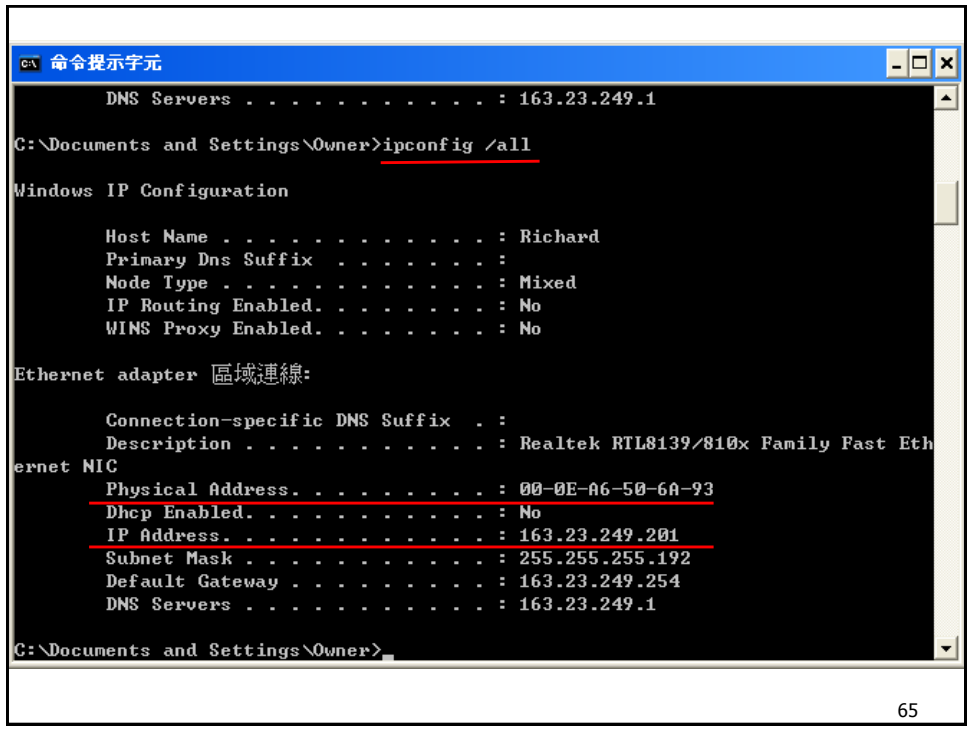
命令提示字元
DNS Servers . . . . . : 163.23.249.1
C:\Documents and Settings\Owner>ipconfig /all
Windows IP Configuration
Host Name . . . . . : Richard
Primary Dns Suffix . . . . . :
Node Type . . . . . : Mixed
IP Routing Enabled. . . . . : No
WINS Proxy Enabled. . . . . : No
Ethernet adapter 區域連線:
Connection-specific DNS Suffix . :
Description . . . . . : Realtek RTL8139/810x Family Fast Ethernet NIC
Physical Address. . . . . : 00-0E-A6-50-6A-93
Dhcp Enabled. . . . . : No
IP Address. . . . . : 163.23.249.201
Subnet Mask . . . . . : 255.255.255.192
Default Gateway . . . . . : 163.23.249.254
DNS Servers . . . . . : 163.23.249.1
C:\Documents and Settings\Owner>

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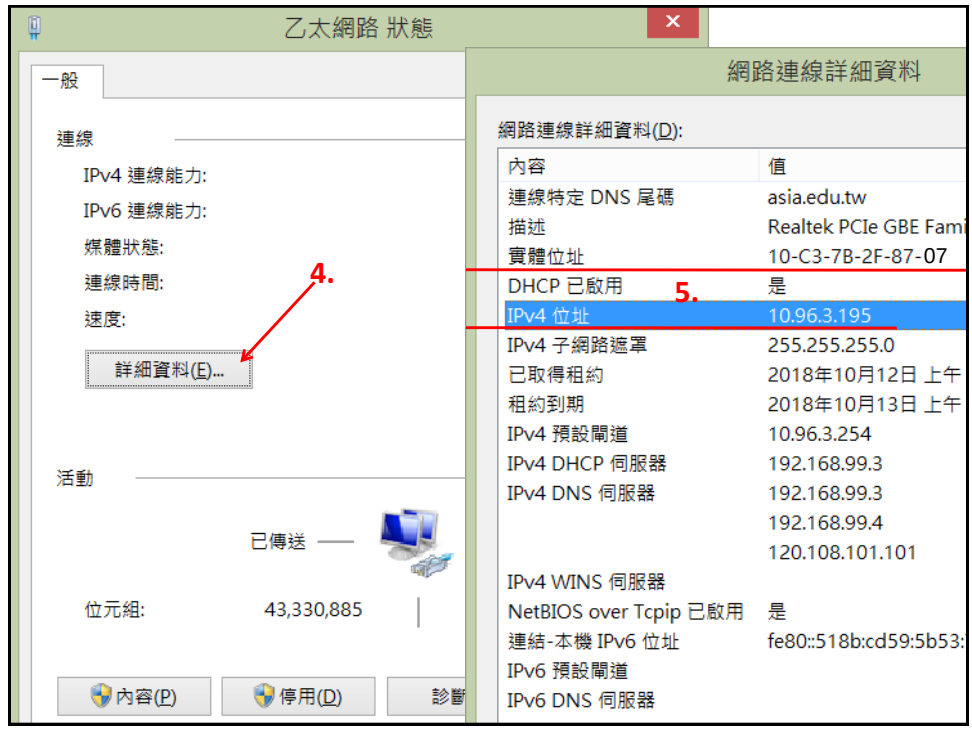
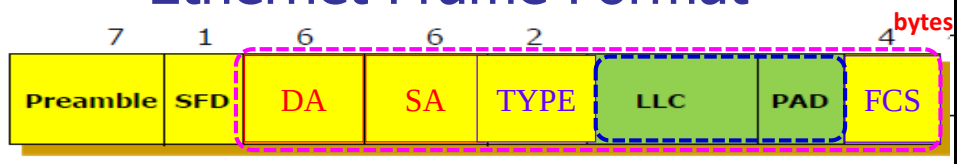
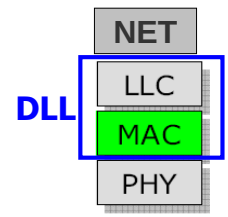
控制台 ▸ 所有控制台項目 ▸ 網路和共用中心
搜尋控制台
檢視你基本的網路資訊並設定連線
查詢電腦IP/MAC
的另一個方法
私人網路
存取類型: 網際網路
HomeGroup: 已加入
連線: 乙太網路
3. 點選Ethernet
或區域網路
變更網路設定
設定新的連線或網路
設定寬頻、撥號或 VPN 連線，或設定路由器或存取點。
疑難排解問題
診斷與修復網路問題，或取得疑難排解資訊。
2. 點選網路設定
1. 網路圖示按滑鼠右鍵
疑難排解問題
開啟網路和共用中心
2018/10/12



Ethernet Frame Format



- Preamble: (101010...1010) for Synchronization
- SFD: Start Frame Delimiter (10101011)
- DA: Destination MAC Address
- SA: Source MAC Address
- Packet type (16bits): 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



46≤LLC≤1500

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Ethernet Addresses

- **Unicast address: each adaptor recognizes those frames addressed to its address 00:60:2F:3A:07:BC**
- **Broadcast address: an Ethernet address consisting of all 1s, e.g., ff:ff:ff:ff:ff:ff**
- **Multicast address has the first bit set to 1, e.g., f0:05:7a:8b:00:13**

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802.3 Ethernet Standards

代碼	IEEE 規格標準	標準通過年份	頻寬	使用線材
10 Base5	802.3	1983	10 Mbps	粗同軸電纜
10 Base2	802.3a	1988	10 Mbps	細同軸電纜
10 BaseT	802.3i	1990	10 Mbps	Category 3等級以上的 UTP 線
10 BaseF	802.3j	1992	10 Mbps	光纖
100 BaseTX	802.3u	1995	100 Mbps	Category 5等級以上的 UTP 線
100 BaseT4	802.3u	1995	100 Mbps	Category 3等級以上的 UTP 線

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100 Mbps Ethernet Spec.

項　　目	100BaseTX	100BaseT4	100BaseFX	100BaseT2
線　　材	雙絞線	雙絞線	光纖	雙絞線
接　　頭	RJ-45	RJ-45	ST、MIC、SC	RJ-45
區段最大長度	100 公尺	100 公尺	2/10 公里	100 公尺
拓　　樸	星狀	星狀	星狀	星狀

- SC：Subscriber Connector
- MIC：Medium-Interface Connector

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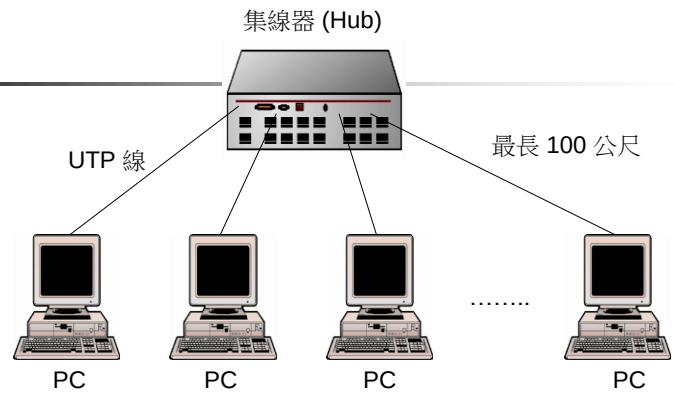
100 BaseTX Ethernet



所有的電腦最終都透過集線器與其它電腦相連，
而集線器到電腦的距離不得超過 100 公尺

- 若是100Mbps Fast-Ethernet，同一碰撞領域任兩節點距離需<250公尺

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Fast Ethernet

The original fast Ethernet cabling.

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

Gigabit Ethernet cabling.

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 μ) or multimode (50, 62.5 μ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

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1000 Mbps Ethernet Spec.

項　　目	1000BaseSX	1000BaseLX	1000BaseCX	1000BaseT
線　　材	光纖	光纖	STP	雙絞線
接　　頭	SC	SC	DB9	RJ-45
區段最大長度	550 公尺	5000 公尺	25 公尺	100 公尺
拓　　樸	星狀	星狀	星狀	星狀

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乙太網路家族一覽表 (二)

代碼	IEEE 規格標準	標準通過年份	頻寬	使用線材
100 BaseFX	802.3u	1995	100 Mbps	光纖
100 BaseT2	802.3y	1997	100 Mbps	Category 3等級以上的 UTP 線
1000 BaseSX	802.3z	1998	1000 Mbps	光纖
1000 BaseLX	802.3z	1998	1000 Mbps	光纖
1000 BaseCX	802.3z	1998	1000 Mbps	特殊電纜
1000 BaseT	802.3ab	1999	1000 Mbps	Category 5 以上等級的雙絞線
10G Base-SR等	802.3ae	2002	10 G bps	光纖

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10 Gigabit Ethernet

Name	Cable	Max. segment	Advantages
10GBase-SR	Fiber optics	Up to 300 m	Multimode fiber (0.85μ)
10GBase-LR	Fiber optics	10 km	Single-mode fiber (1.3μ)
10GBase-ER	Fiber optics	40 km	Single-mode fiber (1.5μ)
10GBase-CX4	4 Pairs of twinax	15 m	Twinaxial copper
10GBase-T	4 Pairs of UTP	100 m	Category 6a UTP

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10 Gigabit Ethernet

- 802.3ae 的特點是只使用光纖、只有點對點的連線、一律為全雙工傳輸，而且依應用場合，共有如下 7 種不同實體規格：

項目	10GBase-SR 10GBase-SW	10GBase-LX4	10GBase-LR 10GBase-LW	10GBase-ER 10GBase-EW
線材	多模光纖	單/多模光纖	單模光纖	單模光纖
最大距離	65 公尺	300 公尺	10 公里	40 公里

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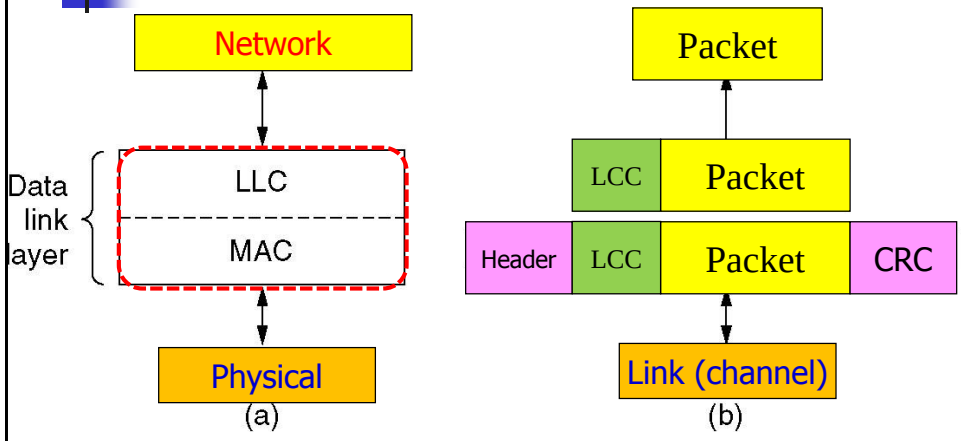
IEEE 802.2: Logical Link Control



(a) Position of LLC. (b) Protocol formats.

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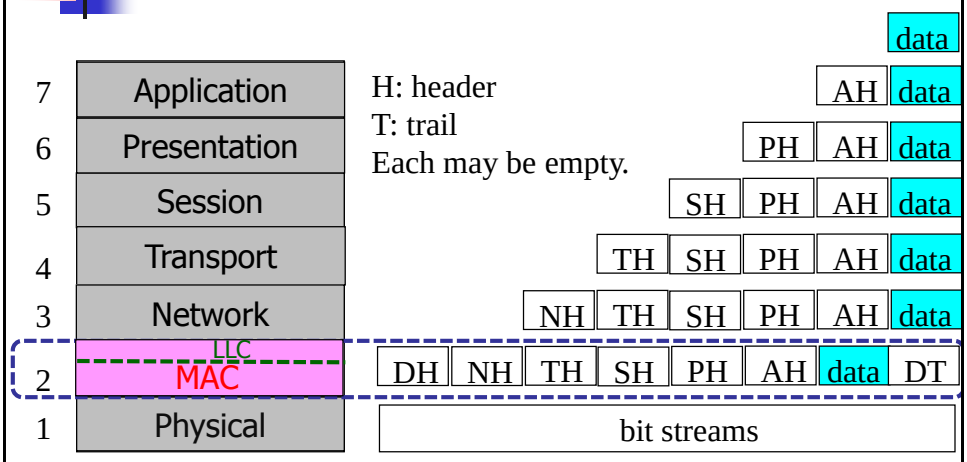
The Medium Access Control Sublayer



OSI Reference Model

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End of Chapter 4

Questions?

Thank you!