Chapter 5 - 2
Routers and Routing Protocols

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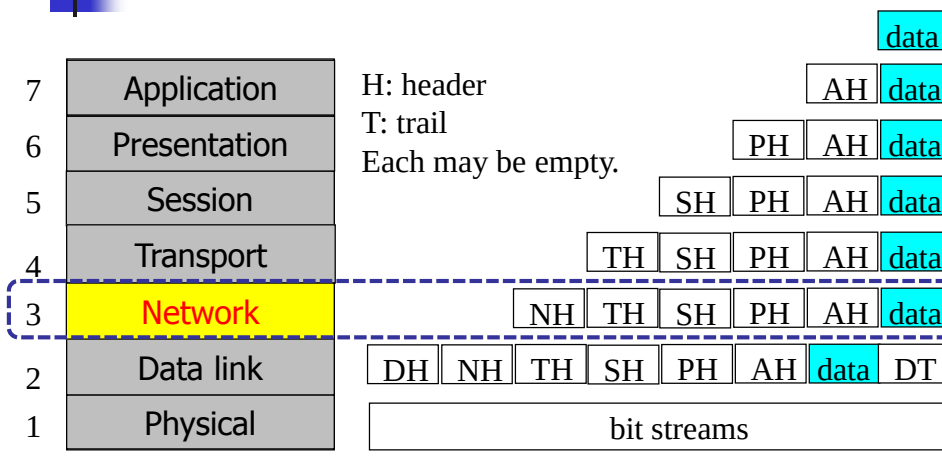
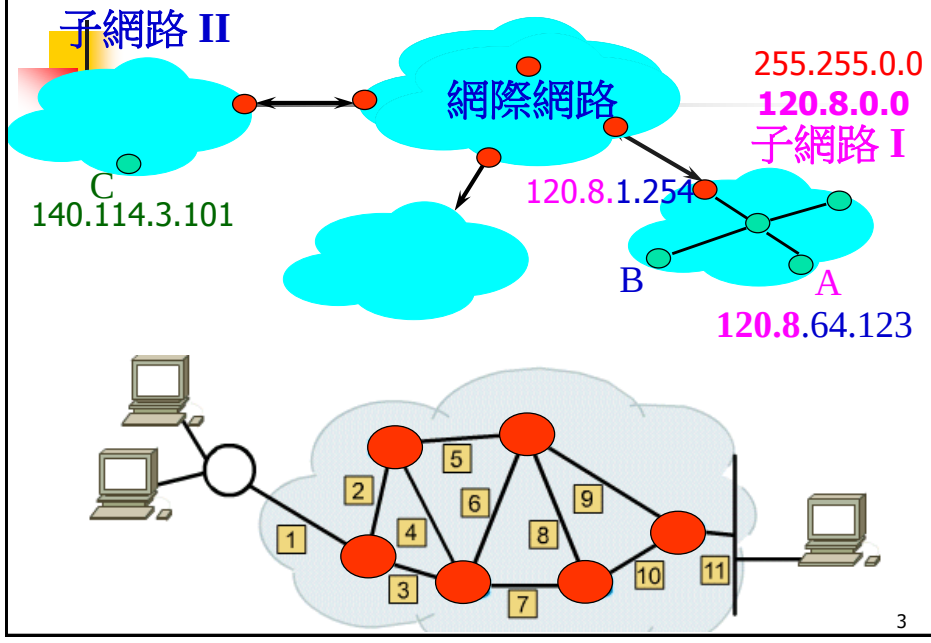
Adapted from Computer Networks,
Andrew S. Tanenbaum, Vrije University, Netherlands
& Computer Networking: A Top Down Approach,
Jim Kurose, Keith Ross
& Slides, Prof. Hwang, CSIE, NTHU, Taiwan

The Network Layer



OSI Reference Model

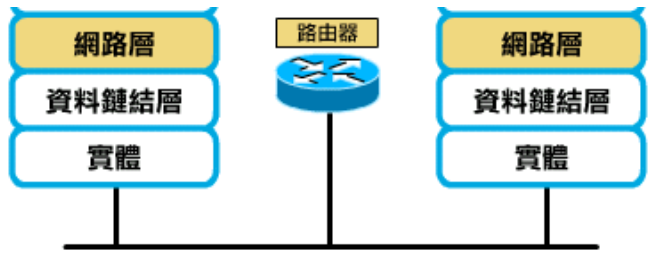
Gateway (default router): 閘道器



3

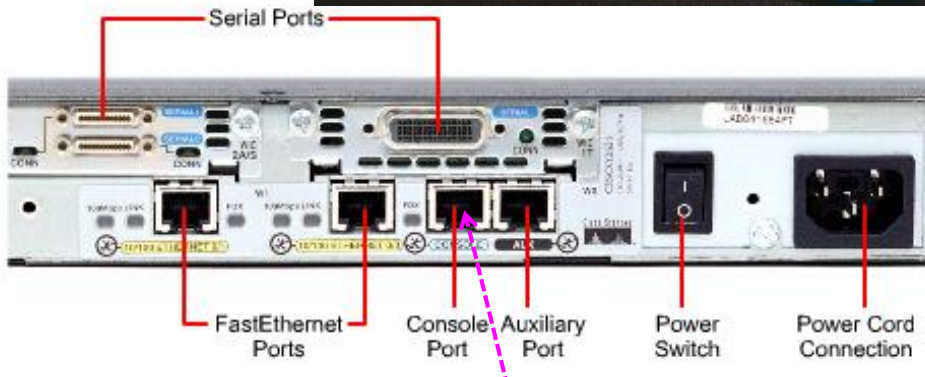
路由器(Router): Layer 3 device

- 檢查進入的封包，根據網路層位址選擇網路上最佳路徑，送至適當的輸出埠。
- 廣播領域之分割, 並做為LAN與WAN之連結
- 必要時進行封包分割(Packet fragmentation)
- 計費(Accounting)
- 需要網管人員設定(不是Plug-and-play)



4

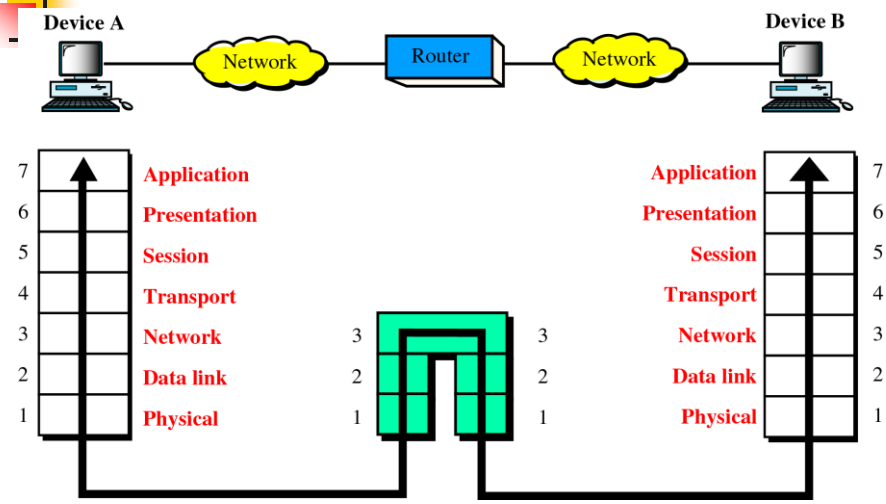
Cisco 2600 router



Picture sources by Cisco Systems, Inc.

5

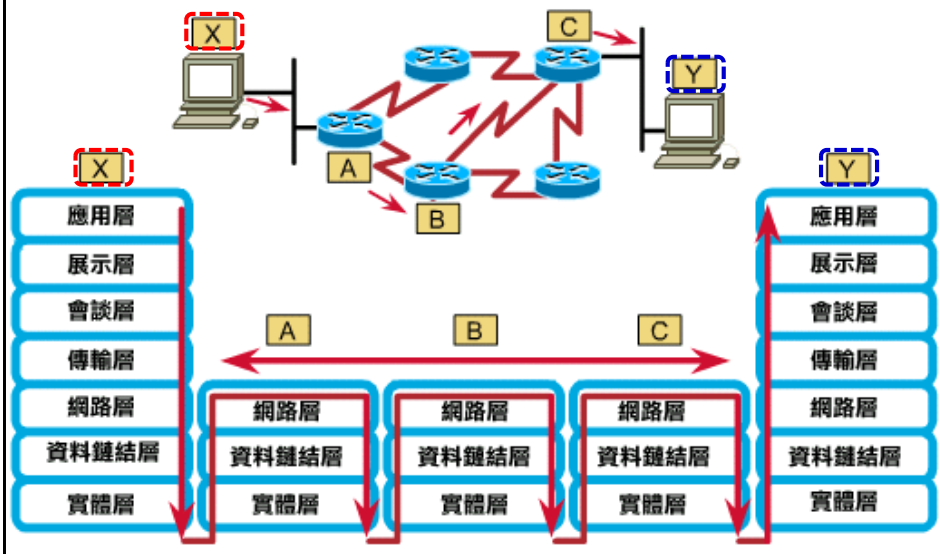
A Router in the OSI Model



6

The OSI Reference Model

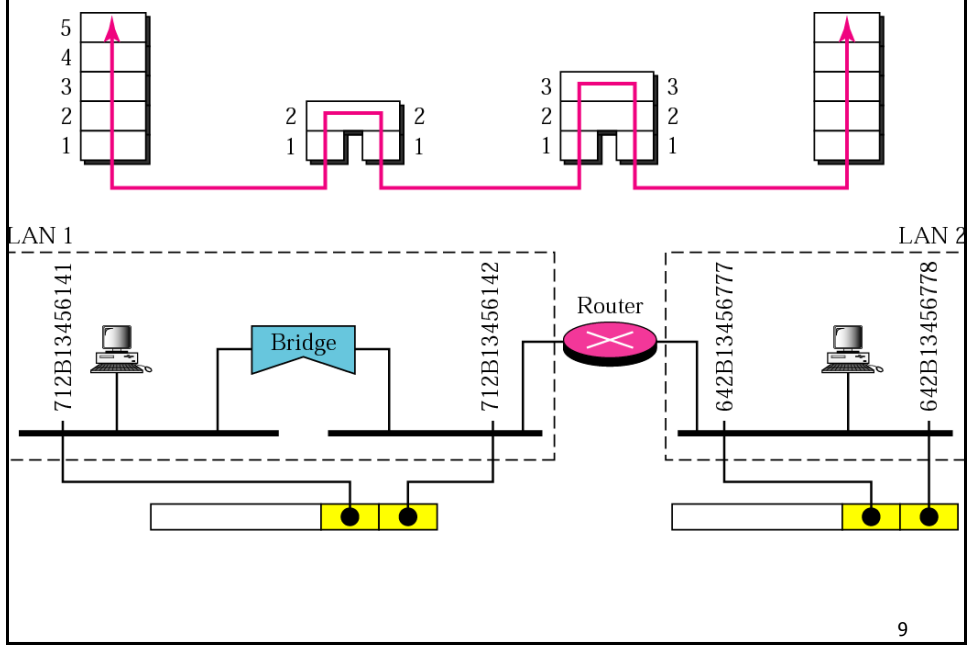
網路協定作業



Source: CISCO, inc.

8

Routing example



9

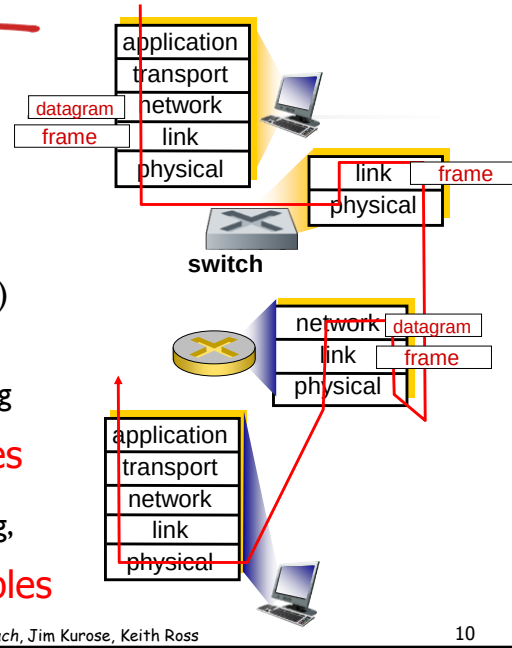
Switches vs. routers

both are store-and-forward:

- *routers:* network-layer devices (examine network-layer headers)
- *switches:* link-layer devices (examine link-layer headers)

both have forwarding tables:

- *routers:* compute tables using routing algorithms, IP addresses Routing tables
- *switches:* learn forwarding table using flooding, learning, MAC addresses Switching tables

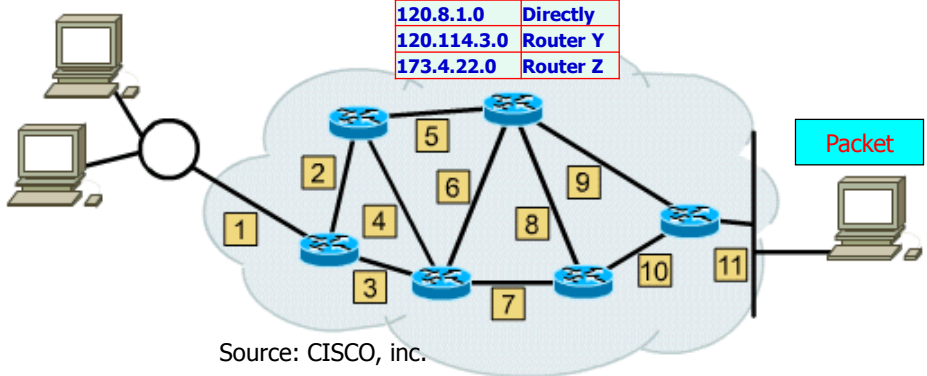


Source: Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross

Store-and-Forward Packet Routing

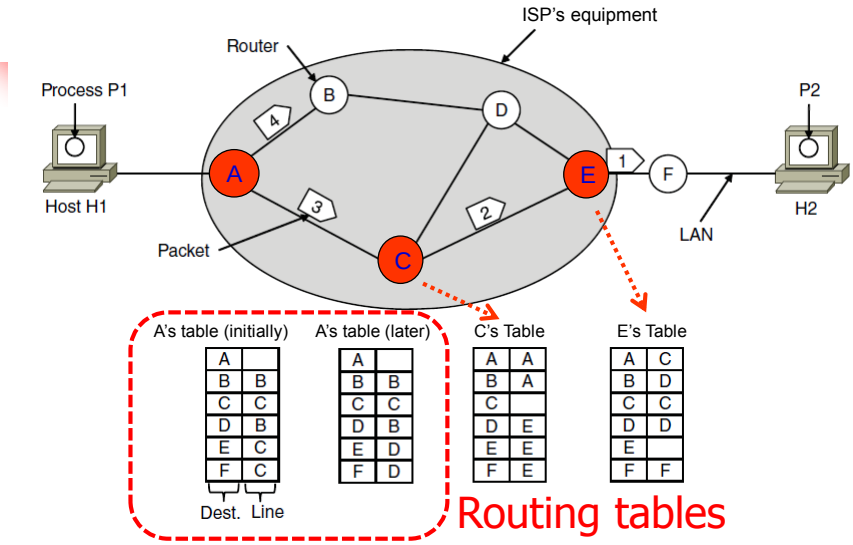
- **Routers** forward incoming **IP packets (datagrams)**
  - **IP Address Lookup** (Forwarding Table: Routing Table) constructed by routing protocols

IP	Next
120.8.64.0	Directly
120.8.1.0	Directly
120.114.3.0	Router Y
173.4.22.0	Router Z



Source: CISCO, inc.

Implementation of Connectionless Service



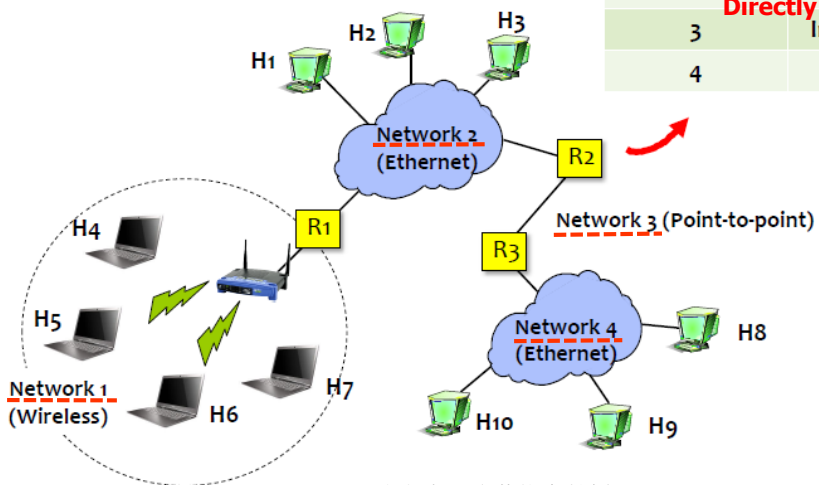
Routing within a datagram network

IP Datagram Forwarding

- Example (router R2)

NetworkNum	NextHop
1	R1
2	Interface 1
3	Interface 0
4	R3

Directly



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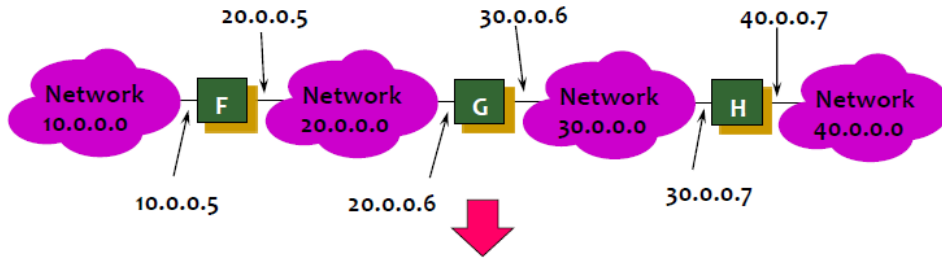
An Internet Routing Example



To reach hosts on network	Route to this address
20.0.0.0	Deliver Direct
30.0.0.0	Deliver Direct
10.0.0.0	20.0.0.5
40.0.0.0	30.0.0.7

each host has a default router

- Routing Table

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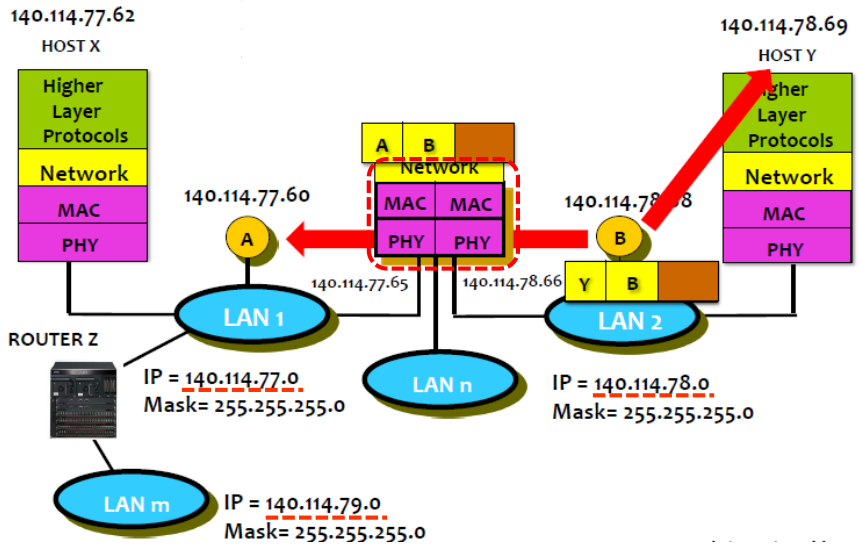
IP/MAC mapping table (ARP table)

Routing table



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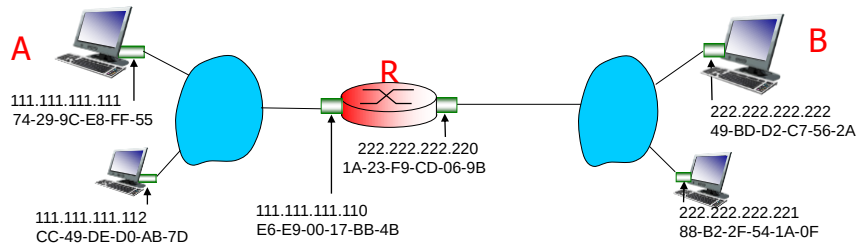
15

Addressing: routing to another LAN

walkthrough: send datagram from A to B via R

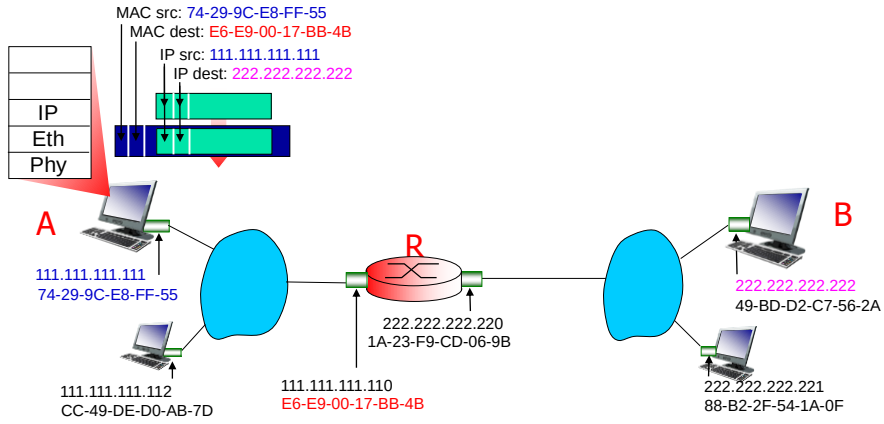
- focus on addressing – at IP (datagram) and MAC layer (frame)
- assume A knows B's IP address (how?)
- assume A knows IP address of first hop router, R (how?)
- assume A knows R's MAC address (how?)



Source: Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross 16

Addressing: routing to another LAN

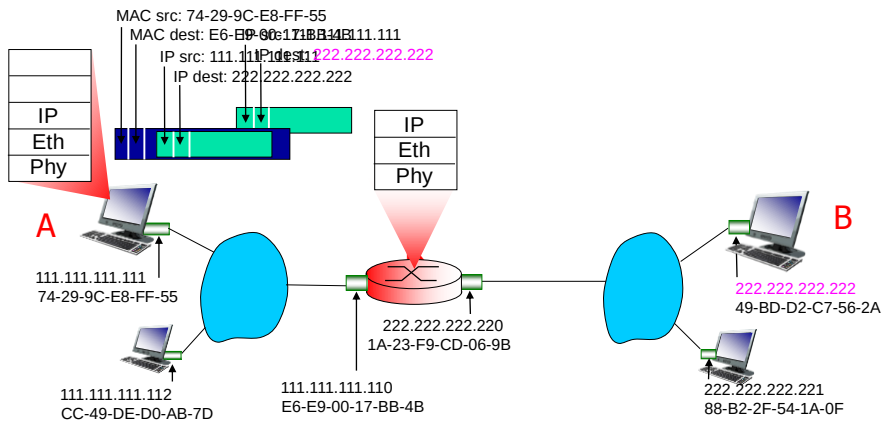
- A creates IP datagram with IP source A, destination B
- A creates link-layer frame with R's MAC address as destination address, frame contains A-to-B IP datagram



Source: Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross 17

Addressing: routing to another LAN

- frame sent from A to R
- frame received at R, datagram removed, passed up to IP

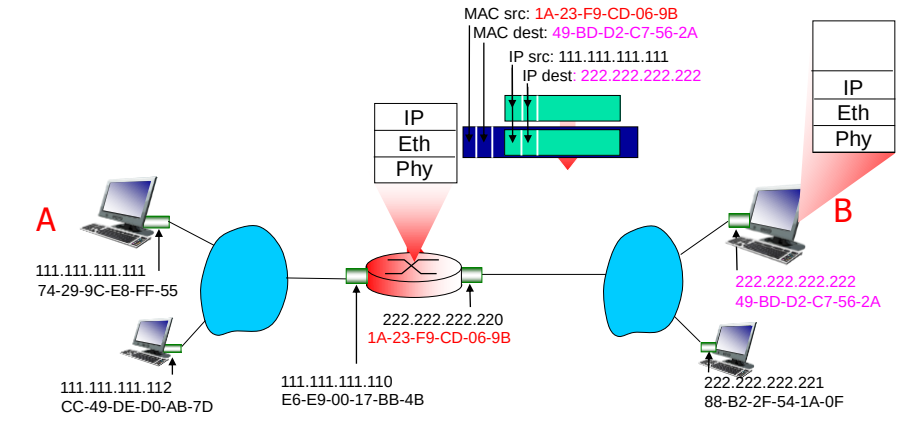


Source: Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross

18

Addressing: routing to another LAN

- R looks its routing table up and forwards datagram with IP source A, destination B
- R creates link-layer frame with B's MAC address as destination address, frame contains A-to-B IP datagram

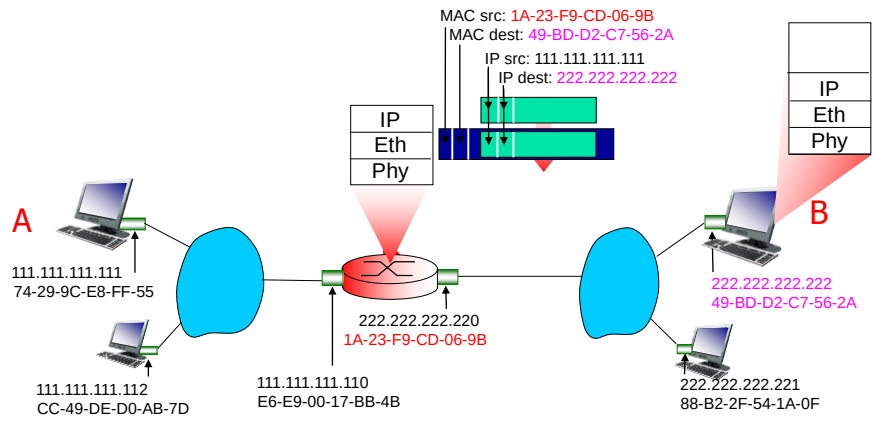


Source: Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross

19

Addressing: routing to another LAN

- R forwards datagram with IP source A, destination B
- R creates link-layer frame with B's MAC address as destination address, frame contains A-to-B IP datagram

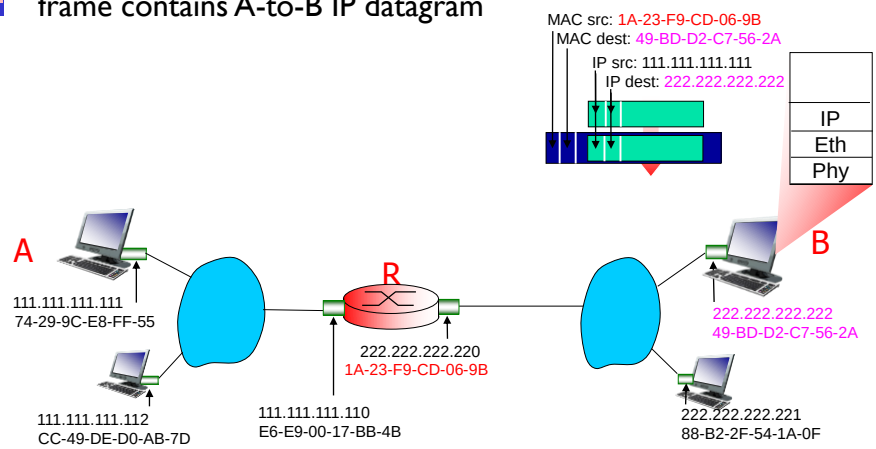


Source: Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross

20

Addressing: routing to another LAN

- R forwards datagram with IP source A, destination B
- R creates link-layer frame with B's MAC address as dest, frame contains A-to-B IP datagram



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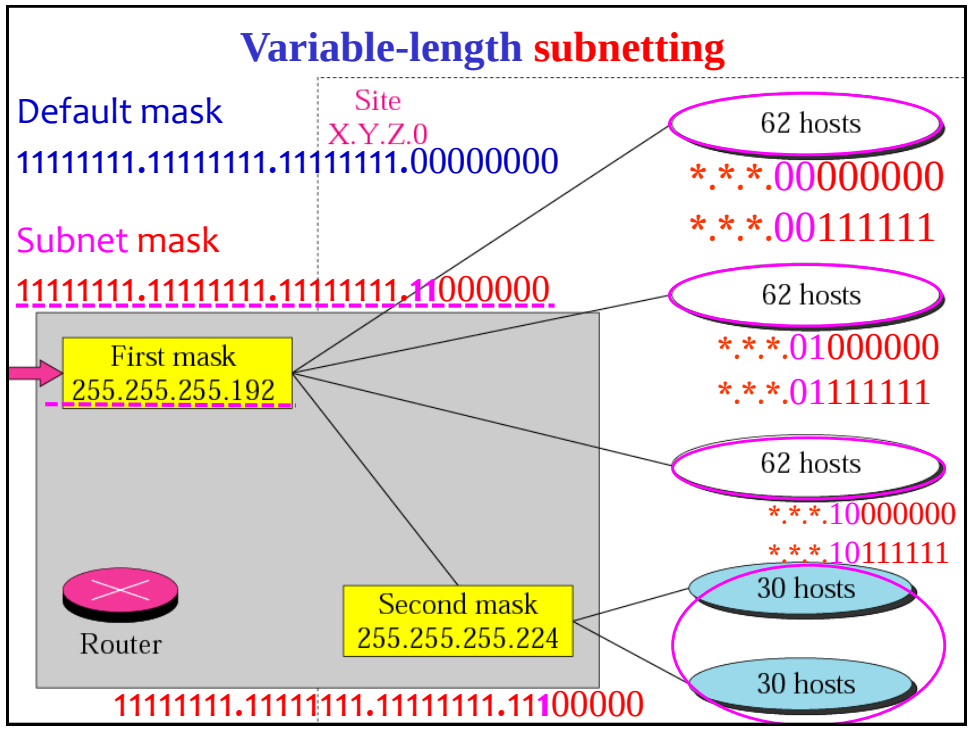
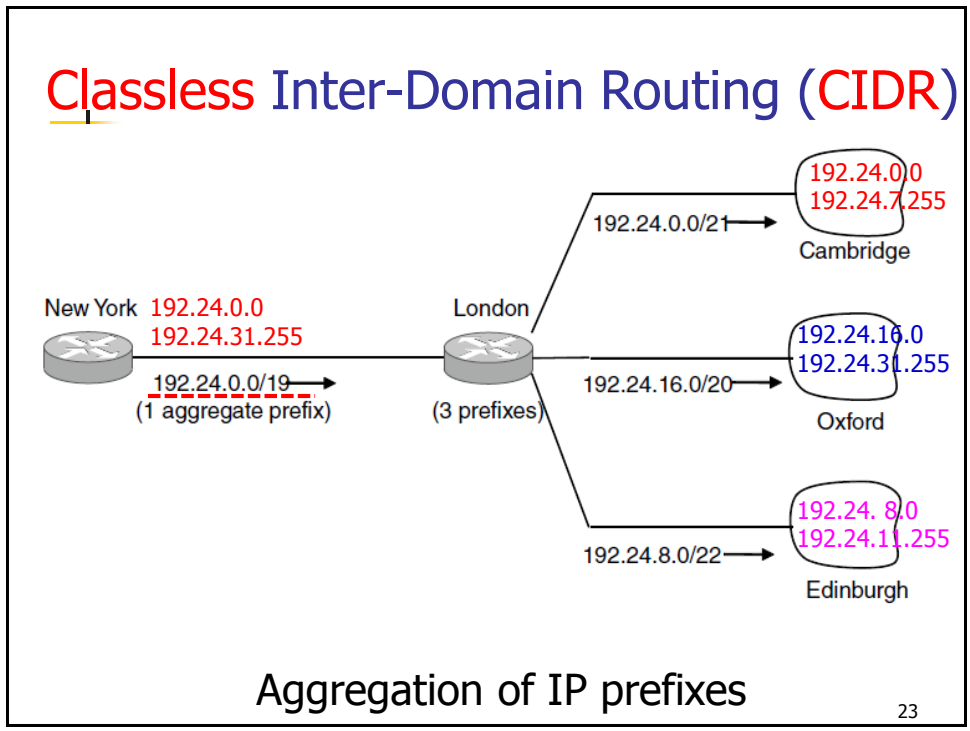
21


Variable-length subnetting
Default mask
11111111.11111111.11111111.00000000
Subnet mask
11111111.11111111.11111111.11000000
Site
X.Y.Z.0
First mask
255.255.255.192
Second mask
255.255.255.224
Router
62 hosts
..*.00000000
..*.00111111
62 hosts
..*.01000000
..*.01111111
62 hosts
..*.10000000
..*.10111111
30 hosts
30 hosts
11111111.11111111.11111111.11100000

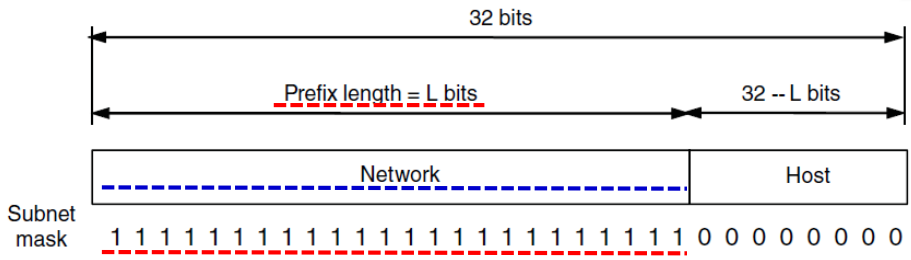

Classless Inter-Domain Routing (CIDR)
192.24.0.0
192.24.7.255
192.24.0.0/21
Cambridge
New York
192.24.0.0
192.24.31.255
London
192.24.16.0
192.24.31.255
192.24.0.0/19
(1 aggregate prefix)
(3 prefixes)
192.24.16.0/20
Oxford
192.24.8.0
192.24.11.255
192.24.8.0/22
Edinburgh
Aggregation of IP prefixes
23

Classless Inter-Domain Routing (CIDR)

- The growth of backbone routing table
  e.g., **16** class C subnets **need 16 entries**
- Large storage requirement for routing table at the routers
- Packet forwarding efficiency
- Routes aggregation (reduces table size):
  - Uses a single entry in the forwarding table to reach a lot of different networks
  - Breaks the rigid boundaries between address classes
- Share a common **prefix (代表號)**

24

Classless Addressing (IPv4)



An IP prefix.
w.x.y.z/L

25

Classless Addressing

11000000 00000100 0001

192.4.16.**0**	1100 0000	0000 0100	0001	0000.00000000	
192.4.17	1100 0000	0000 0100	0001	0001	
192.4.18	1100 0000	0000 0100	0001	0010	
192.4.19	1100 0000	0000 0100	0001	0011	
192.4.20	1100 0000	0000 0100	0001	0100	
192.4.21	1100 0000	0000 0100	0001	0101	
192.4.22	1100 0000	0000 0100	0001	0110	
192.4.23	1100 0000	0000 0100	0001	0111	
192.4.24	1100 0000	0000 0100	0001	1000	
192.4.25	1100 0000	0000 0100	0001	1001	
192.4.26	1100 0000	0000 0100	0001	1010	
192.4.27	1100 0000	0000 0100	0001	1011	
192.4.28	1100 0000	0000 0100	0001	1100	
192.4.29	1100 0000	0000 0100	0001	1101	
192.4.30	1100 0000	0000 0100	0001	1110	
192.4.31	1100 0000	0000 0100	0001	1111	

192.4.16.0/21

(192.4.16.0/20)

192.4.16/20

a block of contiguous class C addresses

192.4.28.0/22

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26

Classless Inter-Domain Routing (CIDR)

A set of IP address assignments.

194.24.0.0 = 11000010.00011000.00000000.00000000
194.24.7.255 = 11000010.00011000.00000111.11111111

University	First address	Last address	How many	Written as
Cambridge	194.24.0.0	194.24.7.255	2048	194.24.0.0/21
Edinburgh	194.24.8.0	194.24.11.255	1024	194.24.8.0/22
(Available)	194.24.12.0	194.24.15.255	1024	194.24.12/22
Oxford	194.24.16.0	194.24.31.255	4096	194.24.16.0/20

194.24.16.0 = 11000010.00011000.00010000.00000000
194.24.31.255 = 11000010.00011000.00011111.11111111

Subnet mask

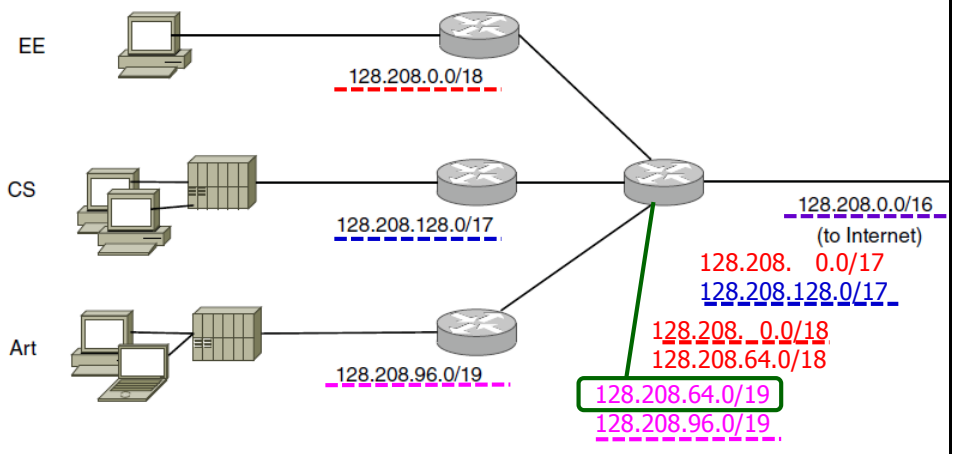
255.255.240.0 = 11111111.111111.1111**0000**.00000000

Prefix expression: **/20** ➔ FF FF F0 00

➔ 255.255.240.0

27

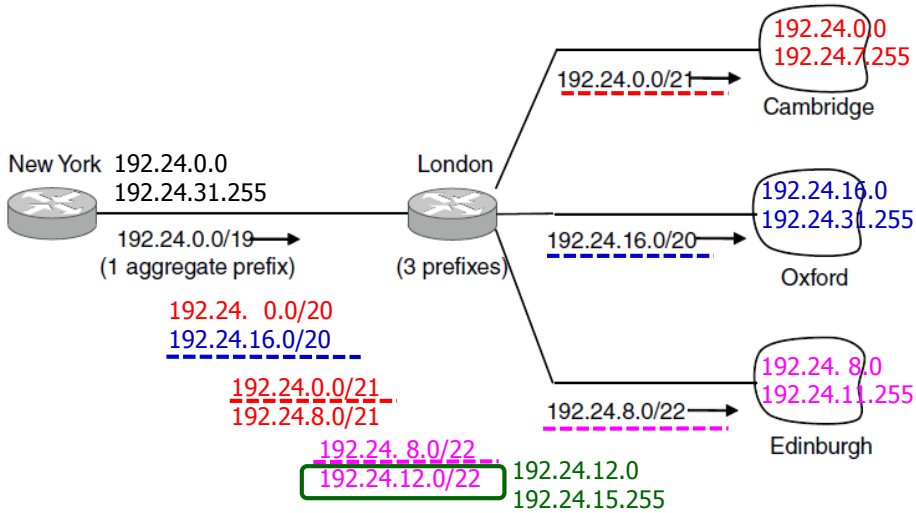
Classless Inter-Domain Routing (CIDR)



Splitting an IP prefix into separate networks with subnetting.

28

Classless Inter-Domain Routing (CIDR)



Aggregation of IP prefixes

29

Classless Inter-Domain Routing (CIDR)

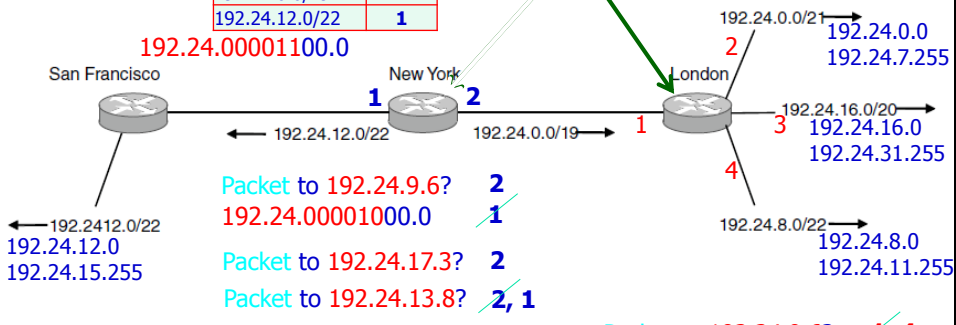
IP	Next
192.24.0.0/21	2
192.24.16.0/20	3
192.24.0.0/19	1
192.24.8.0/22	4
Default route	1

Routing table (CIDR)

IP	Next
192.24.0.0/19	2
192.24.12.0/22	1

Packet

192.24.000011**00.0**



Packet to 192.24.9.6? **2**
192.24.000010**00.0** **1**

Packet to 192.24.17.3? **2**

Packet to 192.24.13.8? **2, 1**

Packet to 192.24.9.6? **1, 4**

Packet to 192.24.17.3? **1, 3**

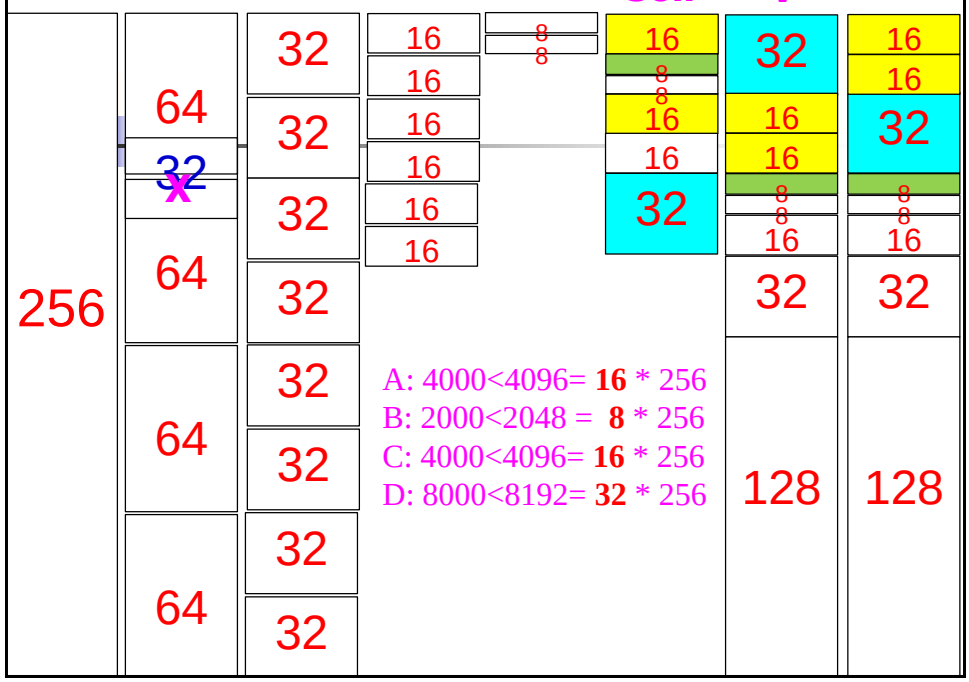
Packet to 192.24.13.8? **1**

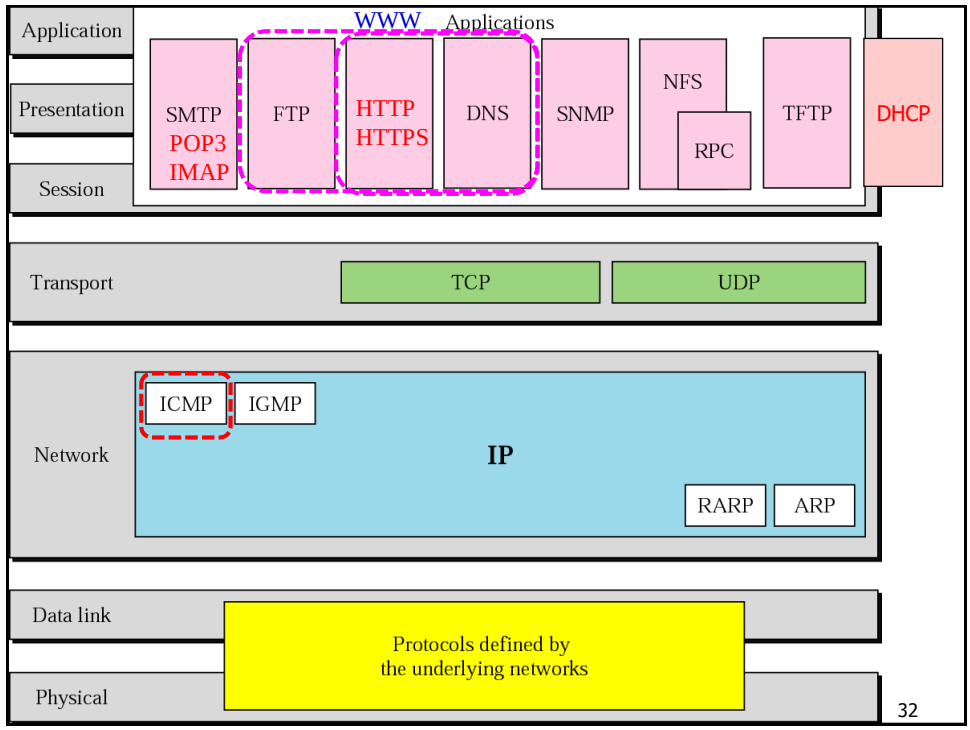
(Longest prefix matching)

Longest matching prefix routing at the New York router.

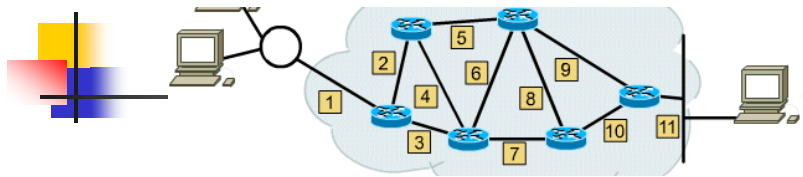
30

256 class C networks





Internet Control Protocols (1)

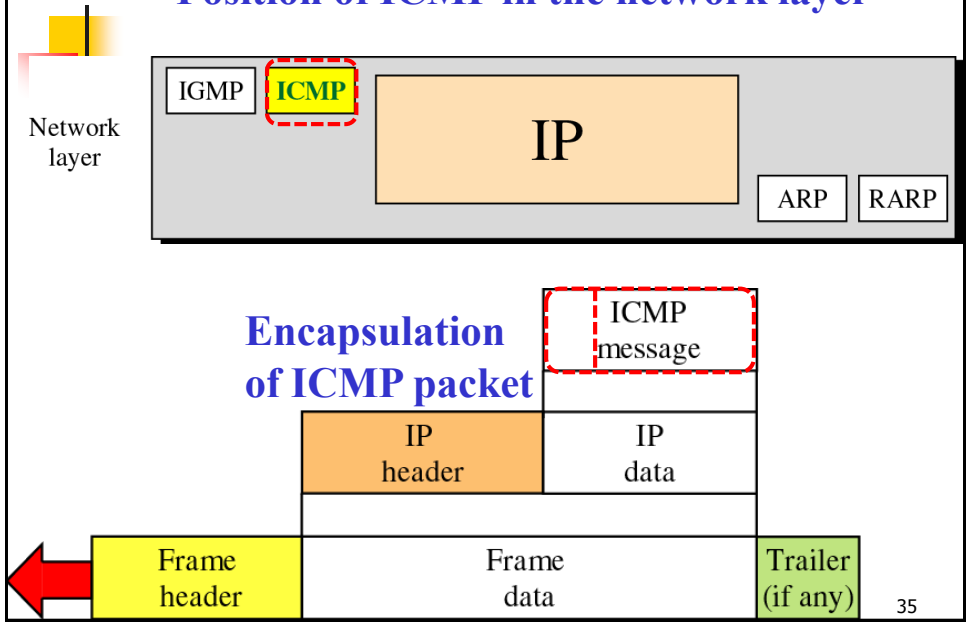


Message type	Description
Destination unreachable	Packet could not be delivered
Time exceeded	Time to live field hit 0 (TTL)
Parameter problem	Invalid header field
Source quench	Choke packet
Redirect	Teach a router about geography
Echo and Echo reply	Check if a machine is alive
Timestamp request/reply	Same as Echo, but with timestamp
Router advertisement/solicitation	Find a nearby router

The principal ICMP message types.

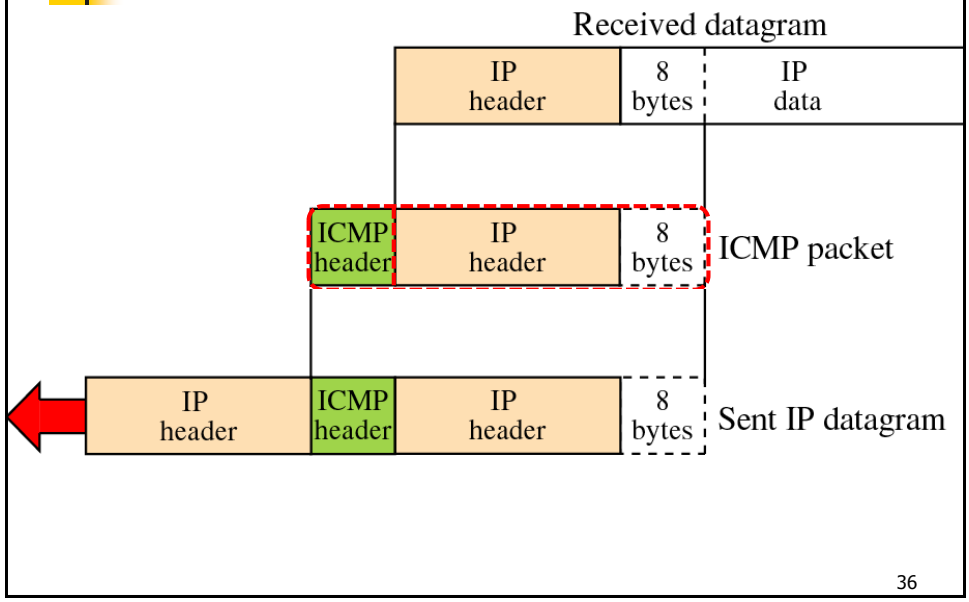
33

Position of ICMP in the network layer



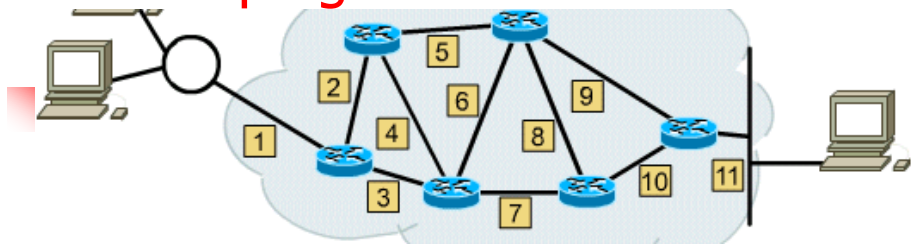
35

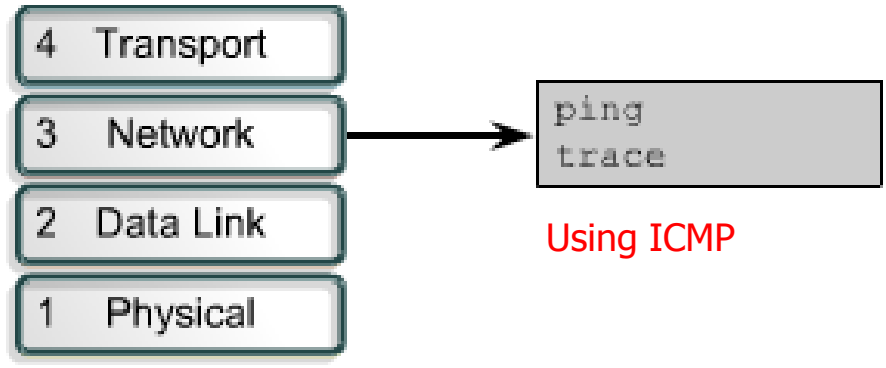
Contents of data field for error messages



36

ping and traceroute

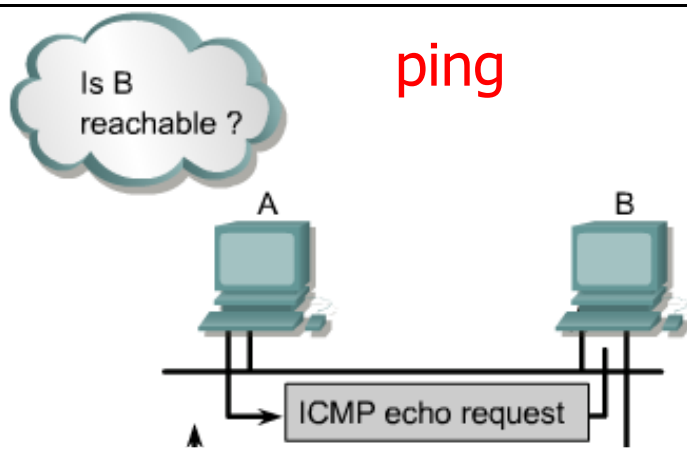




Using ICMP

Picture sources by Cisco Systems, Inc.

ping

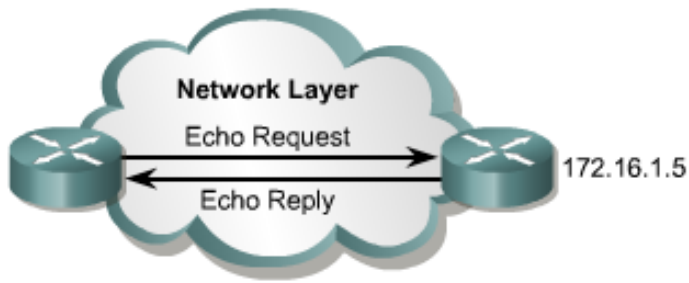


Picture sources by Cisco Systems, Inc.

Traffic generated by the **ping** command

```
C:\WINNT\System32\cmd.exe
Microsoft Windows 2000 [Version 5.00.2195]
<C> Copyright 1985-2000 Microsoft Corp.

C:\> ping 198.133.219.25

Pinging 198.133.219.25 with 32 bytes of data:

Reply from 198.133.219.25: bytes= 32 time= 16ms TTL=247
Reply from 198.133.219.25: bytes= 32 time= 16ms TTL=247
Reply from 198.133.219.25: bytes= 32 time= 16ms TTL=247
Reply from 198.133.219.25: bytes= 32 time= 16ms TTL=247

Ping statistics for 198.133.219.25:
    Packets: Sent = 4, Recieived = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 16ms, Maximum = 16ms, Average = 16vms
C:\>
```

ping



Picture sources by Cisco Systems, Inc.

```
Router>ping 172.16.1.5
Type escape sequence to abort.
Sending 5, 100 byte ICMP Echos to 172.16.1.5,
timeout is 2 seconds:
!!!!!
Success rate is 100 percent,
round-trip min/avg/max = 1/3/4 ms
Router>
```

40

www.usyd.edu.au(雪梨大學)

```
C:\Program Files (x86)\Microsoft Visual Studio 14.0>ping www.usyd.edu.au

Ping rp0.ucc.usyd.edu.au [129.78.5.11] (使用 32 位元組的資料):
回覆自 129.78.5.11: 位元組=32 時間=306ms TTL=234
回覆自 129.78.5.11: 位元組=32 時間=358ms TTL=234
回覆自 129.78.5.11: 位元組=32 時間=318ms TTL=234
回覆自 129.78.5.11: 位元組=32 時間=383ms TTL=234

129.78.5.11 的 Ping 統計資料:
    封包: 已傳送 = 4，已收到 = 4，已遺失 = 0 (0% 遺失)，
大約的來回時間 (毫秒):
    最小值 = 306ms，最大值 = 383ms，平均 = 341ms
```

41

Windows Ping 工具程式參數

參數	說明
-?	條列所有可跟著 Ping 一起使用的參數
-a	同時將 ping 的位址解譯成主機名稱
-n #	Ping 特定主機多次(參數中的#就是表示指定的 ping 次數)
-t	持續地 ping 某部主機, 一直到你按下 Ctrl+C 鍵爲止
-r #	Ping 封包在路由期間所能經過的躍程(hop)次數。這個參數需要一個數字(#)來指定躍程次數。這跟 tracert 指令(我們稍待會討論)很相似

Windows ipconfig 參數表(ifconfig)

參數	說明
/?	顯示所有可用的參數及說明
/All	顯示所有的 TCP/IP 組態資訊, 這跟在 Windows 95/98**IP 組態**交談窗裡按下**尚有資訊**鈕的效果一樣
/Release	釋放所有取自於 DHCP 的 TCP/IP 組態資訊, 這跟在 Windows 95/98 **IP 組態**交談窗裡按下**全部釋放**鈕的效果一樣
/Renew	釋放並更新取自於 DHCP 伺服器的所有 TCP/IP 組態資訊

42

Windows ipconfig使用範例

C:\>**ipconfig /all**

```
Ethernet adapter 區域連線:
 Connection-specific DNS Suffix  . : dhcp.vbird.org
    Description . . . . . . . . . . . : Realtek RTL8139(A) PCI Fast Ethernet Adapter
    Physical Address. . . . . . . . . : 00-41-95-31-43-B4
    DHCP Enabled. . . . . . . . . . . : Yes
    Autoconfiguration Enabled . . . . : Yes
    IP Address. . . . . . . . . . . . : 192.168.1.98
    Subnet Mask . . . . . . . . . . . : 255.255.255.0
    Default Gateway . . . . . . . . . : 192.168.1.254
    DHCP Server . . . . . . . . . . . : 192.168.1.2
    DNS Servers . . . . . . . . . . . : 167.95.1.1
                                        149.165.11.21
    Lease Obtained. . . . . . . . . . : 2005年11月24日 AM 11:32:54
    Lease Expires . . . . . . . . . . : 2005年11月27日 AM 11:32:54
C:\> ipconfig /renew
```

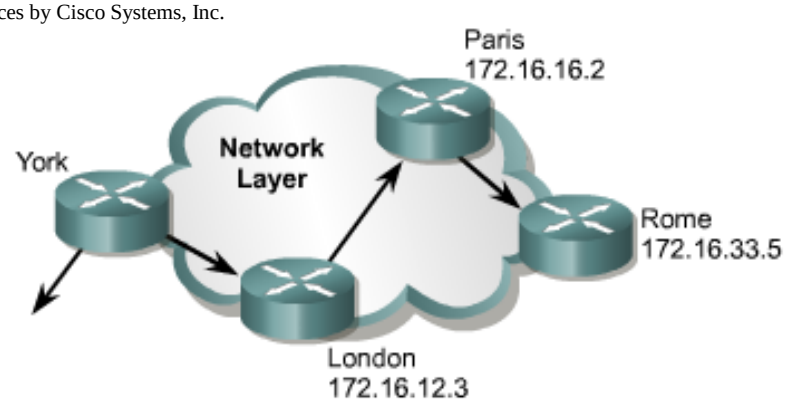
43

TraceRoute 診斷公用程式

- 傳送ICMP回應封包給目的地，以確定到目的地所經的路徑。 TRACERT 會使用各種不同的 IP 存留時間 (TTL) 值。 因為每台路由器在轉送封包之前必須至少將封包的 TTL 遞減 1。 當封包的 TTL 達到 0時，路由器會將 ICMP「超過時間」訊息傳回給來源電腦。
- 每次傳輸都將 TTL 遞增 1，直到目的地回應或達到最大 TTL 為止。 有些路由器會將 TTL 已經過期的封包悄悄丟棄，因此 TraceRoute 不會察覺到這些封包。

44

Picture sources by Cisco Systems, Inc.




```
York#traceroute ROME
Type escape to abort.
Tracing the route to Rome (172.16.33.5)
  1 LONDON (172.16.12.3) 8 msec 8 msec 4 msec
  2 PARIS (172.16.16.2) 8 msec 8msec 8msec
  3 ROME (172.16.33.5) 8msec 8msec 4msec

York#
```

tracert www.usyd.edu.au(雪梨)

```
C:\Program Files (x86)\Microsoft Visual Studio 14.0>tracert -w 300 -h 60 www.usyd.edu.au

在上限 60 個躍點上
追蹤 rp0.ucc.usyd.edu.au [129.78.5.11] 的路由:

  1     5 ms     1 ms     1 ms  192.168.0.1  Default router (Gateway)
  2     *       34 ms    18 ms  175-181-59-1.adsl.dynamic.seed.net.tw [175.181.59.1]
  3    38 ms    35 ms    36 ms  h65-192-72-168.seed.net.tw [192.72.168.65]
  4    34 ms    39 ms    46 ms  tpns.seed.net.tw [139.175.57.109]
  5    41 ms    44 ms    39 ms  r56-141.seed.net.tw [139.175.56.141]
  6     *      169 ms   175 ms  r59-102.seed.net.tw [139.175.59.102]

 10     *      329 ms     *     et-3-1-0.pe1.brwy.nsw.aarnet.net.au [113.197.15.146]
 11     *      316 ms     *     gw1.vl216.ae11.pe1.brwy-pe1.aarnet.net.au [138.44.5.47]
 12     *        *        *     要求等候逾時。
 13     *        *        *     要求等候逾時。
 14   329 ms     *      322 ms  bwfoundry.com [129.78.5.11]

追蹤完成。
```

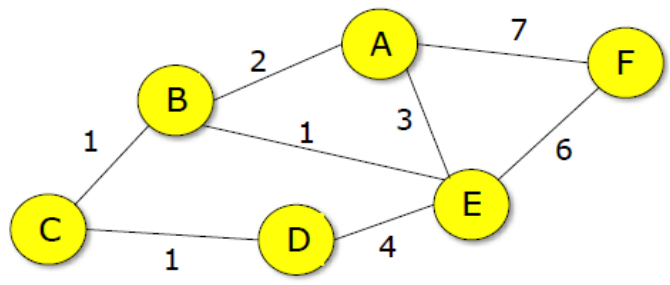
tracert www.vu.nl(阿姆斯特丹)

```
追蹤 www.vu.nl [37.60.194.64] 的路由:

  1     4 ms     4 ms     1 ms  192.168.0.1
  2    55 ms    40 ms    56 ms  175-181-59-1.adsl.dynamic.seed.net.tw [175.181.5
9.1]
  3    39 ms    18 ms    17 ms  h65-192-72-168.seed.net.tw [192.72.168.65]
  4    61 ms    54 ms    48 ms  tpns.seed.net.tw [139.175.57.109]
  5    50 ms     *       22 ms  r57-185.seed.net.tw [139.175.57.185]
  6    66 ms    54 ms    56 ms  h162-192-72-155.seed.net.tw [192.72.155.162]
  7   128 ms    96 ms     *     as6939.ix.jpix.ad.jp [210.171.224.40]
  8   167 ms   195 ms     *     100ge11-1.core1.sea1.he.net [184.105.213.117]
  9   195 ms     *      231 ms  100ge4-2.core1.msp1.he.net [184.105.223.194]
 10   219 ms     *      307 ms  100ge13-1.core2.chi1.he.net [184.105.223.177]
 11   217 ms     *      251 ms  100ge16-1.core1.nyc4.he.net [184.105.223.162]
 12   238 ms     *      234 ms  100ge11-1.core1.nyc5.he.net [184.105.213.218]
 13   295 ms     *      253 ms  100ge8-2.core1.dub1.he.net [184.105.65.246]
 14   260 ms     *      294 ms  100ge3-2.core1.man1.he.net [72.52.92.197]
 15   321 ms     *      301 ms  100ge16-1.core1.ams1.he.net [184.105.213.65]
 16   273 ms     *      300 ms  broadband-hosting.10gigabitethernet1-15.core1.am
s1.he.net [216.66.90.78]
 17   309 ms     *      293 ms  gi2-24.sara-r9-alm.com.sara.nl [217.170.10.220]
```

47

Routing

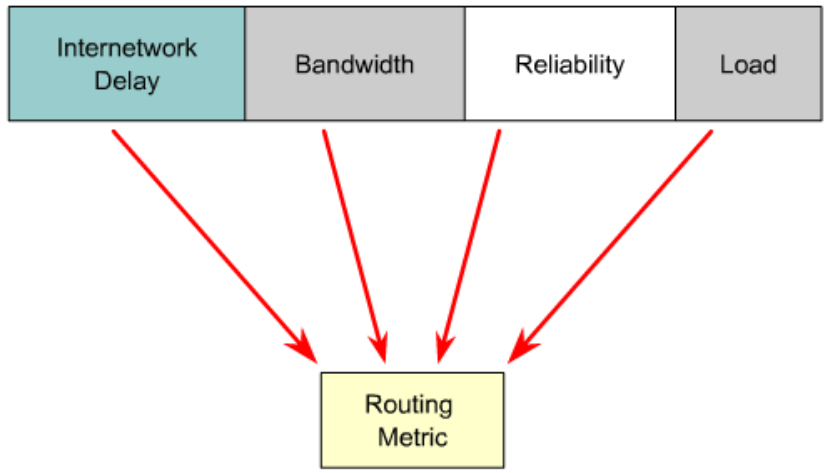
- Network as a Graph



- **The basic problem of routing is to find the lowest-cost path between any two nodes**

By 清大資工系黃能富教授 48

Routing Metric Components



Picture sources by Cisco Systems, Inc.

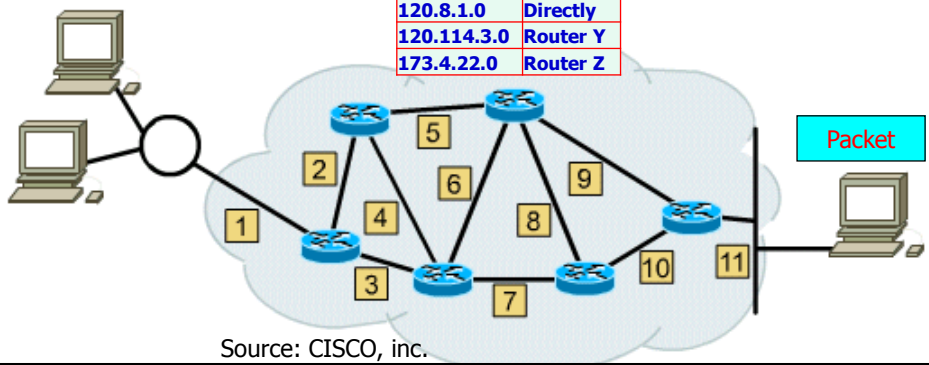
49

Routing Algorithms

- Distance Vector Routing
- Link State Routing

Routing table

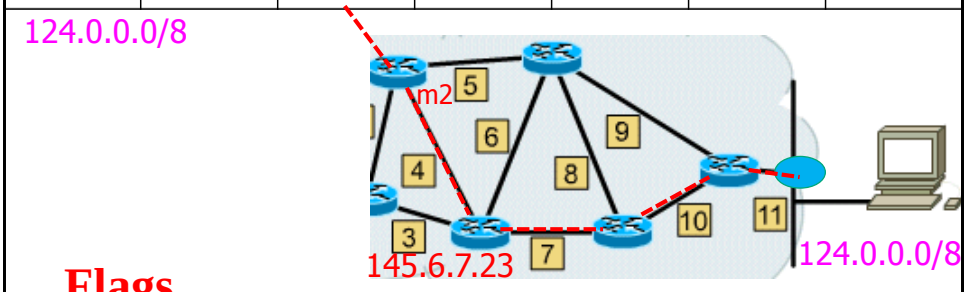
IP	Next
120.8.64.0	Directly
120.8.1.0	Directly
120.114.3.0	Router Y
173.4.22.0	Router Z



Source: CISCO, inc.

Routing Table

Mask	Destination address	Next-hop address	Flags	Reference count	Use	Interface
255.0.0.0	124.0.0.0	145.6.7.23	UG	4	20	m2



Flags

U	The router is up and running.
G	The destination is in another network.
H	Host-specific address.
D	Added by redirection.
M	Modified by redirection.

51

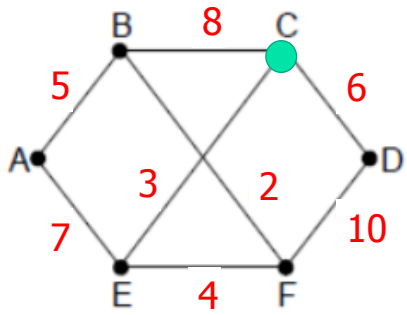
Routing vs. Routed protocols

- Routing Protocols:
  - RIP (Distance Vector Routing), RIP2, IGRP, EIGRP, IS-IS, OSPF (Link State Routing), BGP
- Routed Protocols:
  - IP, IPX, Appletalk

52

Distance Vector Routing

- Each node constructs a one dimensional array (a vector) containing the "distances" (costs) to all other nodes and distributes that vector to its immediate neighbors

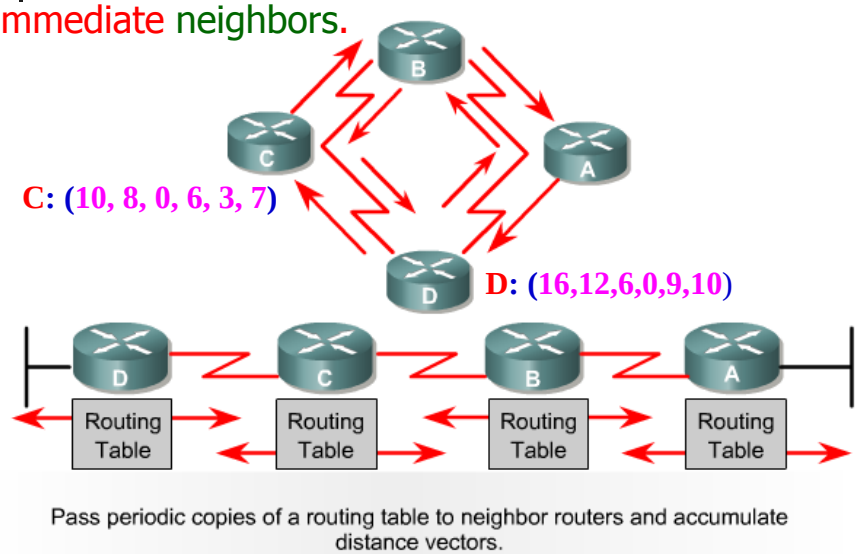


Routing table
C: (10, 8, 0, 6, 3, 7)
To:(A,B,C, D,E, F)

53

Distance Vector Concepts

Each node distributes the distance vector to its immediate neighbors.



Pass periodic copies of a routing table to neighbor routers and accumulate distance vectors.

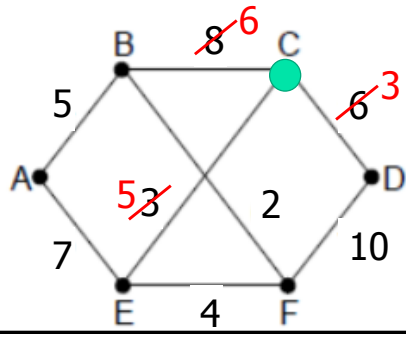
Every T seconds each router sends its routing table to its neighbors

Picture sources by Cisco Systems, Inc.

54

B:(5,0,8,12,6,2) D:(16,12,6,0,9,10) E:(7,6,3,9,0,4)傳給C

- 從C到B、D及E的新成本分別為6, 3及5
- Going via *B* gives (11, 6, 8+6, 18, 12, 8) **to:(A,B,C,D,E,F)**
- Going via *D* gives (19, 15, 6+3, 3, 12, 13).
- Going via *E* gives (12, 11, 3+5, 14, 5, 9).
- Taking the minimum for each destination except *C* gives (11, 6, 0, 3, 5, 8).
- The outgoing lines are (*B*, *B*, –, *D*, *E*, *B*).



舊表C:(10,8,0,6,3,7)

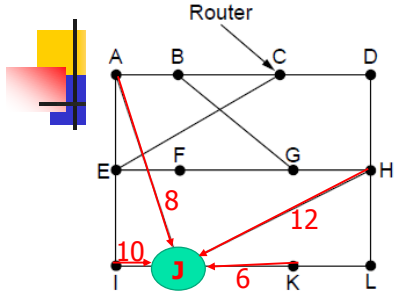
新表C: (11, 6, 0, 3, 5, 8)

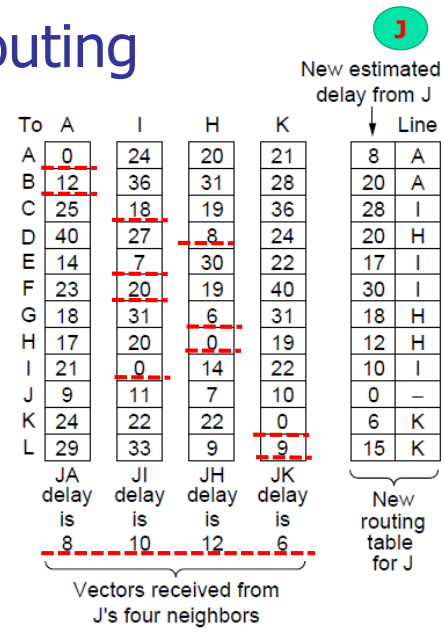
下一站: (*B*, *B*, –,*D*, *E*,*B*)

可到: (A, B,C,D, E,F)

55

Distance Vector Routing



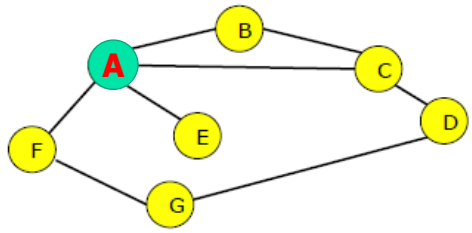


(a) A network. (a)

(b) Input from *A, I, H, K, and the new routing table* for *J*. (b)

56

Cost per link = 1



Distance vector
A: (0,1,1,∞,1,1,∞)
Via: (A,B,C,–,E,F, –)
To:(A,B,C,D,E,F,G)

Destination	Cost	NextHop
B	1	B
C	1	C
D	∞	--
E	1	E
F	1	F
G	∞	--

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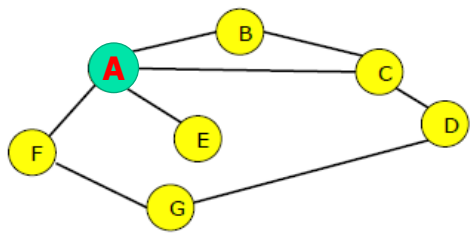
Initial routing table at node A

57



Distance vector
A: (0,1,1,2,1,1,2)
Via: (A,B,C,C,E,F,F)
To:(A,B,C,D,E,F,G)

Destination	Cost	NextHop
B	1	B
C	1	C
D	2	C
E	1	E
F	1	F
G	2	F

Final routing table at node A

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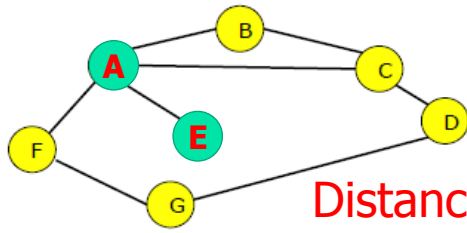
58



To:(A,B,C,D,E,F,G)
A: (0,1,1,2,1,1,2)
E: (1,2,2,3,0,2,3)

Distance Vector Routing: RIP

Final distances stored at each node (global view)

Information at node	Distance to reach node						
	A	B	C	D	E	F	G
A	0	1	1	2	1	1	2
B	1	0	1	2	2	2	3
C	1	1	0	1	2	2	2
D	2	2	1	0	3	2	1
E	1	2	2	3	0	2	3
F	1	2	2	2	2	0	1
G	2	3	2	1	3	1	0

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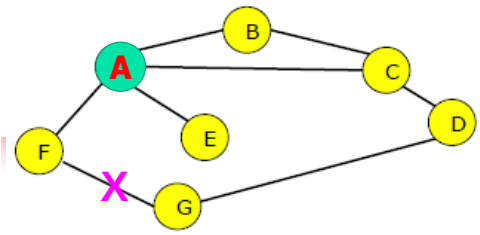


Figure adapted from 清大資工系黃能富教授

A: (0,1, 1,2, 1,1,2)
Via: (A,B,C,C,E,F,F)
C: (1,1, 0,1,2, 2,2)
Via: (A,B,C,D,A,A,D)
F: (1,2, 2,2,2, 0,1)
Via: (A,A,A,G,A,F,G)
To:(A,B,C,D,E,F,G)

When a node detects a link failure,

F: (1,2, 2,∞,2,0,∞) ➔ F: (1,2, 2,3,2,0,4)
Via: (A,A,A,A,A,F,A)

A: (0,1, 1, 2,1,1,∞) ➔ A: (0,1, 1, 2,1,1,3)
Via: (A,B,C,C,E,F,C)
To:(A,B,C,D,E,F,G)

C: (1,1, 0,1,2, 2,2)

60

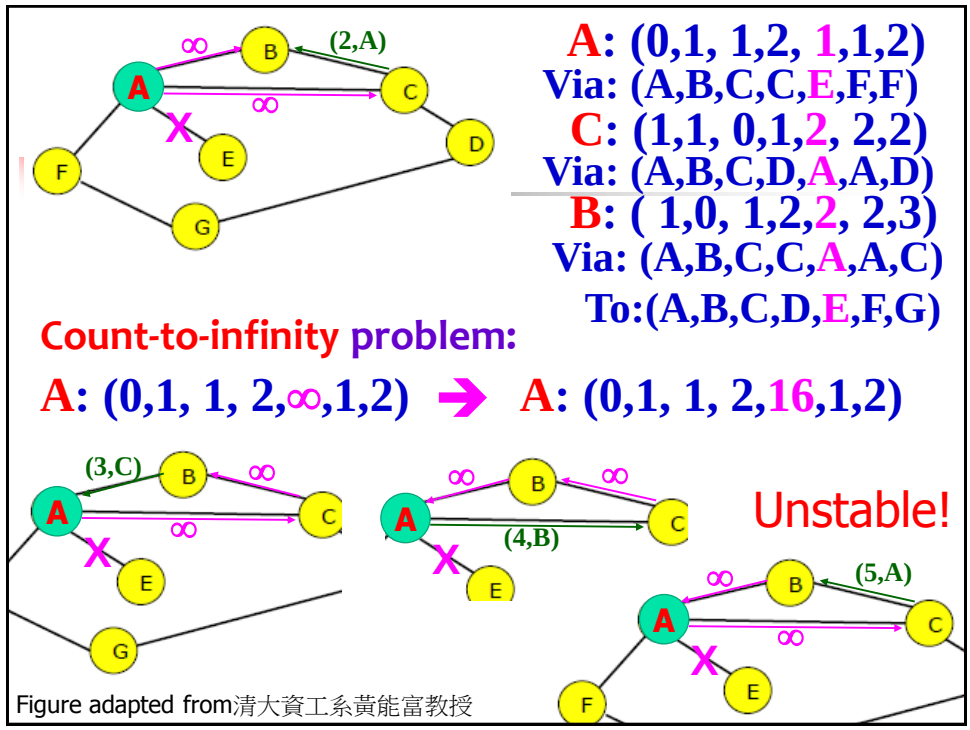
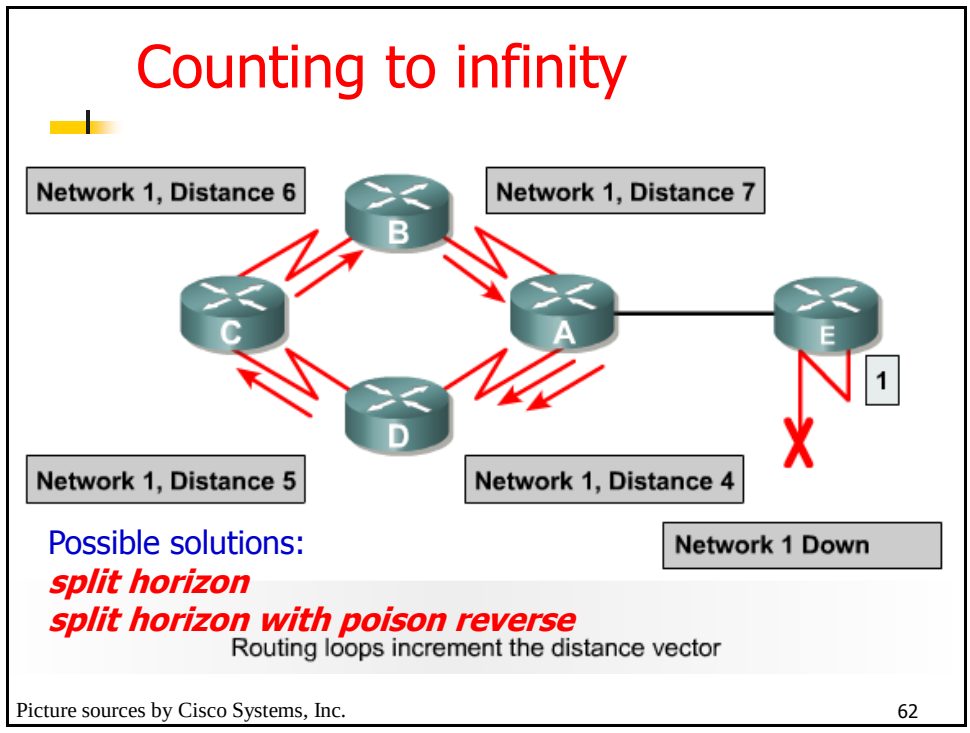
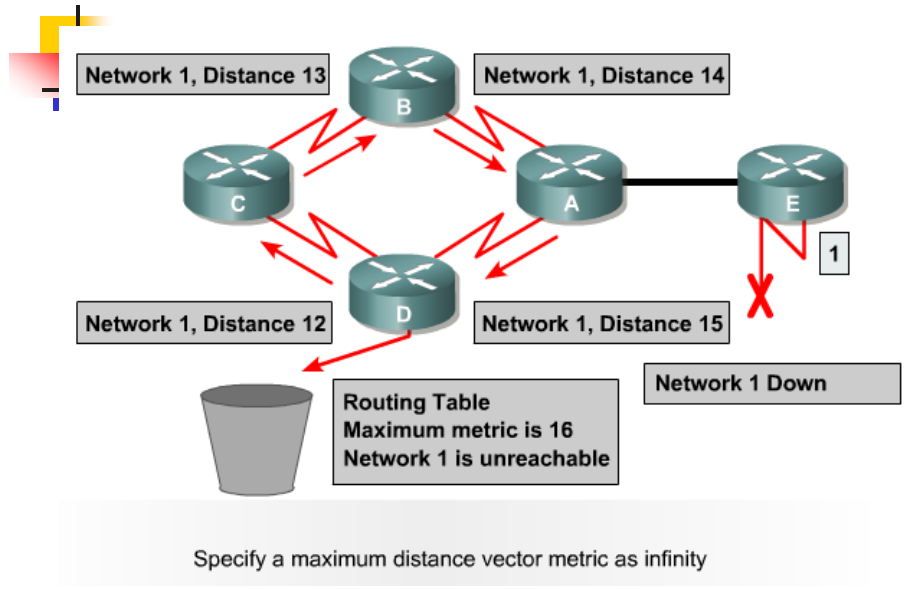


Figure adapted from清大資工系黃能富教授

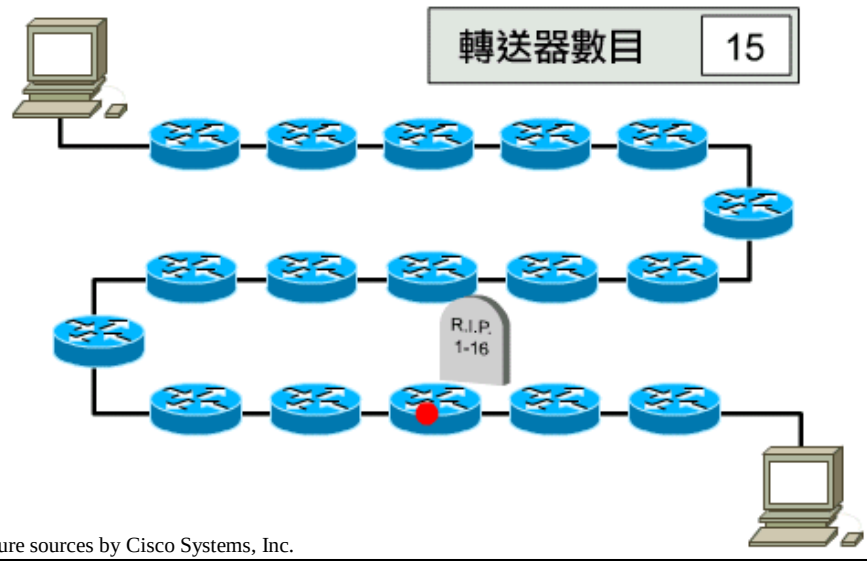


Solution: Defining a Maximum



Picture sources by Cisco Systems, Inc. 63

Distance Vector Routing Protocol:
路由協定：RIP(Routing Information Protocol)



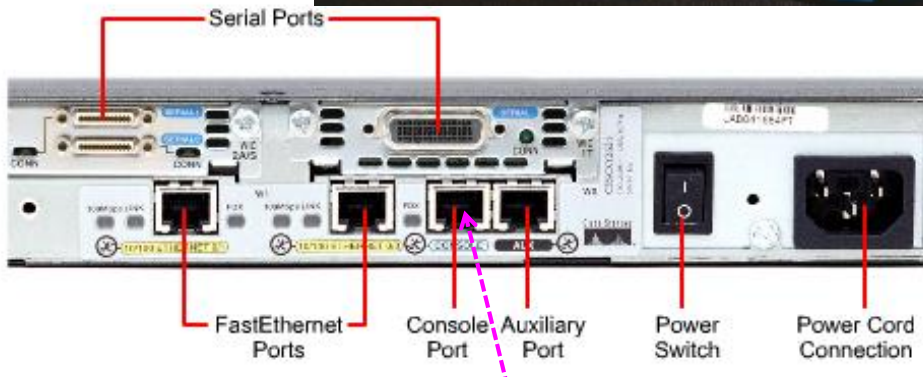
Picture sources by Cisco Systems, Inc.

RIP 之特性

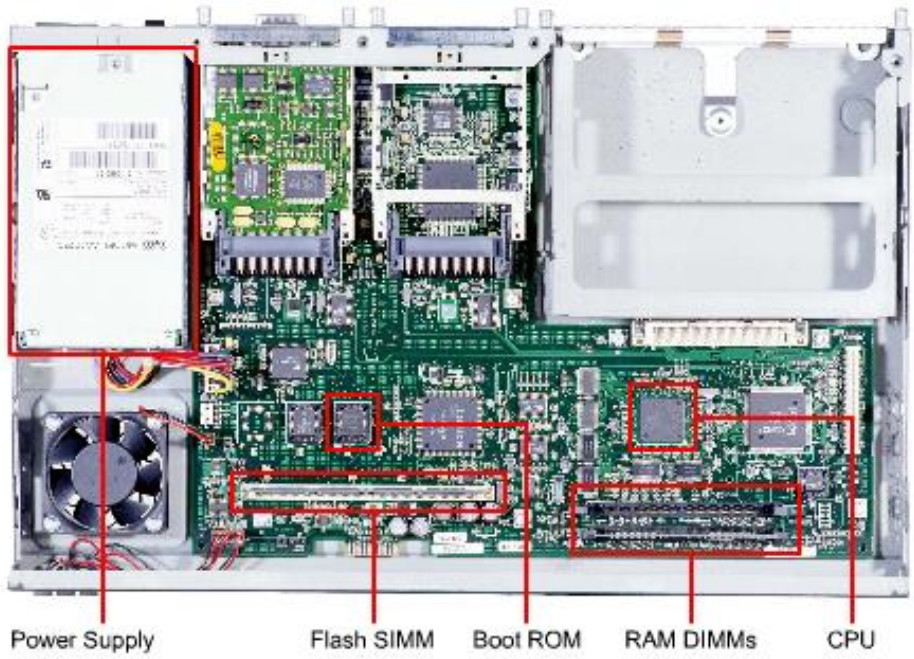
- 距離向量路徑選擇協定 (Distance Vector Routing Protocol)
- 只有權值為跳躍次數(Cost = hop#)
- 最大跳躍次數為 15
- 每 30 秒更新
- 不要總是選取封包最快傳輸路徑
- 更新產生許多網路流量

Picture sources by Cisco Systems, Inc. 65

Cisco 2600 router



Picture sources by Cisco Systems, Inc. 67



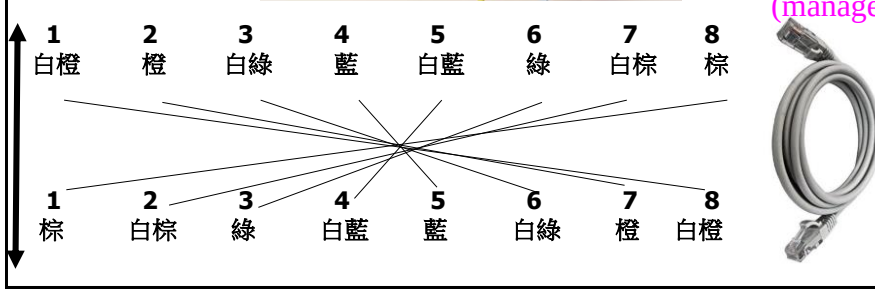
Picture sources by Cisco Systems, Inc.

68

主控台纜線(Rollover)

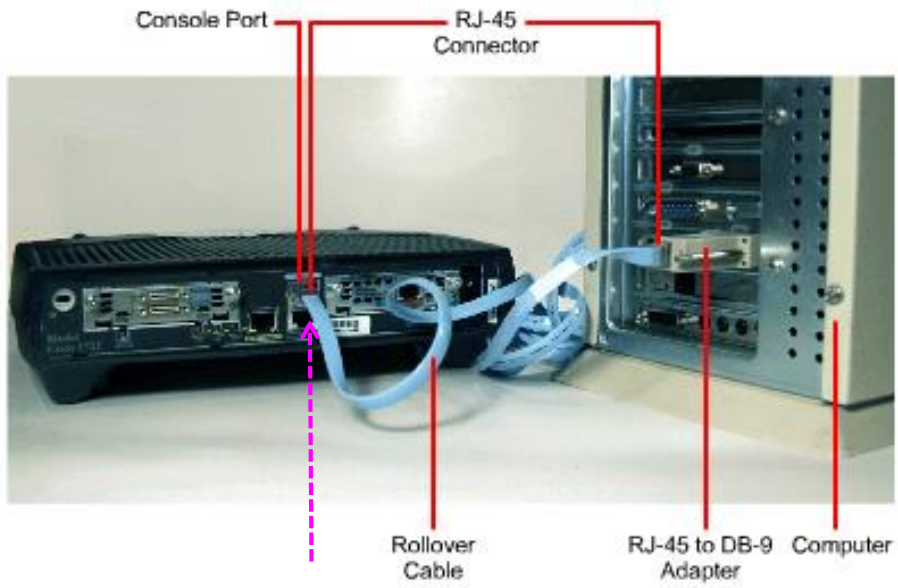
- 這條纜線是用來連接電腦到路由器(Router)或交換器(Switch)，用以管理及設定。

Console port (management)



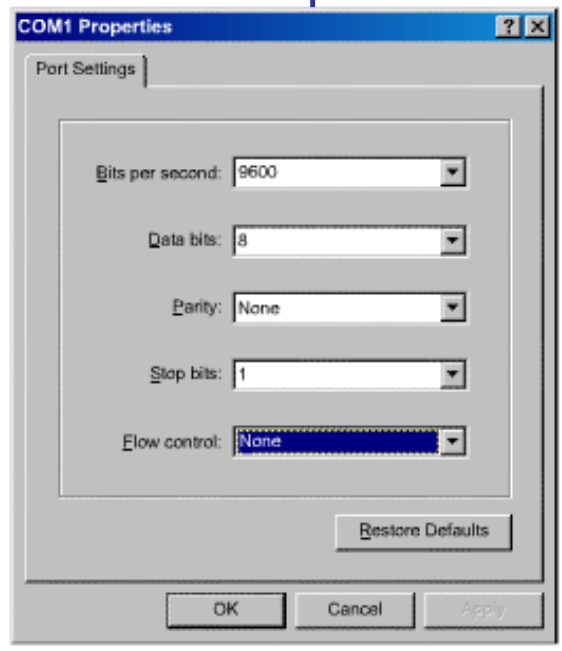
69

Terminal console connection

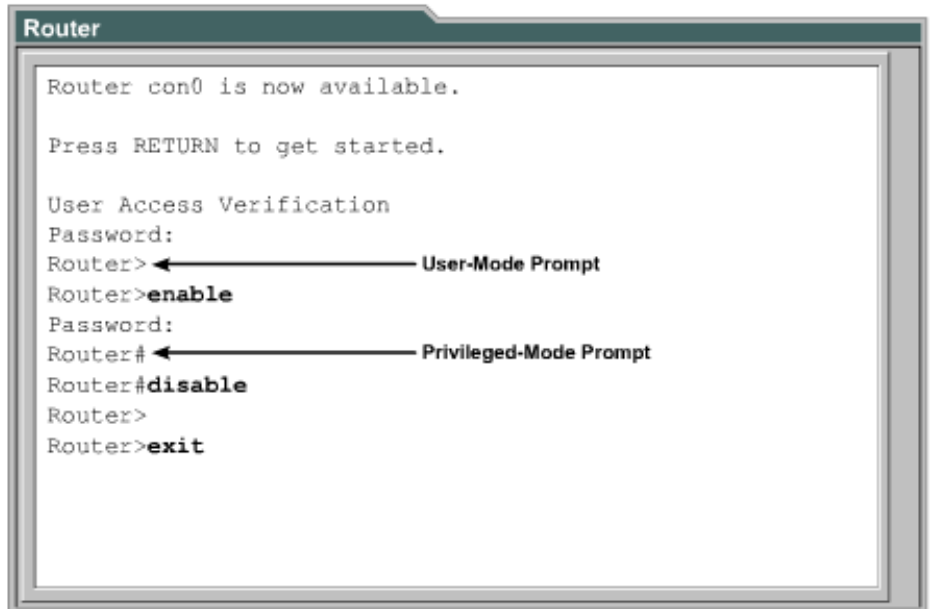


Picture sources by Cisco Systems, Inc.

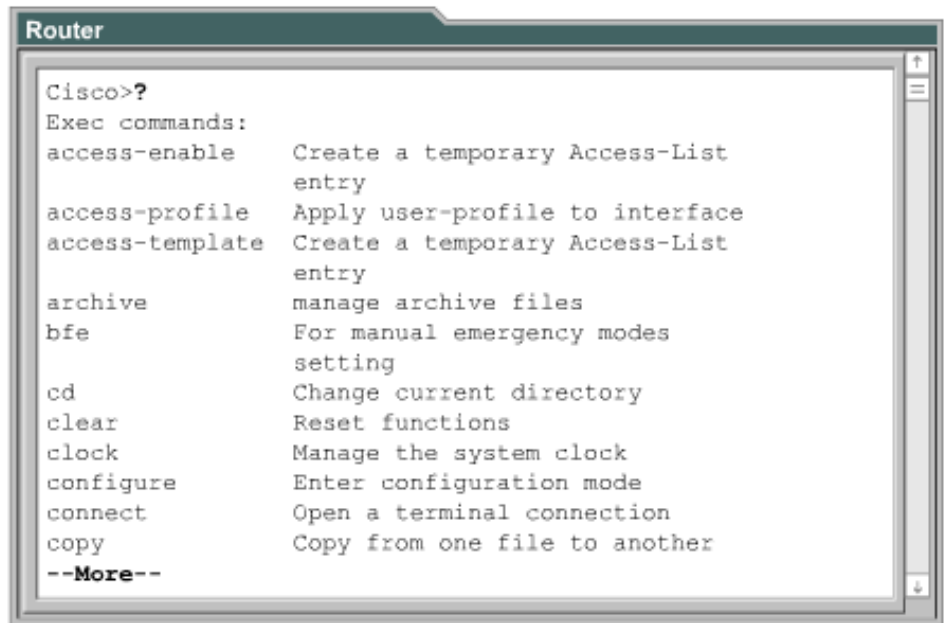
HyperTerminal Session Properties



Picture sources by Cisco Systems, Inc.

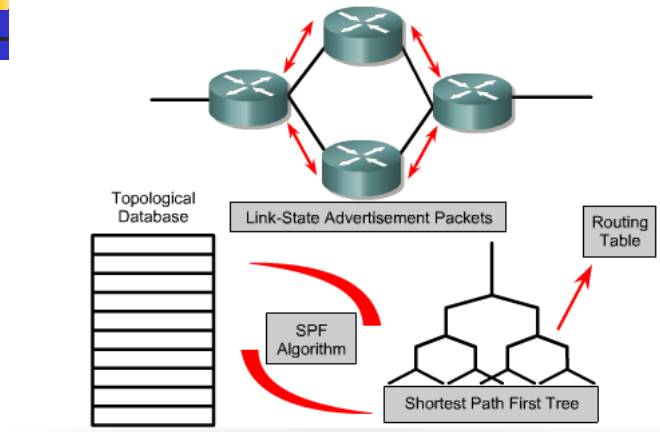


Picture sources by Cisco Systems, Inc. 73



Picture sources by Cisco Systems, Inc. 74

Link-State Concepts



Routers send LSAs to their neighbors. The LSAs are used to build a topological database. The SPF algorithm is used to calculate the shortest path first tree in which the root is the individual router. A routing table is then created.

Picture sources by Cisco Systems, Inc.

75

Link State Routing

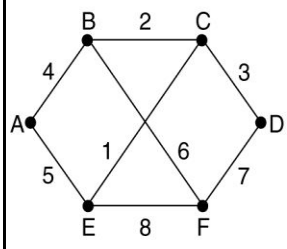
Strategy: Send to all nodes (not just neighbors) information about directly connected links (not entire routing table).

- Link State Packet (LSP)
  - ID of the node that created the LSP
  - Cost of link to each directly connected neighbor
  - Sequence number (SEQNO)
  - Time-to-live (TTL) for this packet

By 清大資工系黃能富教授

76

Building Link State Packets



(a)

Link State Packets

A	B	C	D	E	F
Seq.	Seq.	Seq.	Seq.	Seq.	Seq.
Age	Age	Age	Age	Age	Age
B 4	A 4	B 2	C 3	A 5	B 6
E 5	C 2	D 3	F 7	C 1	D 7
	F 6	E 1		F 8	E 8

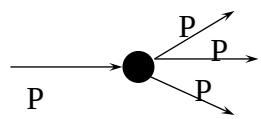
(b)

(a) A subnet. (b) The link state packets for this subnet.

78

Reliable Flooding

flooding



Transmit a copy of each packet it receives on every one of its transmission links

- Store most recent LSP from each node
- Forward LSP to all nodes but one that sent it
- Generate new LSP periodically; increment SEQNO
- Start SEQNO at 0 when reboot
- Decrement TTL of each stored LSP; discard when TTL=0

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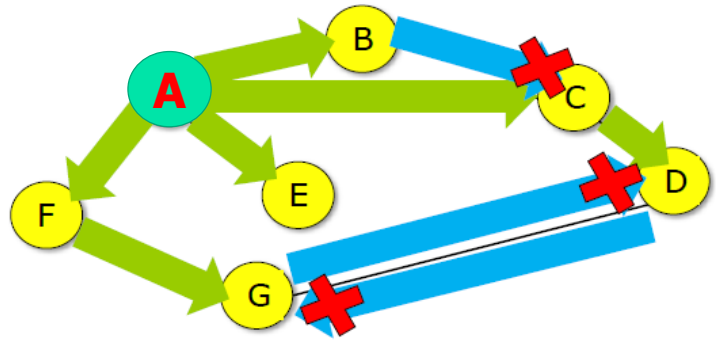
79

Link State Routing

Example of reliable flooding of LSP packets

From node A



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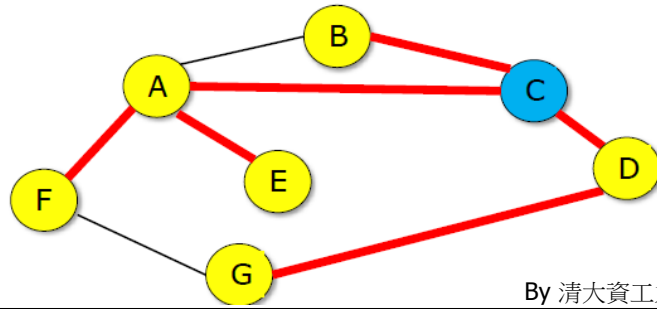
Shortest Path Routing

- OSPF (Open Shortest Path First)
- Each router computes its routing table directly from the LSP's it has collected using the Dijkstra's algorithm
- Find the shortest path from the router to each other node.



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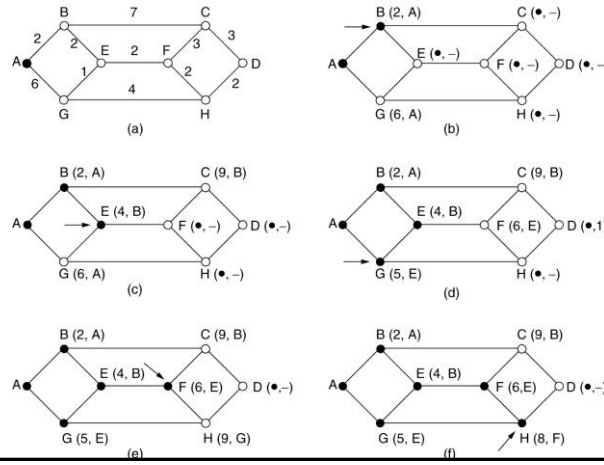
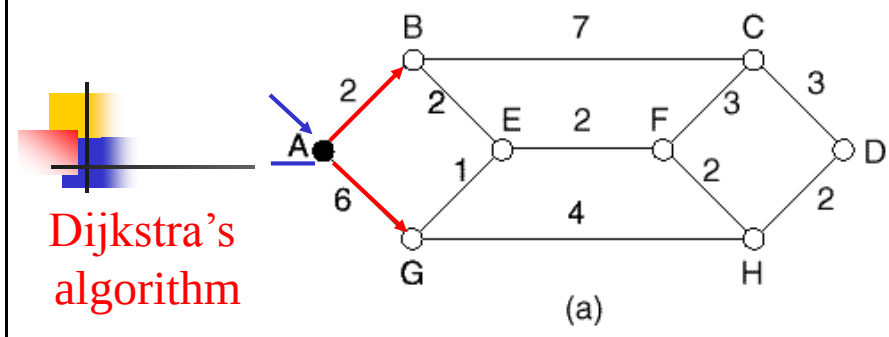
Shortest Path Routing

The first 5 steps used in computing the shortest path from A to D. The arrows indicate the working node.

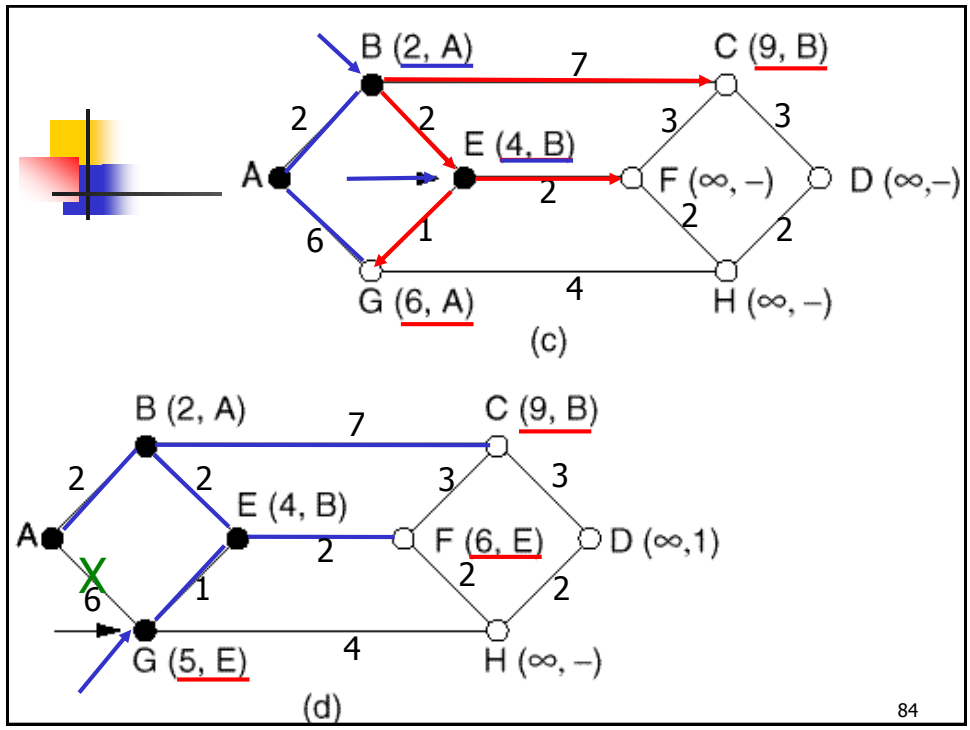
(Dijkstra's algorithm)

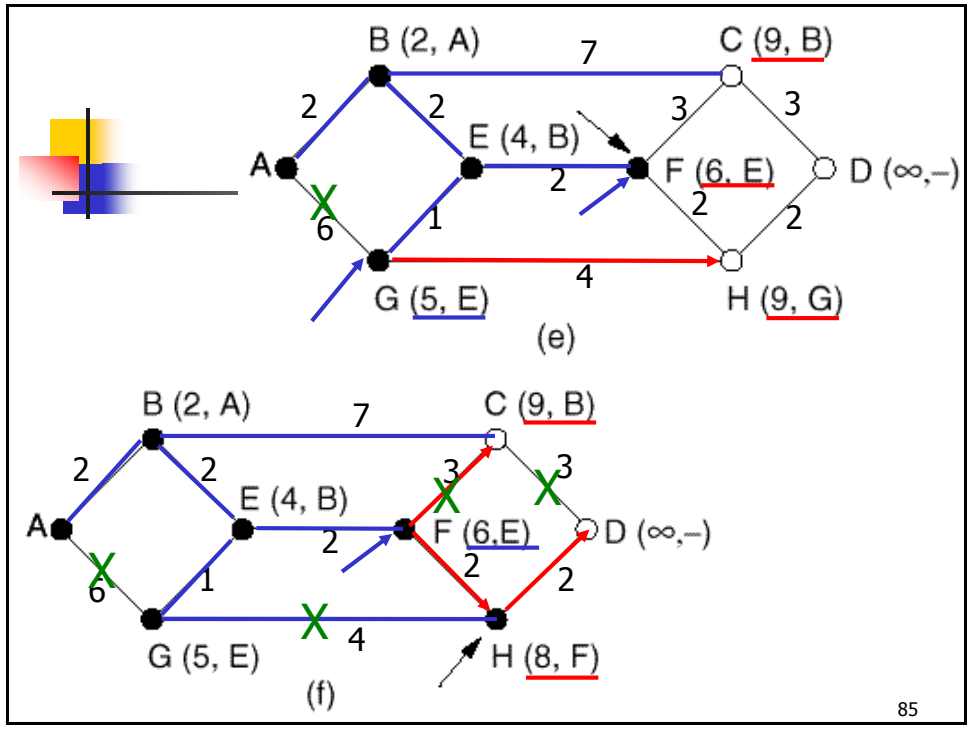


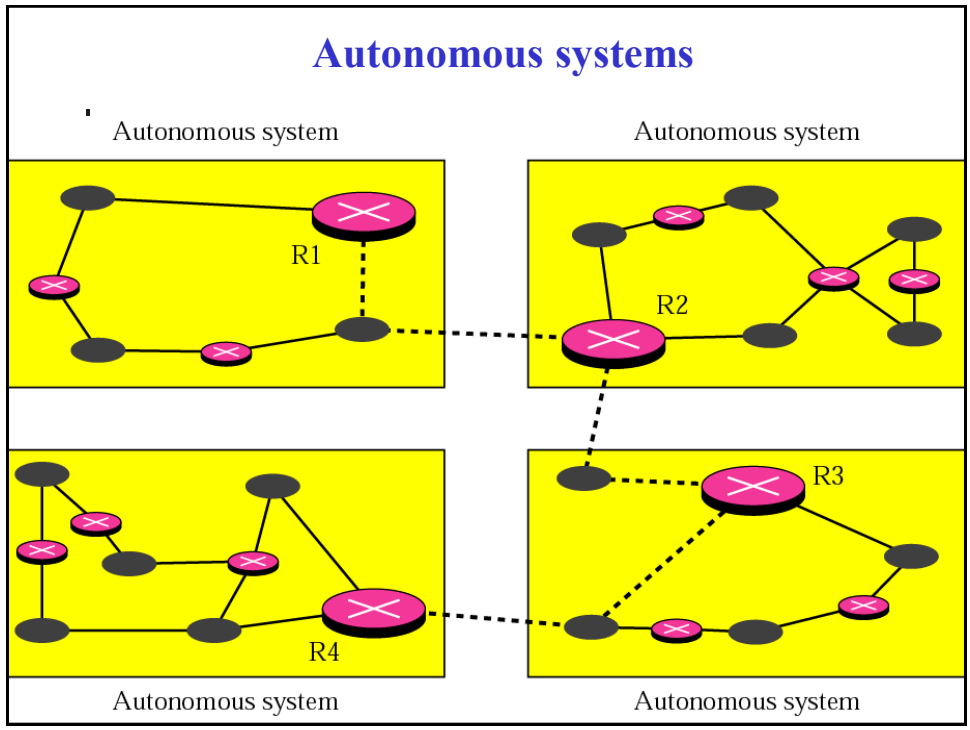
82

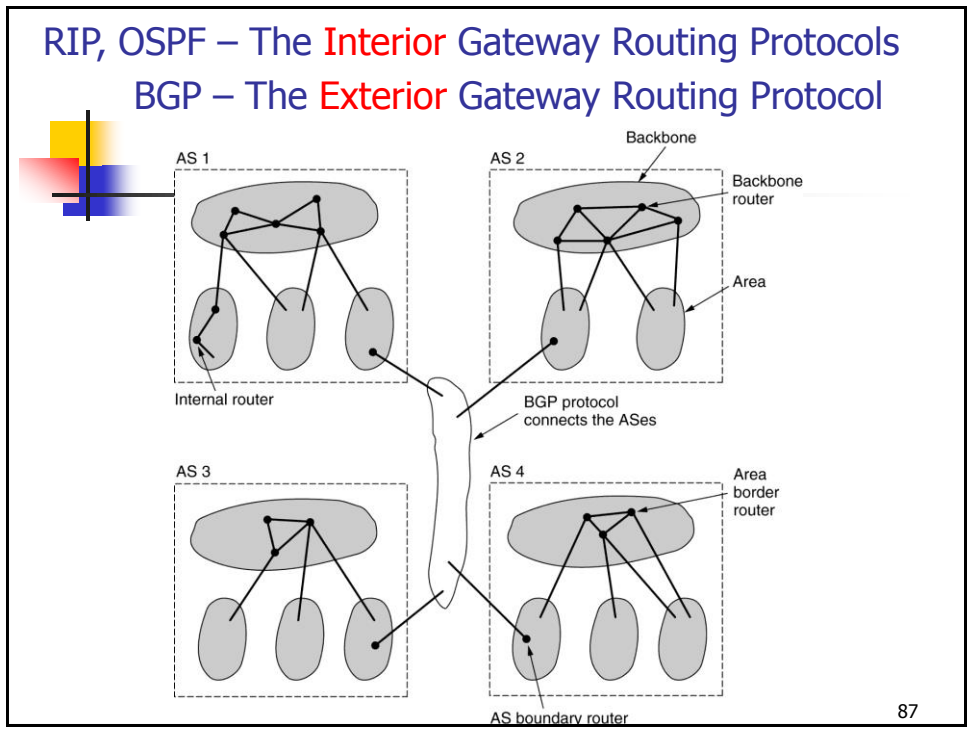


83

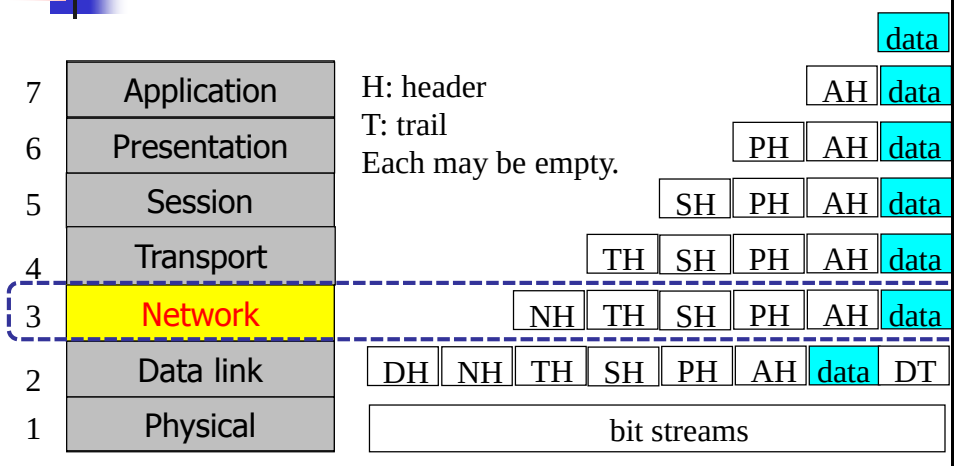

B (2, A)
C (9, B)
7
2
2
E (4, B)
3
3
A
F (∞, –)
D (∞,–)
2
2
6
1
2
G (6, A)
4
H (∞, –)
(c)
B (2, A)
C (9, B)
7
2
2
3
3
E (4, B)
A
F (6, E)
D (∞,1)
2
2
2
6
1
G (5, E)
4
H (∞, –)
(d)
84


B (2, A)
C (9, B)
7
2
2
E (4, B)
3
3
A
F (6, E)
D (∞,–)
2
2
6
1
2
G (5, E)
4
H (9, G)
(e)
B (2, A)
C (9, B)
7
2
2
3
3
E (4, B)
A
F (6,E)
D (∞,–)
2
2
6
1
2
G (5, E)
4
H (8, F)
(f)
85


Autonomous systems
Autonomous system
Autonomous system
R1
R2
R3
R4
Autonomous system
Autonomous system


RIP, OSPF – The Interior Gateway Routing Protocols
BGP – The Exterior Gateway Routing Protocol
AS 1
AS 2
Backbone
Backbone router
Area
Internal router
BGP protocol connects the ASes
AS 3
AS 4
Area border router
AS boundary router
87

The Network Layer



OSI Reference Model

88

End of Chapter 5-2

- Questions?
- HW#3:
  - Chapter 5 exercises 5, 24, 25, 27, 28, 29, 30, 35, 43
  - Possible solutions 6*, 27, 28, 30*, 31, 32*, 33, 38, -- (in ISM)
- Thank you!

89