Network Basics

Contents

- TCP/IP Protocol
- Routing
- Network Hardware

TCP/IP Protocol

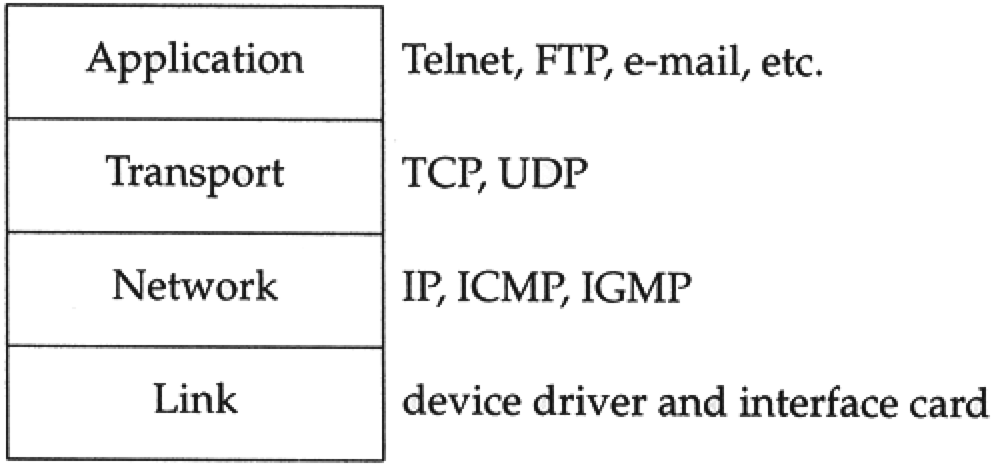
TCP/IP and the Internet

- In 1969
  - ARPA funded and created the “ARPA*net*” network
    - Robust, reliable, vendor-independent data communications
- In 1975
  - Convert from experimental to operational network
  - TCP/IP begun to be developed
- In 1983
  - The TCP/IP is adopted as Military Standards
  - ARPnet → MILNET + ARPnet = Internet
- In 1985
  - The NSF created the NSFnet to connect to Internet
- In 1990
  - ARPA passed out of existence, and in 1995, the NSFnet became the primary Internet backbone network

ARPA = Advanced Research Project Agency
NSF = National Science Foundation

Introduction (1)

- TCP/IP
  - Used to provide data communication between hosts
    - How to delivery data reliably
    - How to address remote host on the network
    - How to handle different type of hardware device
  - 4 layers architecture
    - Each layer perform certain tasks
    - Each layer only need to know how to pass data to adjacent layers

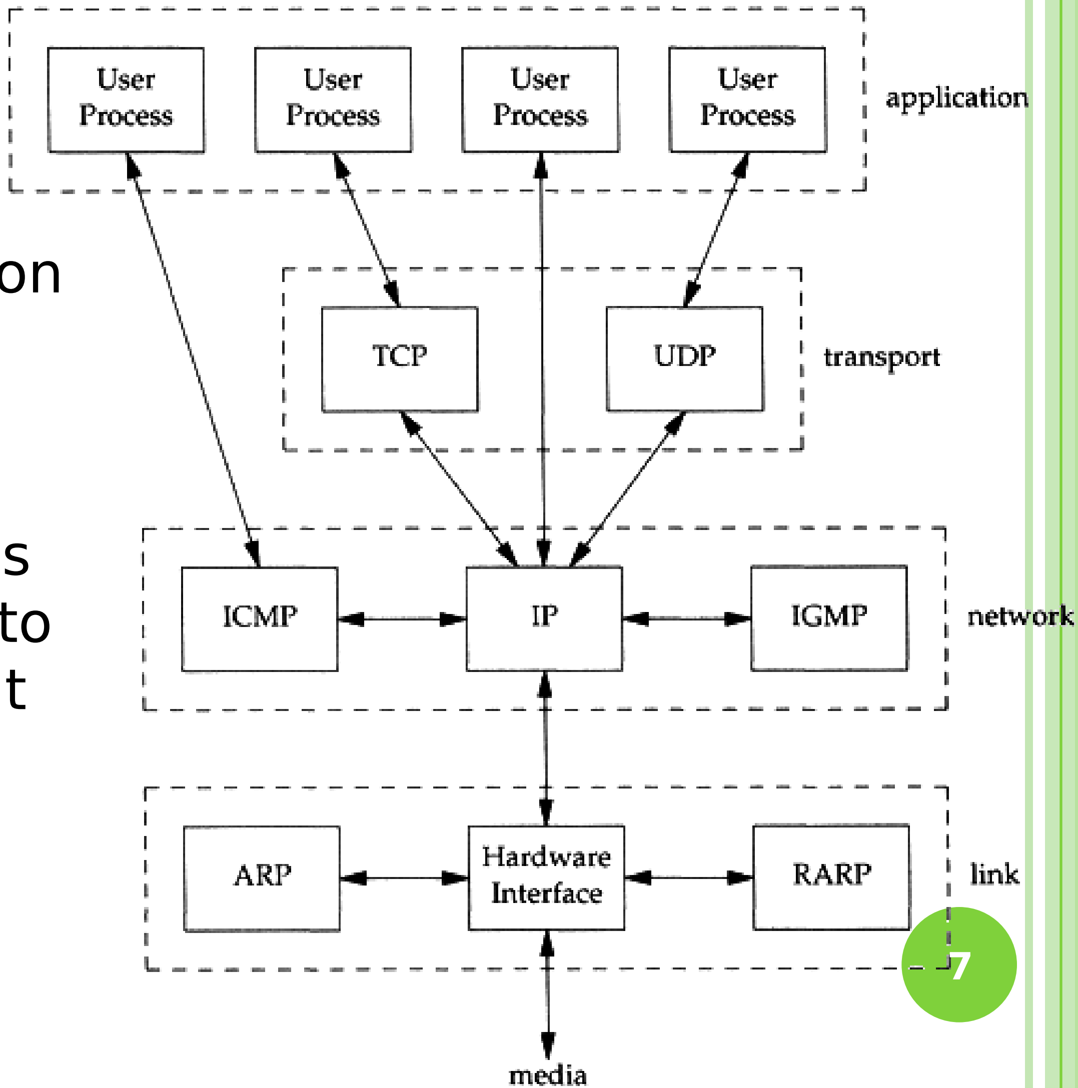


Introduction (2)

- Four layer architecture
  - Link Layer (Data Link Layer)
    - Network Interface Card + Driver
    - Handle all the hardware detail of whatever type of media
  - Network Layer (Internet Layer)
    - Handle the movement of packets on the network
  - Transport Layer
    - Provide end-to-end data delivery services
  - Application Layer
    - Handle details of the particular application

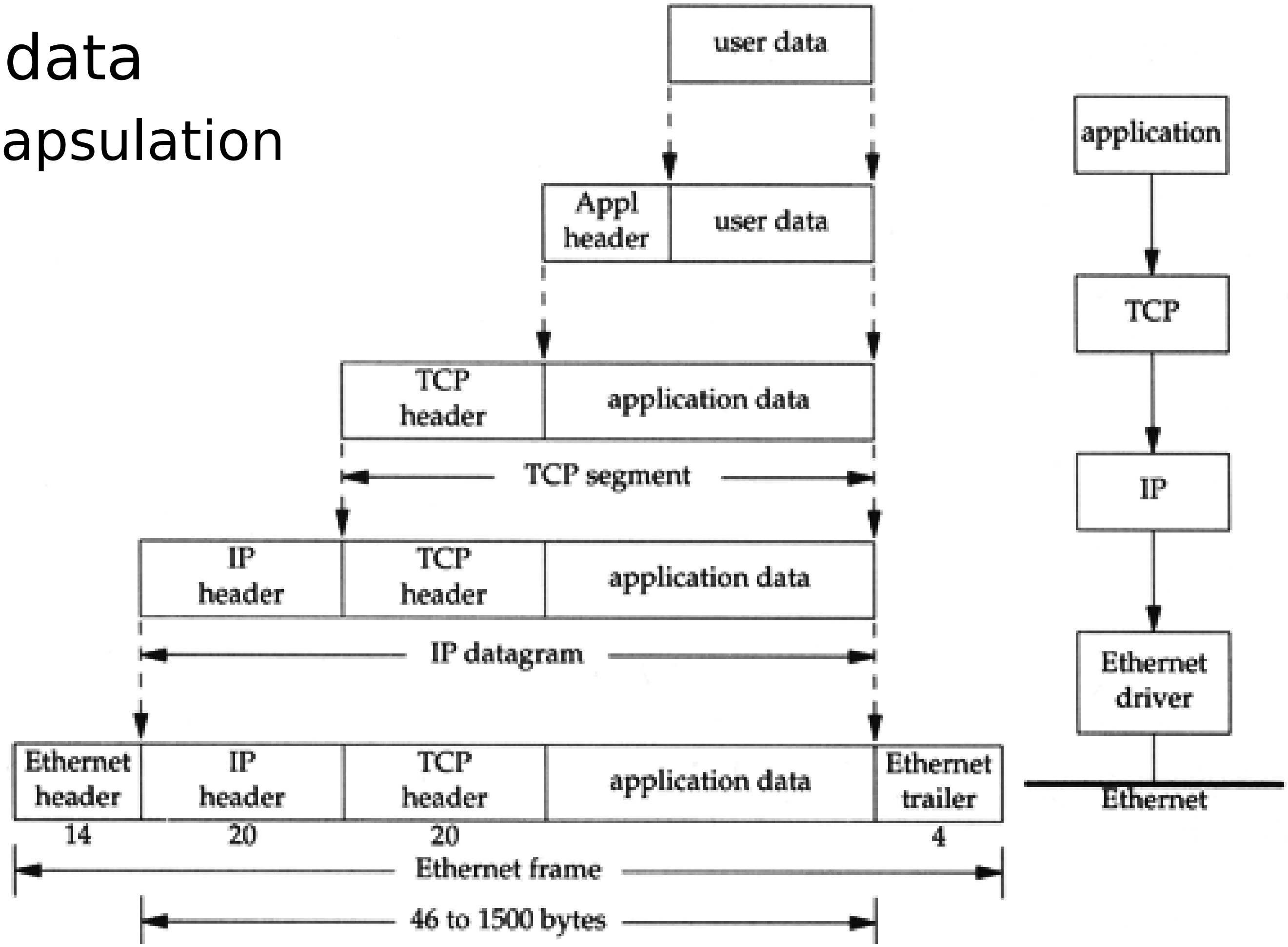
Introduction (3)

- Each layer has several protocols
  - A layer define a data communication function that may be performed by certain protocols
  - A protocol provides a service suitable to the function of that layer



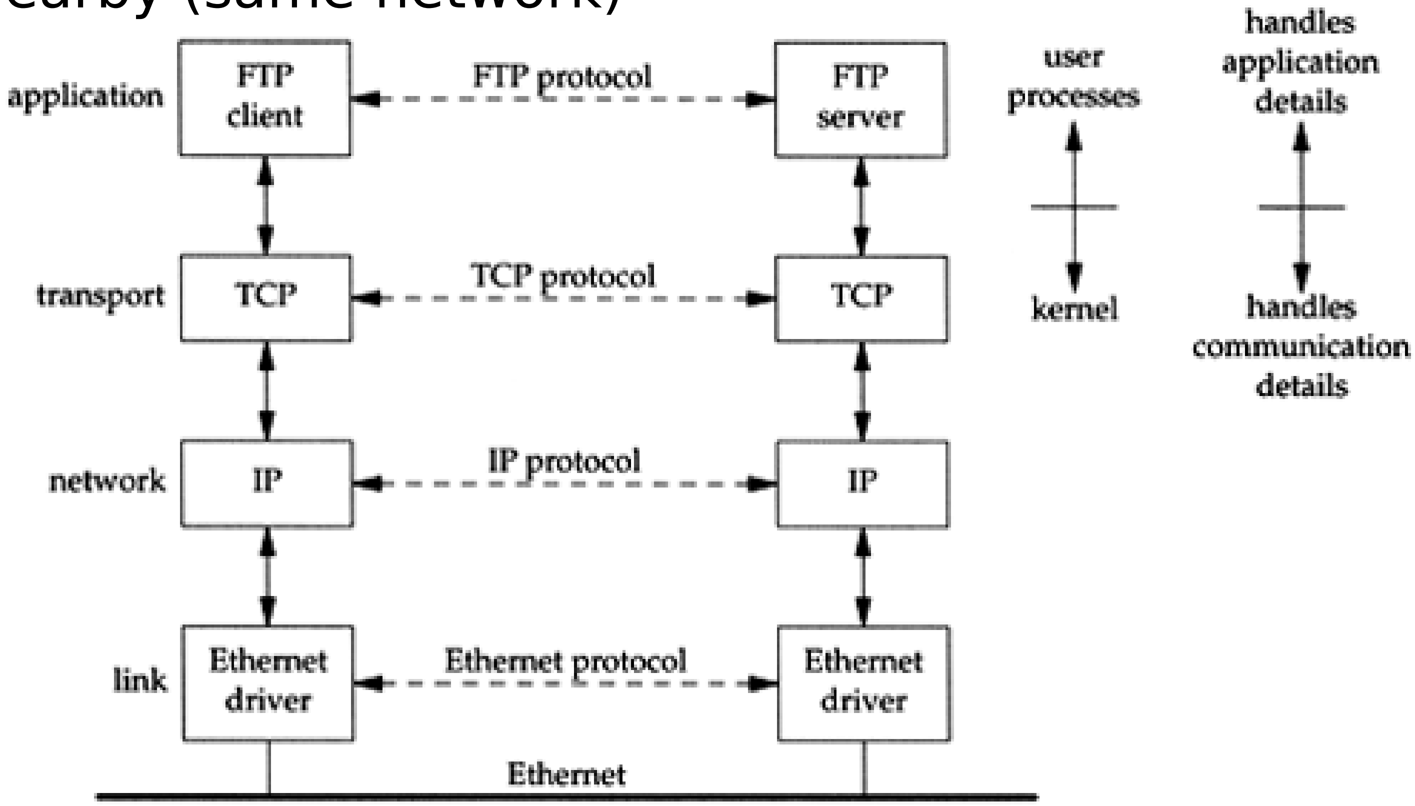
Introduction (4)

- Send data
  - encapsulation



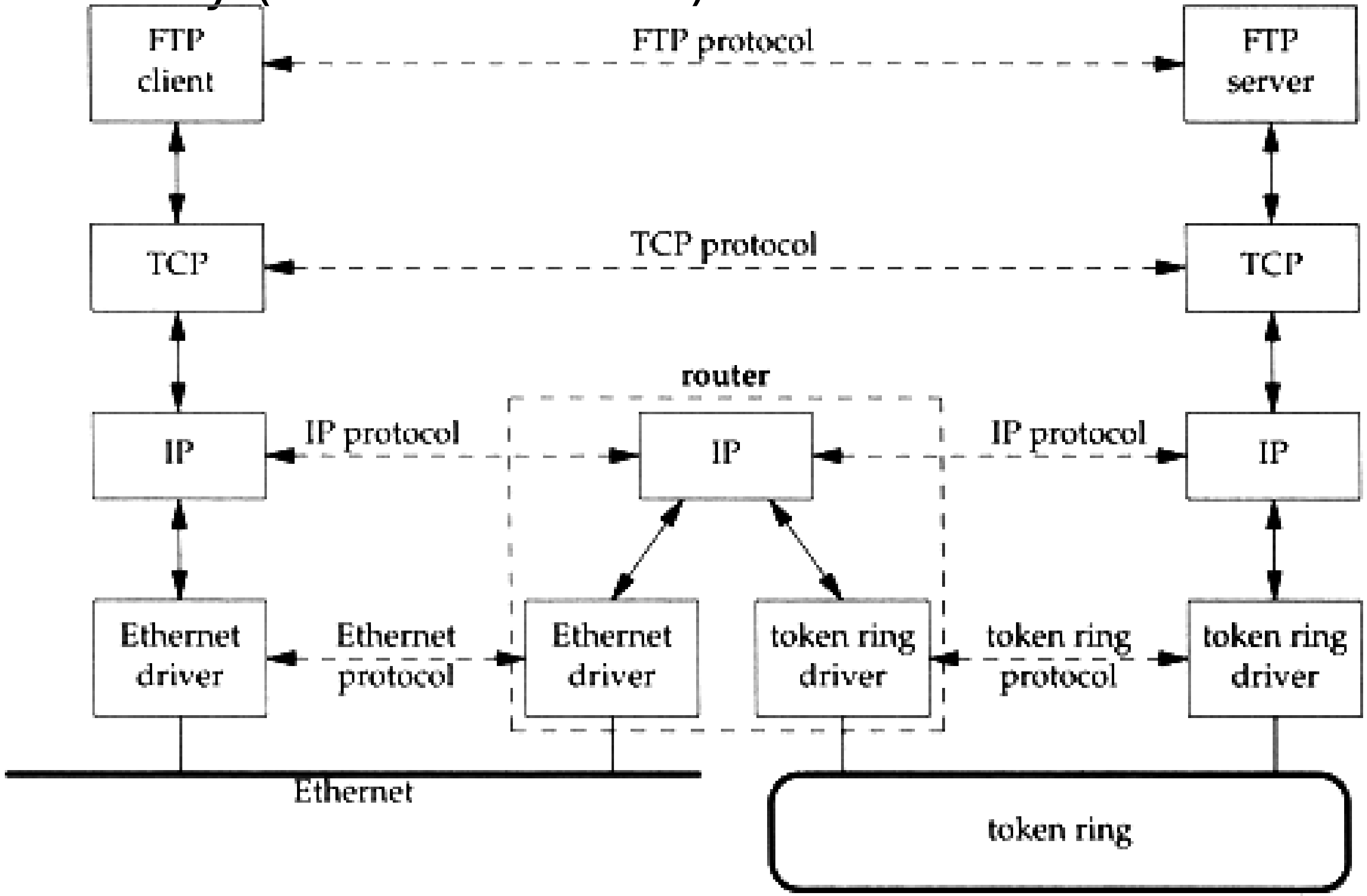
Introduction (5)

- Addressing
  - Nearby (same network)



Introduction (6)

- Addressing
  - Faraway (across network)

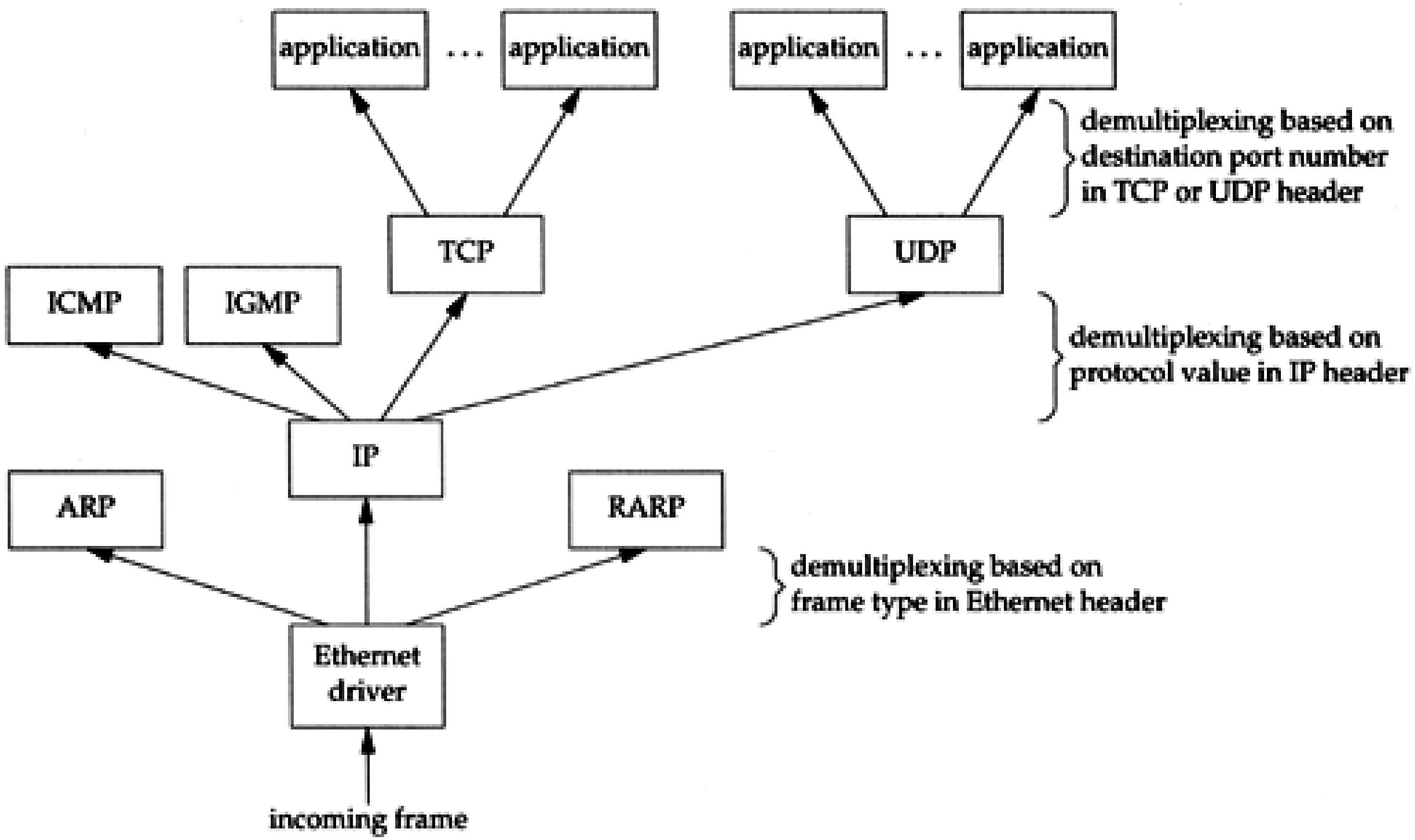


Introduction (7)

- Addressing
  - MAC Address
    - Media Access Control Address
    - 48-bit Network Interface Card Hardware Address
      - 24bit manufacture ID
      - 24bit serial number
    - Ex:
      - 00:07:e9:10:e6:6b
  - IP Address
    - 32-bit Internet Address (IPv4)
    - Ex:
      - 140.113.209.64
  - Port
    - 16-bit uniquely identify application (1 ~ 65536)
    - Ex:
      - FTP port 21, ssh port 22, telnet port 23

Introduction (8)

- Receive Data
  - Demultiplexing



Link Layer

Link Layer
– Introduction of Link Layer

- Purpose of the link layer
  - Send and receive IP datagram for IP module
  - ARP request and reply
  - RARP request and reply

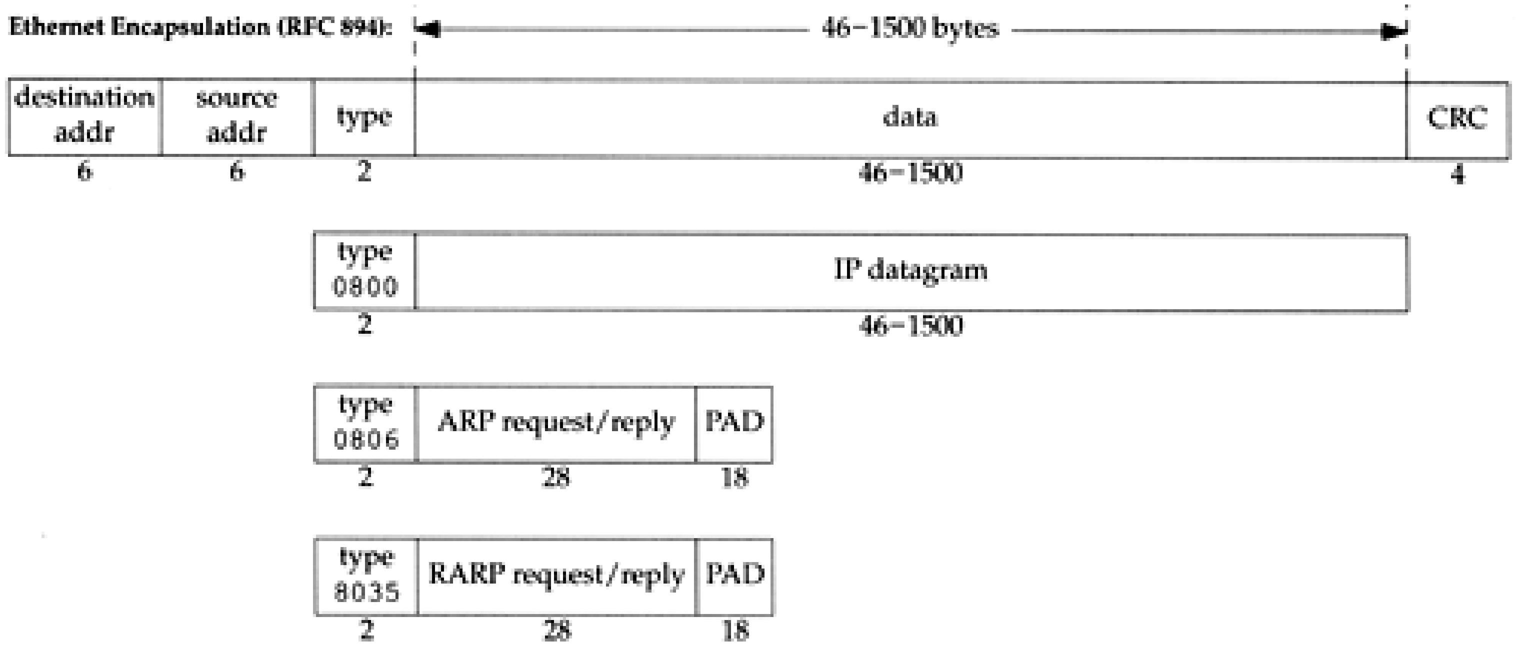
- TCP/IP support various link layers, depending on the type of hardware used:
  - Ethernet
    - Teach in this class
  - Token Ring
  - FDDI (Fiber Distributed Data Interface)
  - Serial Line

Link Layer
– Ethernet

- Features
  - Predominant form of local LAN technology used today
  - Use CSMA/CD
    - Carrier Sense, Multiple Access with Collision Detection
  - Use 48bit MAC address
  - Operate at 10 Mbps
    - Fast Ethernet at 100 Mbps
    - Gigabit Ethernet at 1000Mbps
  - Ethernet frame format is defined in RFC894
    - This is the actually used format in reality

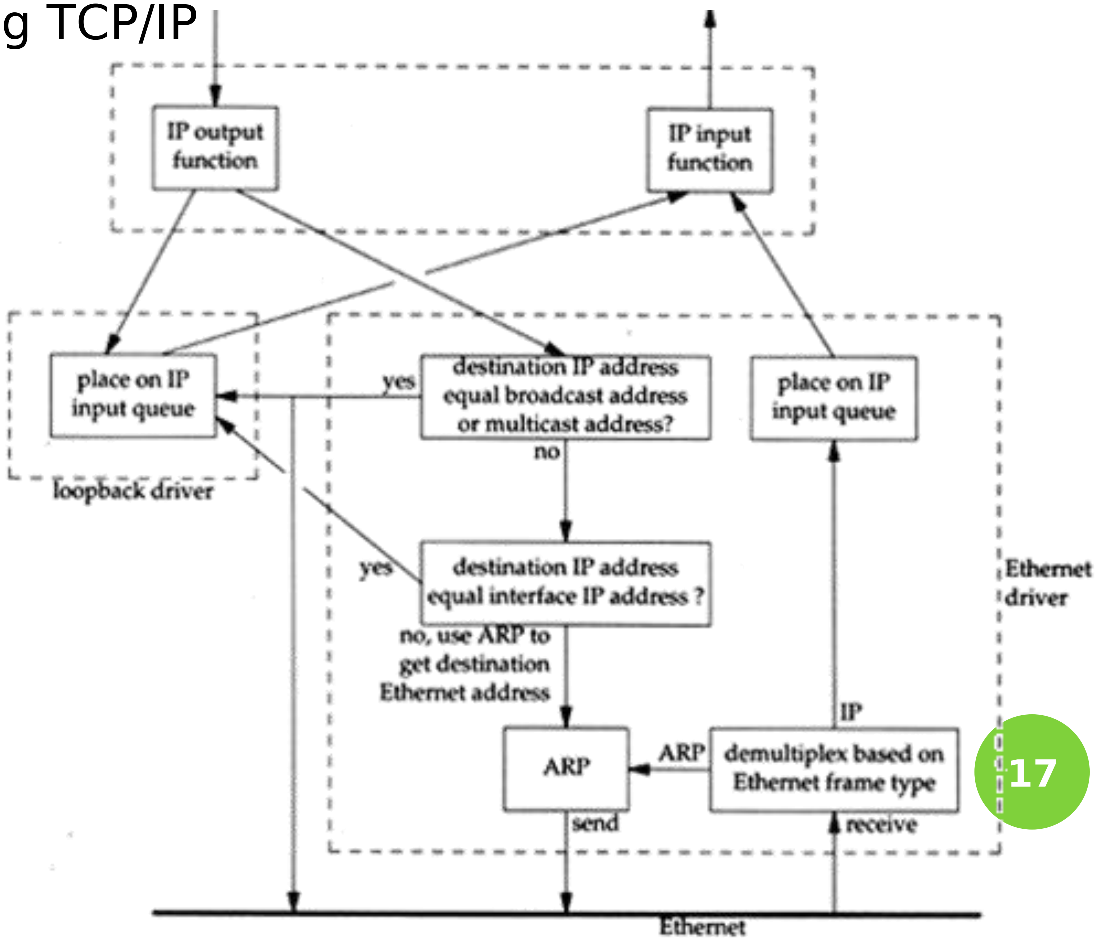
Link Layer
– Ethernet Frame Format

- 48bit hardware address
  - For both destination and source address
- 16bit type is used to specify the type of following data
  - 0800 → IP datagram
  - 0806 → ARP, 8035 → RARP



Link Layer
– Loopback Interface

- Pseudo NIC
  - Allow client and server on the same host to communicate with each other using TCP/IP
  - IP
    - 127.0.0.1
  - Hostname
    - localhost



Link Layer – MTU

- Maximum Transmission Unit
  - Limit size of payload part of Ethernet frame
    - 1500 bytes
  - If the IP datagram is larger than MTU,
    - IP performs “fragmentation”
- MTU of various physical device
- Path MTU
  - Smallest MTU of any data link MTU between the two hosts
  - Depend on route

Network	MTU (bytes)
Hyperchannel	65535
16 Mbits/sec token ring (IBM)	17914
4 Mbits/sec token ring (IEEE 802.5)	4464
FDDI	4352
Ethernet	1500
IEEE 802.3/802.2	1492
X.25	576
Point-to-point (low delay)	296

Link Layer
– MTU

```
x:~ -lwhsu- ifconfig
em0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 9000
        options=b<RXCSUM,TXCSUM,VLAN_MTU>
        inet 192.168.7.1 netmask 0xffffff00 broadcast 192.168.7.255
        ether 00:0e:0c:01:d7:c8
        media: Ethernet autoselect (1000baseTX <full-duplex>)
        status: active
fxp0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        options=b<RXCSUM,TXCSUM,VLAN_MTU>
        inet 140.113.17.24 netmask 0xffffff00 broadcast 140.113.17.255
        ether 00:02:b3:99:3e:71
        media: Ethernet autoselect (100baseTX <full-duplex>)
        status: active
```

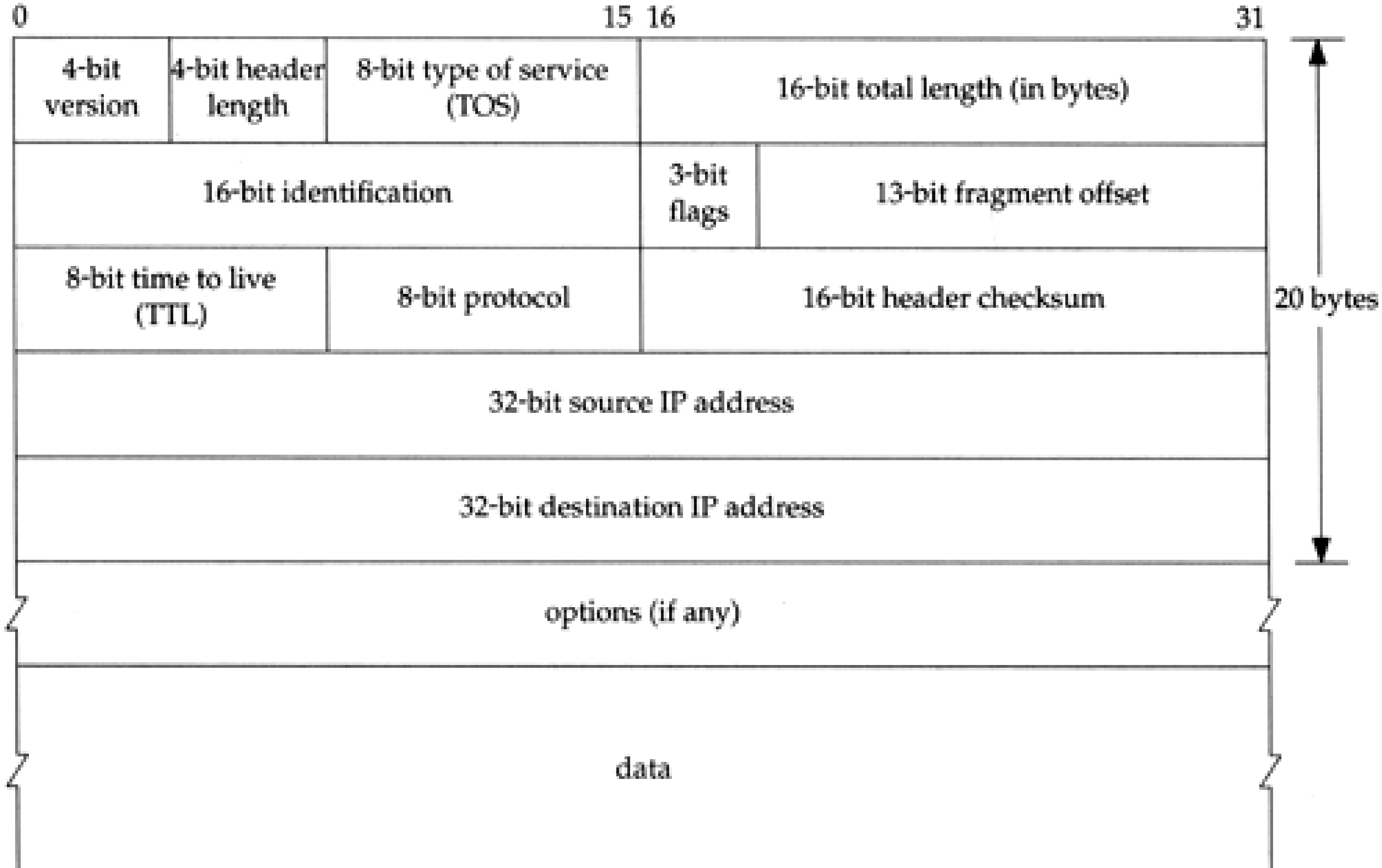
Network Layer

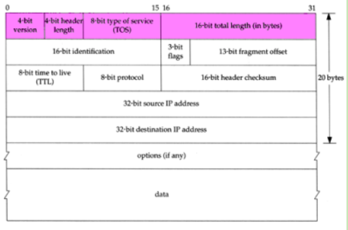
Network Layer
– Introduction to Network Layer

- Unreliable and connectionless datagram delivery service
  - IP Routing
  - IP provides best effort service (unreliable)
  - IP datagram can be delivered out of order (connectionless)
- Protocols using IP
  - TCP, UDP, ICMP, IGMP

Network Layer
– IP Header (1)

- 20 bytes in total length, excepts options



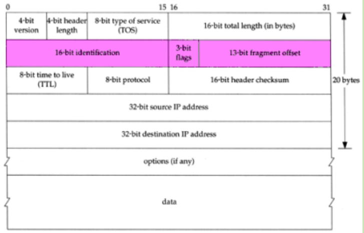


Network Layer – IP Header (2)

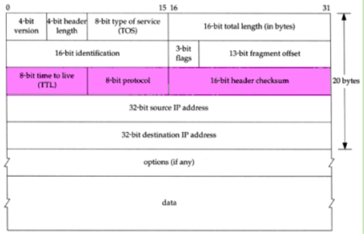
- Version (4bit)
  - 4 for IPv4 and 6 for IPv6
- Header length (4bit)
  - The number of 32bit words in the header (15*4=60bytes)
  - Normally, the value is 5 (no option)
- TOS-Type of Service (8bit)
  - 3bit precedence + 4bit TOS + 1bit unused
- Total length (16bit)
  - Total length of the IP datagram in bytes

Application	Minimize delay	Maximize throughput	Maximize reliability	Minimize monetary cost	Hex value
Telnet/Rlogin	1	0	0	0	0x10
FTP					
control	1	0	0	0	0x10
data	0	1	0	0	0x08
any bulk data	0	1	0	0	0x08
TFTP	1	0	0	0	0x10
SMTP					
command phase	1	0	0	0	0x10
data phase	0	1	0	0	0x08

Network Layer – IP Header (3)



- Identification (16bit)
- Fragmentation offset (13bit)
- Flags (3bit)
  - All these three fields are used for fragmentation



Network Layer – IP Header (4)

- TTL (8bit)
  - Limit of next hop count of routers
- Protocol (8bit)
  - Used to demultiplex to other protocols
  - TCP, UDP, ICMP, IGMP
- Header checksum (16bit)
  - Calculated over the IP header only
  - If checksum error, IP discards the datagram and no error message is generated

Network Layer – IP Routing (1)

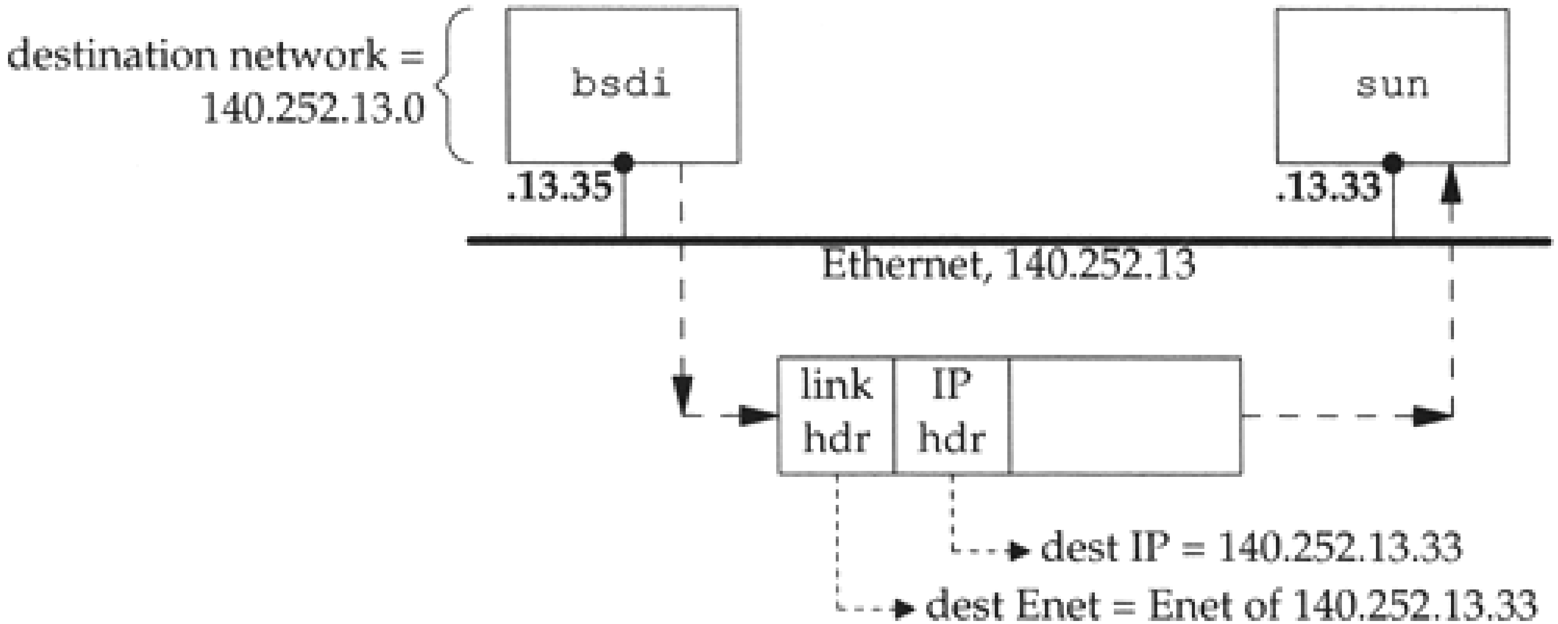
- Difference between Host and Router
  - Router forwards datagram from one of its interface to another, while host does not
  - Almost every Unix system can be configured to act as a router or both
- Router
  - IP layer has a routing table, which is used to store the information for forwarding datagram
  - When router receiving a datagram
    - If Dst. IP = my IP, demultiplex to other protocol
    - Other, forward the IP based on routing table

Network Layer – IP Routing (2)

- Routing table information
  - Destination IP
  - IP address of next-hop router or IP address of a directly connected network
  - Flags
  - Next interface
- IP routing
  - Done on a hop-by-hop basis
  - It assumes that the next-hop router is closer to the destination
  - Steps:
    - Search routing table for complete matched IP address
      - Send to next-hop router or to the directly connected NIC
    - Search routing table for matched network ID
      - Send to next-hop router or to the directly connected NIC
    - Search routing table for default route
      - Send to this default next-hop router
    - host or network unreachable

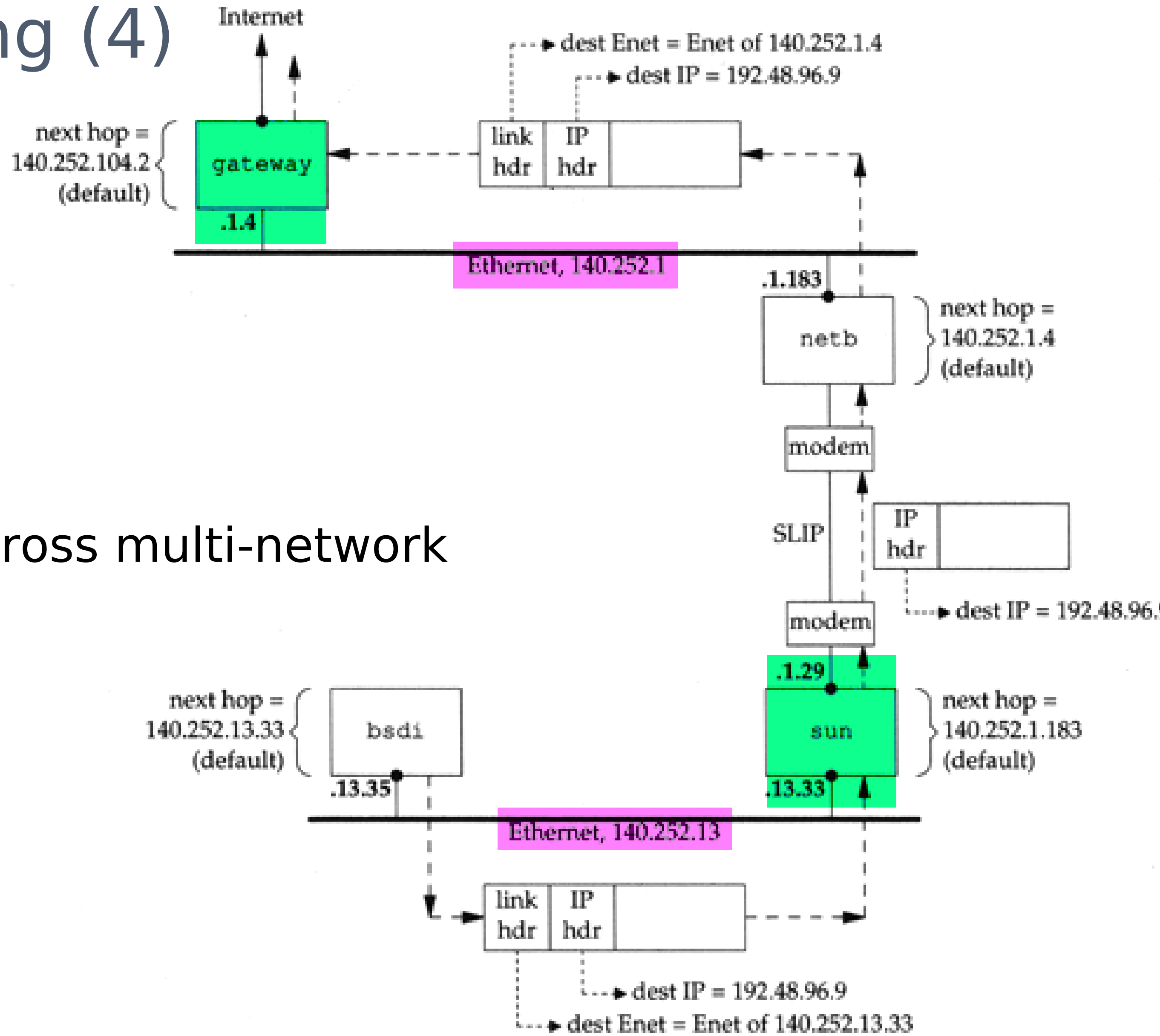
Network Layer
– IP Routing (3)

- Ex1: routing in the same network
  - bsdi: 140.252.13.35
  - sun: 140.252.13.33



Ex Routing table:
140.252.13.33 00:d0:59:83:d9:16 UHLW fxp1

Network Layer – IP Routing (4)



- Ex2:
  - routing across multi-network

Network Layer – IP Address (1)

- 32-bit long
  - Network part
    - Identify a logical network
  - Host part
    - Identify a machine on certain network

- Ex:
  - NCTU
    - Class B address: 140.113.0.0
    - Network ID: 140.113
    - Number of hosts: 255*255 = 65535

- IP address category

Class	1st byte[a]	Format	Comments
A	1-126	N.H.H.H	Very early networks, or reserved for DOD
B	128-191	N.N.H.H	Large sites, usually subnetted, were hard to get
C	192-223	N.N.N.H	Easy to get, often obtained in sets
D	224-239	–	Multicast addresses, not permanently assigned
E	240-254	–	Experimental addresses

a. The values 0 and 255 are special and are not used as the first byte of regular IP addresses. 127 is reserved for the loopback address.

Network Layer
– Subnetting, CIDR, and Netmask (1)

- Problems of Class A or B network
  - Number of hosts is enormous
  - Hard to maintain and management
  - Solution ➔ Subnetting

- Problems of Class C network
  - 255*255*255 number of Class C network make the size of Internet routes huge
  - Solution ➔ Classless Inter-Domain Routing

Network Layer
– Subnetting, CIDR, and Netmask (2)

- Subnetting
  - Borrow some bits from network ID to extends hosts ID
  - Ex:
    - ClassB address : 140.113.0.0
      = 256 ClassC-like IP addresses
      in N.N.N.H subnetting method
    - 140.113.209.0 subnet
  - Benefits of subnetting
    - Reduce the routing table size of Internet's routers
    - Ex:
      - All external routers have only one entry for 140.113 Class B network

Network Layer – Subnetting, CIDR, and Netmask (3)

- Netmask
  - Specify how many bits of network-ID are used for network-ID
  - Continuous 1 bits form the network part
  - Ex:
    - 255.255.255.0 in NCTU-CS example
      - 256 hosts available
    - 255.255.255.248 in ADSL example
      - Only 8 hosts available
  - Shorthand notation
    - Address/prefix-length
      - Ex: 140.113.209.8/24

Network Layer
– Subnetting, CIDR, and Netmask (4)

- How to determine your network ID?
  - Bitwise-AND IP and netmask
  - Ex:
    - **140.113.214.37 & 255.255.255.0 → 140.113.214.0**
    - **140.113.209.37 & 255.255.255.0 → 140.113.209.0**

    - **140.113.214.37 & 255.255.0.0 → 140.113.0.0**
    - **140.113.209.37 & 255.255.0.0 → 140.113.0.0**

    - **211.23.188.78 & 255.255.255.248 → 211.23.188.72**
      - **78 = 01001110**
      - **78 & 248= 01001110 & 11111000 =72**

Network Layer
– Subnetting, CIDR, and Netmask (5)

- In a subnet, not all IP are available
  - The first one IP ➔ network ID
  - The last one IP ➔ broadcast address
  - Ex:

Netmask 255.255.255.0 140.113.209.32/24 140.113.209.0 ➔ network ID 140.113.209.255 ➔ broadcast address 1 ~ 254, total 254 IPs are usable	Netmask 255.255.255.252 211.23.188.78/29 211.23.188.72 ➔ network ID 211.23.188.79 ➔ broadcast address 73 ~ 78, total 6 IPs are usable

Network Layer
– Subnetting, CIDR, and Netmask (6)

- The smallest subnetting
  - Network portion : 30 bits
  - Host portion : 2 bits
  - ➔ 4 hosts, but only 2 IPs are available
- ipcalc
  - /usr/ports/net-mgmt/ipcalc

```
knight:/usr/ports/net-mgmt/ipcalc -lwhsu- ipcalc 140.113.251.213/255.255.255.224
Address:   140.113.251.213      10001100.01110001.11111011.110 10101
Netmask:   255.255.255.224 = 27 11111111.11111111.11111111.111 00000
Wildcard:  0.0.0.31             00000000.00000000.00000000.000 11111
=>
Network:   140.113.251.192/27   10001100.01110001.11111011.110 00000
HostMin:   140.113.251.193      10001100.01110001.11111011.110 00001
HostMax:   140.113.251.222      10001100.01110001.11111011.110 11110
Broadcast: 140.113.251.223      10001100.01110001.11111011.110 11111
Hosts/Net: 30                    Class B
```

Network Layer
– Subnetting, CIDR, and Netmask (7)

- Network configuration for various lengths of netmask

Length[a]	Host bits	Hosts/net[b]	Dec. netmask	Hex netmask
/20	12	4094	255.255.240.0	0xFFFFF000
/21	11	2046	255.255.248.0	0xFFFFF800
/22	10	1022	255.255.252.0	0xFFFFFC00
/23	9	510	255.255.254.0	0xFFFFFE00
/24	8	254	255.255.255.0	0xFFFFFF00
/25	7	126	255.255.255.128	0xFFFFFF80
/26	6	62	255.255.255.192	0xFFFFFFC0
/27	5	30	255.255.255.224	0xFFFFFFE0
/28	4	14	255.255.255.240	0xFFFFFFF0
/29	3	6	255.255.255.248	0xFFFFFFF8
/30	2	2	255.255.255.252	0xFFFFFFFC

Network Layer – Subnetting, CIDR, and Netmask (8)

- CIDR (Classless Inter-Domain Routing)
  - Use address mask instead of old address classes to determine the destination network
  - CIDR requires modifications to routers and routing protocols
    - Need to transmit both destination address and mask
  - Ex:
    - We can merge two ClassC network:
      203.19.68.0/24, 203.19.69.0/24 ➔ 203.19.68.0/23
  - Benefit of CIDR
    - We can allocate continuous ClassC network to organization
      - Reflect physical network topology
      - Reduce the size of routing table

ARP and RARP

Something between

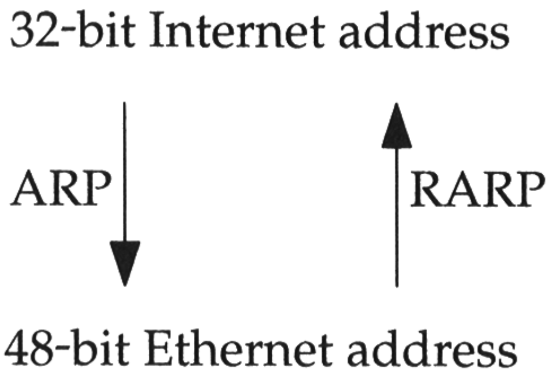
MAC (link layer)

&

IP (network layer)

ARP and RARP

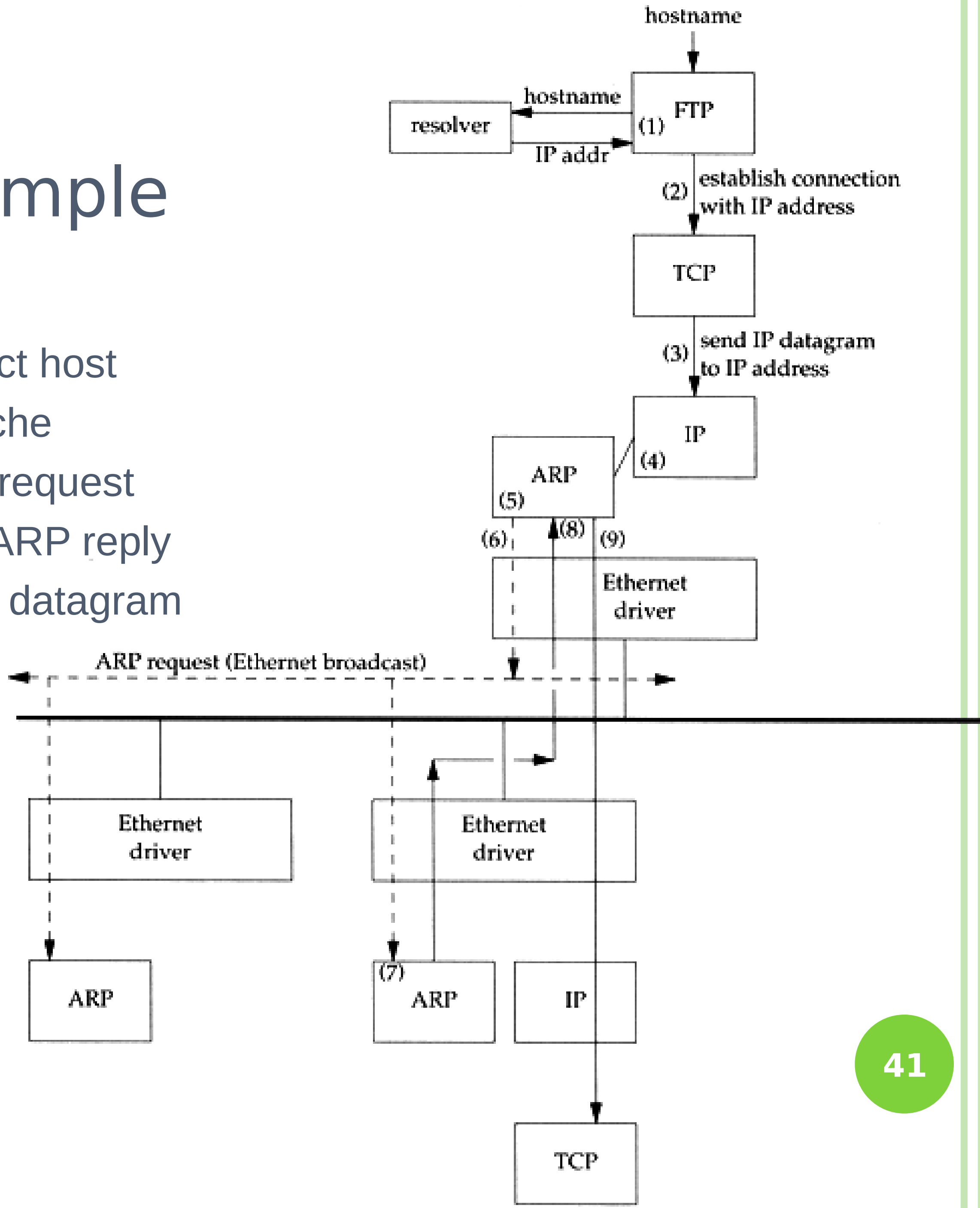
- ARP– Address Resolution Protocol and RARP – Reverse ARP
  - Mapping between IP and Ethernet address



- When an Ethernet frame is sent on LAN from one host to another,
  - It is the 48bit Ethernet address that determines for which interface the frame is destined

ARP and RARP – ARP Example

- Example
  - % ftp bsd1
  - (4) next-hop or direct host
  - (5) Search ARP cache
  - (6) Broadcast ARP request
  - (7) bsd1 response ARP reply
  - (9) Send original IP datagram

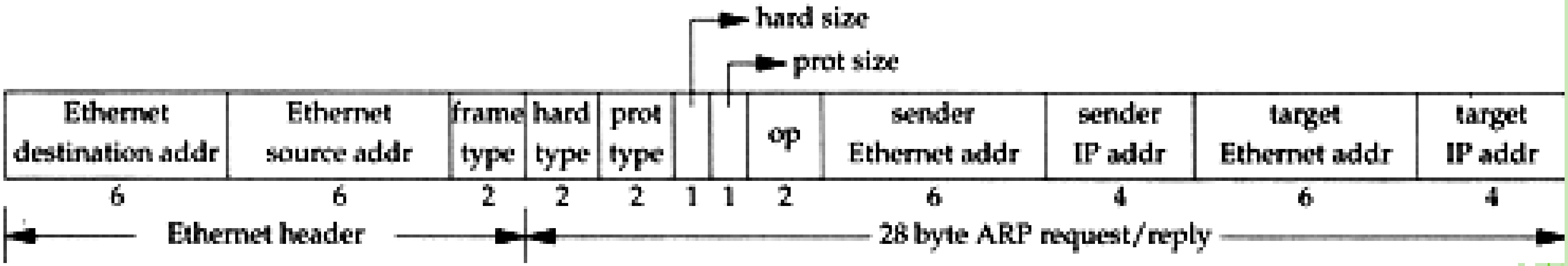


ARP and RARP – ARP Cache

- Maintain recent ARP results
  - come from both ARP request and reply
  - expiration time
    - Complete entry = 20 minutes
    - Incomplete entry = 3 minutes
  - Use arp command to see the cache
  - Ex:
    - % arp –a
    - % arp –da
    - % arp –S 140.113.235.132 00:0e:a6:94:24:6e

```
csduty /home/lwhsu] -lwhsu- arp -a
cshome (140.113.235.101) at 00:0b:cd:9e:74:61 on em0 [ethernet]
bsd1 (140.113.235.131) at 00:11:09:a0:04:74 on em0 [ethernet]
? (140.113.235.160) at (incomplete) on em0 [ethernet]
```

ARP and RARP
– ARP/RARP Packet Format



- Ethernet destination addr: all 1’s (broadcast)
- Known value for IP <-> Ethernet
  - Frame type: 0x0806 for ARP, 0x8035 for RARP
  - Hardware type: type of hardware address (1 for Ethernet)
  - Protocol type: type of upper layer address (0x0800 for IP)
  - Hard size: size in bytes of hardware address (6 for Ethernet)
  - Protocol size: size in bytes of upper layer address (4 for IP)
  - Op: 1, 2, 3, 4 for ARP request, reply, RARP request, reply

ARP and RARP – Use tcpdump to see ARP

- Host 140.113.17.212 → 140.113.17.215
  - Clear ARP cache of 140.113.17.212
    - % sudo arp -d 140.113.17.215
  - Run tcpdump on 140.113.17.215 (**00:11:d8:06:1e:81**)
    - % sudo tcpdump –i sk0 –e arp
    - % sudo tcpdump –i sk0 –n –e arp
    - % sudo tcpdump –i sk0 –n –t –e arp
  - On 140.113.17.212, ssh to 140.113.17.215

```
15:18:54.899779 00:90:96:23:8f:7d > Broadcast, ethertype ARP (0x0806), length 60:
    arp who-has nabsd tell zfs.cs.nctu.edu.tw
15:18:54.899792 00:11:d8:06:1e:81 > 00:90:96:23:8f:7d, ethertype ARP (0x0806), length 42:
    arp reply nabsd is-at 00:11:d8:06:1e:81
```

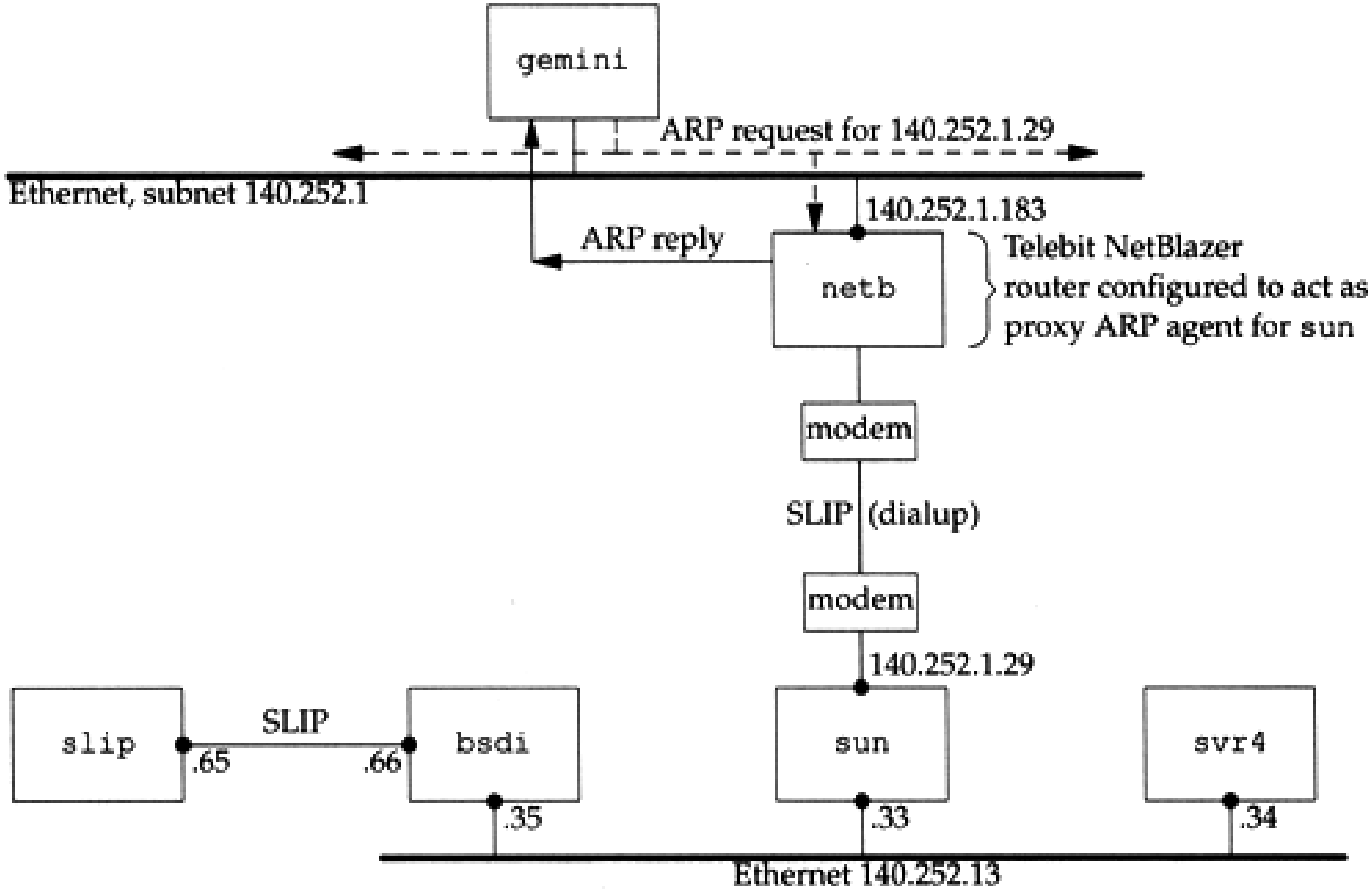
```
15:26:13.847417 00:90:96:23:8f:7d > ff:ff:ff:ff:ff:ff, ethertype ARP (0x0806), length 60:
    arp who-has 140.113.17.215 tell 140.113.17.212
15:26:13.847434 00:11:d8:06:1e:81 > 00:90:96:23:8f:7d, ethertype ARP (0x0806), length 42:
    arp reply 140.113.17.215 is-at 00:11:d8:06:1e:81
```



```
00:90:96:23:8f:7d > ff:ff:ff:ff:ff:ff, ethertype ARP (0x0806), length 60:
    arp who-has 140.113.17.215 tell 140.113.17.212
00:11:d8:06:1e:81 > 00:90:96:23:8f:7d, ethertype ARP (0x0806), length 42:
    arp reply 140.113.17.215 is-at 00:11:d8:06:1e:81
```

ARP and RARP
– Proxy ARP

- Let router answer ARP request on one of its networks for a host on another of its network



ARP and RARP – Gratuitous ARP

- Gratuitous ARP
  - The host sends an ARP request looking for its own IP
  - Provide two features
    - Used to determine whether there is another host configured with the same IP
    - Used to cause any other host to update ARP cache when changing hardware address

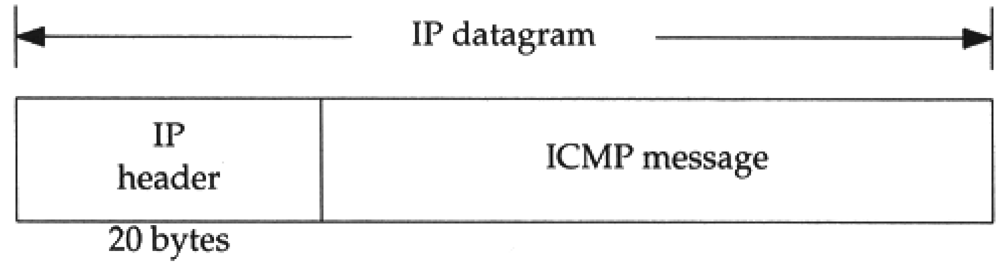
ARP and RARP
– RARP

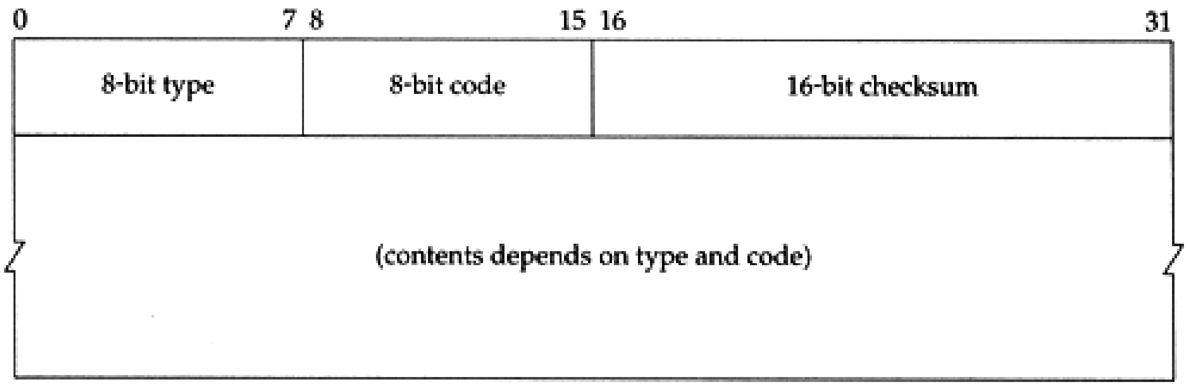
- Principle
  - Used for the diskless system to read its hardware address from the NIC and send an RARP request to gain its IP
- RARP Server Design
  - RARP server must maintain the map from hardware address to an IP address for many host
  - Link-layer broadcast
    - This prevent most routers from forwarding an RARP request

ICMP – Internet Control Message Protocol

ICMP
– Introduction

- Part of the IP layer
  - ICMP messages are transmitted within IP datagram
  - ICMP communicates error messages and other conditions that require attention for other protocols
- ICMP message format





ICMP
– Message Type (1)

type	*code*	Description	Query	Error
0	0	echo reply (Ping reply, Chapter 7)	•	
3		destination unreachable:		
	0	network unreachable (Section 9.3)		•
	1	host unreachable (Section 9.3)		•
	2	protocol unreachable		•
	3	port unreachable (Section 6.5)		•
	4	fragmentation needed but don't-fragment bit set (Section 11.6)		•
	5	source route failed (Section 8.5)		•
	6	destination network unknown		•
	7	destination host unknown		•
	8	source host isolated (obsolete)		•
	9	destination network administratively prohibited		•
	10	destination host administratively prohibited		•
	11	network unreachable for TOS (Section 9.3)		•
	12	host unreachable for TOS (Section 9.3)		•
	13	communication administratively prohibited by filtering		•
	14	host precedence violation		•
	15	precedence cutoff in effect		•
4	0	source quench (elementary flow control, Section 11.11)		•

ICMP – Message Type (2)

5		redirect (Section 9.5):		
	0	redirect for network		•
	1	redirect for host		•
	2	redirect for type-of-service and network		•
	3	redirect for type-of-service and host		•
8	0	echo request (Ping request, Chapter 7)	•	
9	0	router advertisement (Section 9.6)	•	
10	0	router solicitation (Section 9.6)	•	
11		time exceeded:		
	0	time-to-live equals 0 during transit (Traceroute, Chapter 8)		•
	1	time-to-live equals 0 during reassembly (Section 11.5)		•
12		parameter problem:		
	0	IP header bad (catchall error)		•
	1	required option missing		•
13	0	timestamp request (Section 6.4)	•	
14	0	timestamp reply (Section 6.4)	•	
15	0	information request (obsolete)	•	
16	0	information reply (obsolete)	•	
17	0	address mask request (Section 6.3)	•	
18	0	address mask reply (Section 6.3)	•	

ICMP – Query Message
– Address Mask Request/Reply (1)

- Address Mask Request and Reply
  - Used for diskless system to obtain its subnet mask
  - Identifier and sequence number
    - Can be set to anything for sender to match reply with request
  - The receiver will response an ICMP reply with the subnet mask of the receiving NIC

0	8	16	31
TYPE (17 or 18)	CODE (0)	CHECKSUM	
IDENTIFIER		SEQUENCE NUMBER	
ADDRESS MASK			

ICMP – Query Message – Address Mask Request/Reply (2)

- Ex:

```
zfs [/home/lwhsu] -lwhsu- ping -M m sun1.cs.nctu.edu.tw
ICMP_MASKREQ
PING sun1.cs.nctu.edu.tw (140.113.235.171): 56 data bytes
68 bytes from 140.113.235.171: icmp_seq=0 ttl=251 time=0.663 ms mask=255.255.255.0
68 bytes from 140.113.235.171: icmp_seq=1 ttl=251 time=1.018 ms mask=255.255.255.0
68 bytes from 140.113.235.171: icmp_seq=2 ttl=251 time=1.028 ms mask=255.255.255.0
68 bytes from 140.113.235.171: icmp_seq=3 ttl=251 time=1.026 ms mask=255.255.255.0
^C
--- sun1.cs.nctu.edu.tw ping statistics ---
4 packets transmitted, 4 packets received, 0% packet loss
round-trip min/avg/max/stddev = 0.663/0.934/1.028/0.156 ms

zfs [/home/lwhsu] -lwhsu- icmpquery -m sun1
sun1                                    :  0xFFFFFF00
```

※ icmpquery can be found in /usr/ports/net-mgmt/icmpquery

ICMP – Query Message
– Timestamp Request/Reply (1)

- Timestamp request and reply
  - Allow a system to query another for the current time
  - Milliseconds resolution, since midnight UTC
  - Requestor
    - Fill in the originate timestamp and send
  - Reply system
    - Fill in the receive timestamp when it receives the request and the transmit time when it sends the reply

0	8	16	31
TYPE (13 or 14)	CODE (0)	CHECKSUM	
IDENTIFIER		SEQUENCE NUMBER	
ORIGINATE TIMESTAMP			
RECEIVE TIMESTAMP			
TRANSMIT TIMESTAMP			

ICMP – Query Message
– Timestamp Request/Reply (2)

- Ex:

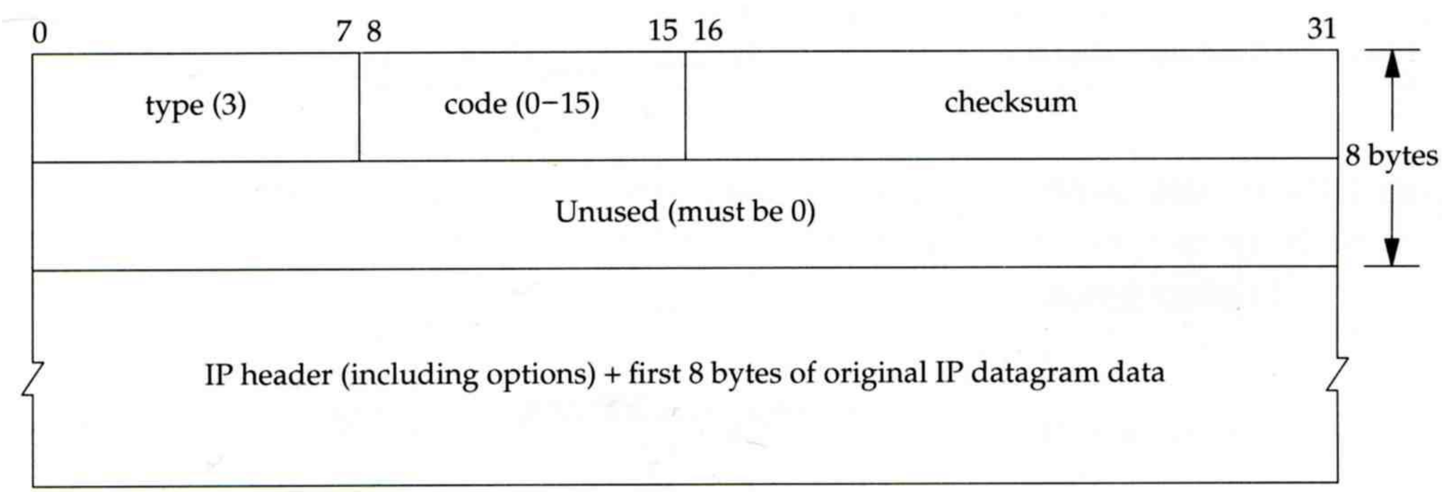
```
zfs [/home/lwhsu] -lwhsu- ping -M time nabsd
ICMP_TSTAMP
PING nabsd.cs.nctu.edu.tw (140.113.17.215): 56 data bytes
76 bytes from 140.113.17.215: icmp_seq=0 ttl=64 time=0.663 ms
    tso=06:47:46 tsr=06:48:24 tst=06:48:24
76 bytes from 140.113.17.215: icmp_seq=1 ttl=64 time=1.016 ms
    tso=06:47:47 tsr=06:48:25 tst=06:48:25

zfs [/home/lwhsu] -lwhsu- icmpquery -t nabsd
nabsd                                   :  14:54:47
```

```
nabsd [/home/lwhsu] -lwhsu- sudo tcpdump -i sk0 -e icmp
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on sk0, link-type EN10MB (Ethernet), capture size 96 bytes
14:48:24.999106 00:90:96:23:8f:7d > 00:11:d8:06:1e:81, ethertype IPv4 (0x0800), length 110:
    zfs.csie.nctu.edu.tw > nabsd: ICMP time stamp query id 18514 seq 0, length 76
14:48:24.999148 00:11:d8:06:1e:81 > 00:90:96:23:8f:7d, ethertype IPv4 (0x0800), length 110:
    nabsd > zfs.csie.nctu.edu.tw: ICMP time stamp reply id 18514 seq 0: org 06:47:46.326,
    recv 06:48:24.998, xmit 06:48:24.998, length 76
14:48:26.000598 00:90:96:23:8f:7d > 00:11:d8:06:1e:81, ethertype IPv4 (0x0800), length 110:
    zfs.csie.nctu.edu.tw > nabsd: ICMP time stamp query id 18514 seq 1, length 76
14:48:26.000618 00:11:d8:06:1e:81 > 00:90:96:23:8f:7d, ethertype IPv4 (0x0800), length 110:
    nabsd > zfs.csie.nctu.edu.tw: ICMP time stamp reply id 18514 seq 1: org 06:47:47.327,
    recv 06:48:25.999, xmit 06:48:25.999, length 76
```

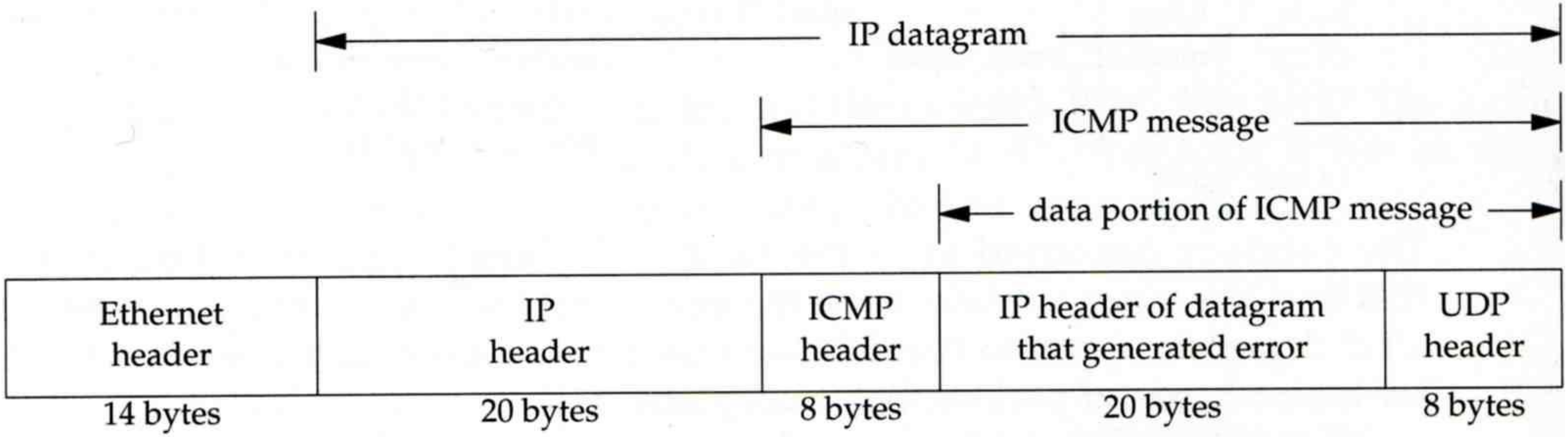
ICMP – Error Message
– Unreachable Error Message

- Format
  - 8bytes ICMP Header
  - Application-depend data portion
    - IP header
      - Let ICMP know how to interpret the 8 bytes that follow
    - first 8bytes that followed this IP header
      - Information about who generates the error



ICMP – Error Message – Port Unreachable (1)

- ICMP port unreachable
  - Type = 3 , code = 3
  - Host receives a UDP datagram but the destination port does not correspond to a port that some process has in use



ICMP – Error Message
– Port Unreachable (2)

- Ex:
  - Using TFTP (Trivial File Transfer Protocol)
    - Original port: 69

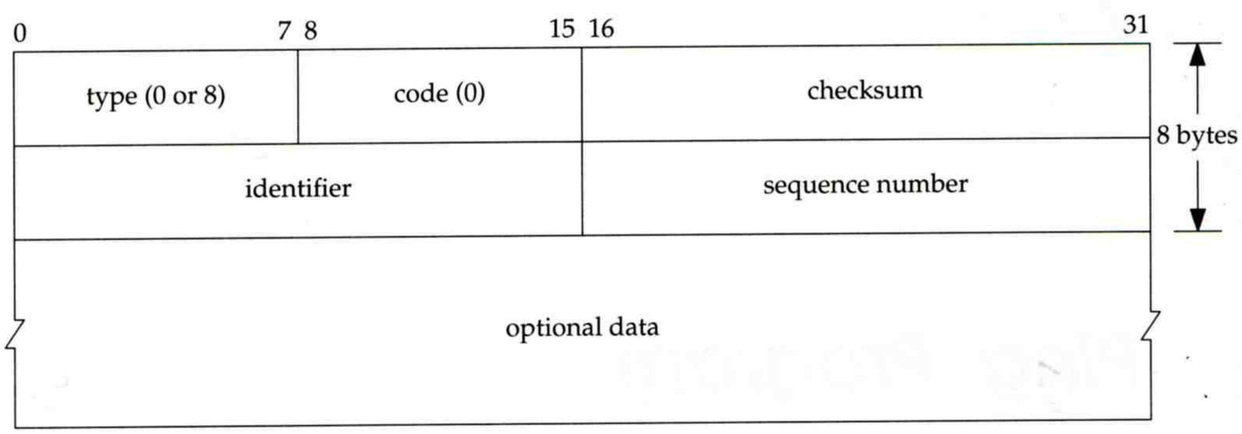
```
zfs [/home/lwhsu] -lwhsu- tftp
tftp> connect localhost 8888
tftp> get temp.foo
Transfer timed out.

tftp>
```

```
zfs [/home/lwhsu] -lwhsu- sudo tcpdump -i lo0
tcpdump: verbose output suppressed, use -v or -vv for full
protocol decode
listening on lo0, link-type NULL (BSD loopback), capture size
96 bytes
15:01:24.788511 IP localhost.62089 > localhost.8888: UDP,
length 16
15:01:24.788554 IP localhost > localhost:
    ICMP localhost udp port 8888 unreachable, length 36
15:01:29.788626 IP localhost.62089 > localhost.8888: UDP,
length 16
15:01:29.788691 IP localhost > localhost:
    ICMP localhost udp port 8888 unreachable, length 36
```

ICMP
– Ping Program (1)

- Use ICMP to test whether another host is reachable
  - Type 8, ICMP echo request
  - Type 0, ICMP echo reply
- ICMP echo request/reply format
  - Identifier: process ID of the sending process
  - Sequence number: start with 0
  - Optional data: any optional data sent must be echoed



ICMP
– Ping Program (2)

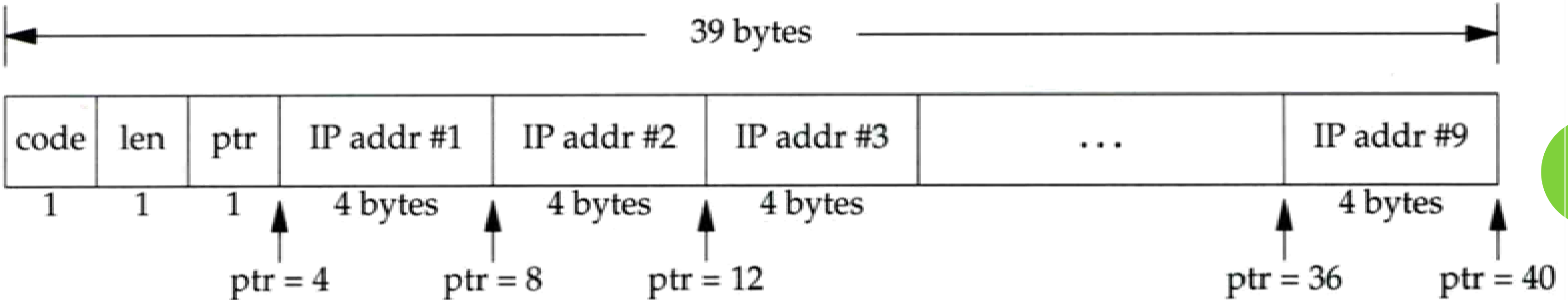
- Ex:
  - zfs ping nabsd
  - execute “tcpdump -i sk0 -X -e icmp” on nabsd

```
zfs [/home/lwhsu] -lwhsu- ping nabsd
PING nabsd.cs.nctu.edu.tw (140.113.17.215): 56 data bytes
64 bytes from 140.113.17.215: icmp_seq=0 ttl=64 time=0.520 ms
```

```
15:08:12.631925 00:90:96:23:8f:7d > 00:11:d8:06:1e:81, ethertype IPv4 (0x0800), length 98:
    zfs.csie.nctu.edu.tw > nabsd: ICMP echo request, id 56914, seq 0, length 64
        0x0000:  4500 0054 f688 0000 4001 4793 8c71 11d4  E..T....@.G..q..
        0x0010:  8c71 11d7 0800 a715 de52 0000 45f7 9f35  .q.......R..E..5
        0x0020:  000d a25a 0809 0a0b 0c0d 0e0f 1011 1213  ...Z............
        0x0030:  1415 1617 1819 1a1b 1c1d 1e1f 2021 2223  .............!"#
        0x0040:  2425 2627 2829 2a2b 2c2d 2e2f 3031 3233  $%&'()*+,-./0123
        0x0050:  3435                                     45
15:08:12.631968 00:11:d8:06:1e:81 > 00:90:96:23:8f:7d, ethertype IPv4 (0x0800), length 98:
     nabsd > zfs.csie.nctu.edu.tw: ICMP echo reply, id 56914, seq 0, length 64
        0x0000:  4500 0054 d97d 0000 4001 649e 8c71 11d7  E..T.}..@.d..q..
        0x0010:  8c71 11d4 0000 af15 de52 0000 45f7 9f35  .q.......R..E..5
        0x0020:  000d a25a 0809 0a0b 0c0d 0e0f 1011 1213  ...Z............
        0x0030:  1415 1617 1819 1a1b 1c1d 1e1f 2021 2223  .............!"#
        0x0040:  2425 2627 2829 2a2b 2c2d 2e2f 3031 3233  $%&'()*+,-./0123
        0x0050:  3435                                     45
```

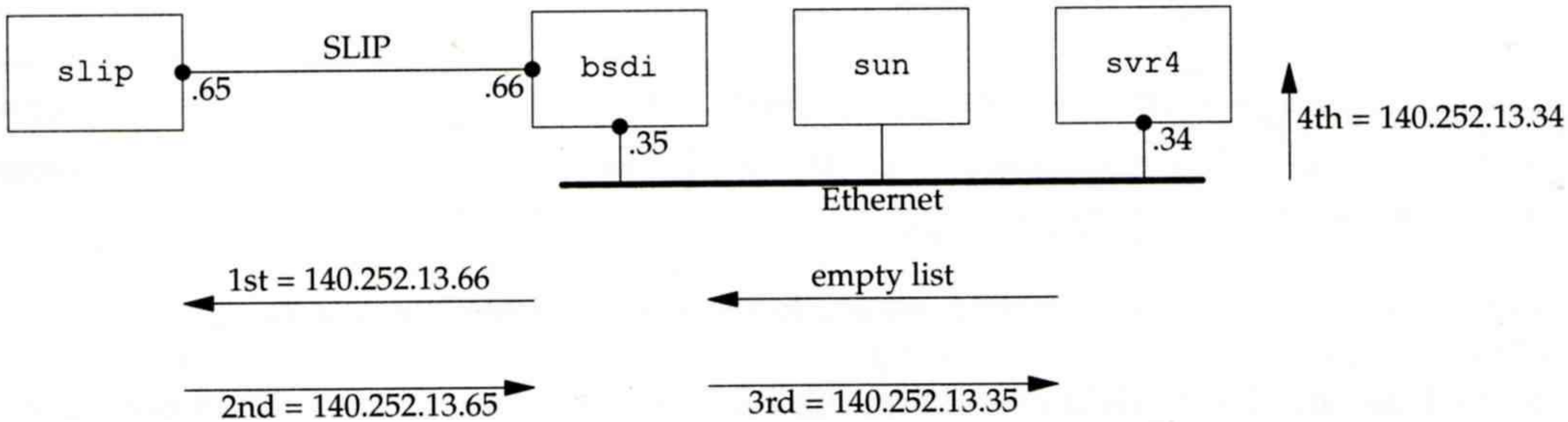
ICMP
– Ping Program (3)

- To get the route that packets take to network host
  - Taking use of “IP Record Route Option”
  - Command: ping -R
  - Cause every router that handles the datagram to add its (outgoing) IP address to a list in the options field.
  - Format of Option field for IP RR Option
    - code: type of IP Option (7 for RR)
    - len: total number of bytes of the RR option
    - ptr:4 ~ 40 used to point to the next IP address
  - Only 9 IP addresses can be stored
    - Limitation of IP header



ICMP
– Ping Program (4)

- Example:




```
svr4 % ping -R slip
PING slip (140.252.13.65): 56 data bytes
64 bytes from 140.252.13.65: icmp_seq=0 ttl=254 time=280 ms
RR:     bsdi (140.252.13.66)
        slip (140.252.13.65)
        bsdi (140.252.13.35)
        svr4 (140.252.13.34)
64 bytes from 140.252.13.65: icmp_seq=1 ttl=254 time=280 ms (same route)
64 bytes from 140.252.13.65: icmp_seq=2 ttl=254 time=270 ms (same route)
^?
--- slip ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max = 270/276/280 ms
```

ICMP
– Ping Program (5)

- Example

```
zfs [/home/lwhsu] -lwhsu- ping -R www.nctu.edu.tw
PING www.nctu.edu.tw (140.113.250.5): 56 data bytes
64 bytes from 140.113.250.5: icmp_seq=0 ttl=61 time=2.361 ms
RR:     ProjE27-253.NCTU.edu.tw (140.113.27.253)
        140.113.0.57
        CC250-gw.NCTU.edu.tw (140.113.250.253)
        www.NCTU.edu.tw (140.113.250.5)
        www.NCTU.edu.tw (140.113.250.5)
        140.113.0.58
        ProjE27-254.NCTU.edu.tw (140.113.27.254)
        e3rtn.csie.nctu.edu.tw (140.113.17.254)
        zfs.csie.nctu.edu.tw (140.113.17.212)
64 bytes from 140.113.250.5: icmp_seq=1 ttl=61 time=3.018 ms    (same route)
```

```
zfs [/home/lwhsu] -lwhsu- sudo tcpdump -v -n -i dc0 -e icmp
tcpdump: listening on dc0, link-type EN10MB (Ethernet), capture size 96 bytes
22:57:04.507271 00:90:96:23:8f:7d > 00:90:69:64:ec:00, ethertype IPv4 (0x0800), length 138:
   (tos 0x0, ttl  64, id 17878, offset 0, flags [none], proto: ICMP (1), length: 124,
   options ( RR (7) len 390.0.0.00.0.0.00.0.0.00.0.0.00.0.0.00.0.0.00.0.0.00.0.0.00.0.0.0EOL
   (0) len 1 )) 140.113.17.212 > 140.113.250.5: ICMP echo request, id 45561, seq 0, length 64
22:57:04.509521 00:90:69:64:ec:00 > 00:90:96:23:8f:7d, ethertype IPv4 (0x0800), length 138:
   (tos 0x0, ttl  61, id 33700, offset 0, flags [none], proto: ICMP (1), length: 124,
   options ( RR (7) len 39140.113.27.253, 140.113.0.57, 140.113.250.253, 140.113.250.5,
   140.113.250.5, 140.113.0.58, 140.113.27.254, 140.113.17.254, 0.0.0.0EOL (0) len 1 ))
   140.113.250.5 > 140.113.17.212: ICMP echo reply, id 45561, seq 0, length 64
```

Traceroute Program (1)

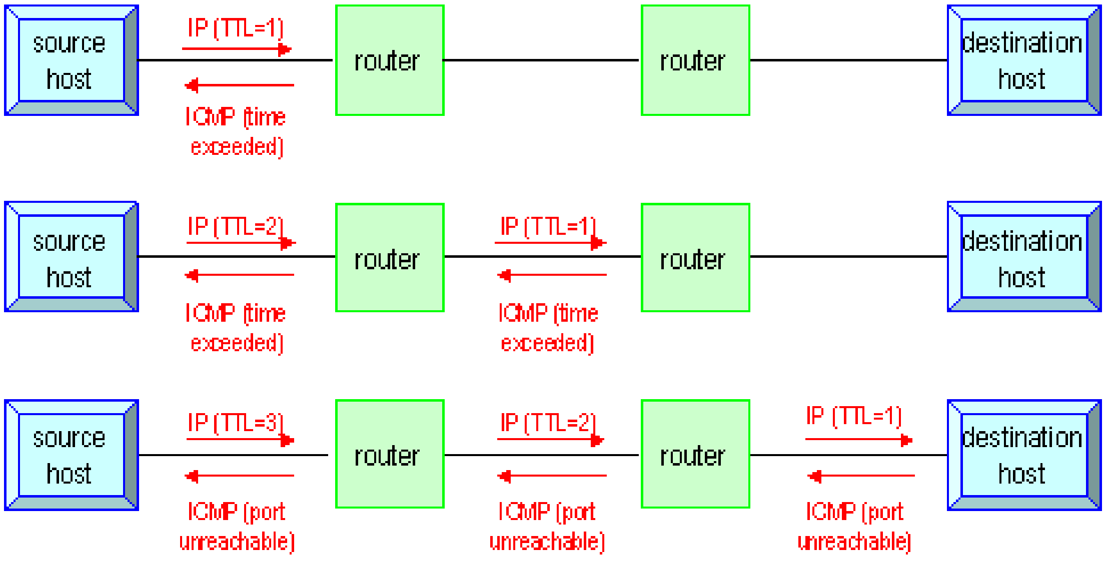
- To print the route packets take to network host

- Drawbacks of IP RR options (ping -R)
  - Not all routers have supported the IP RR option
  - Limitation of IP header length

- Background knowledge of traceroute
  - When a router receive a datagram, , it will decrement the TTL by one
  - When a router receive a datagram with TTL = 0 or 1,
    - it will through away the datagram and
    - sends back a "Time exceeded" ICMP message
  - Unused UDP port will generate a "port unreachable" ICMP message

Traceroute Program (2)

- Operation of traceroute
  - Send UDP with port > 30000, encapsulated with IP header with TTL = 1, 2, 3, … continuously
  - When router receives the datagram and TTL = 1, it returns a "Time exceed" ICMP message
  - When destination host receives the datagram and TTL = 1, it returns a "Port unreachable" ICMP message



Traceroute Program (3)

- Time exceed ICMP message
  - Type = 11, code = 0 or 1
    - Code = 0 means TTL=0 during transit
    - Code = 1 means TTL=0 during reassembly
  - First 8 bytes of datagram
    - UDP header

0	8	16 31
TYPE (11)	CODE (0 or 1)	CHECKSUM
UNUSED (MUST BE ZERO)		
INTERNET HEADER + FIRST 64 BITS OF DATAGRAM		
. . .		

Traceroute Program (4)

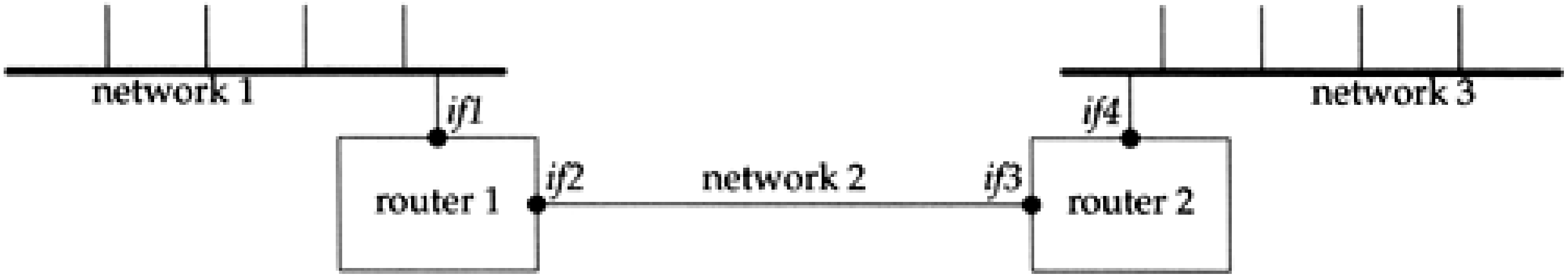
- Ex:

```
nabsd [/home/lwhsu] -lwhsu- traceroute bsd1.cs.nctu.edu.tw
traceroute to bsd1.cs.nctu.edu.tw (140.113.235.131), 64 hops max, 40 byte packets
 1  e3rtn.csie.nctu.edu.tw (140.113.17.254)  0.377 ms  0.365 ms  0.293 ms
 2  ProjE27-254.NCTU.edu.tw (140.113.27.254)  0.390 ms  0.284 ms  0.391 ms
 3  140.113.0.58 (140.113.0.58)  0.292 ms  0.282 ms  0.293 ms
 4  140.113.0.165 (140.113.0.165)  0.492 ms  0.385 ms  0.294 ms
 5  bsd1.cs.nctu.edu.tw (140.113.235.131)  0.393 ms  0.281 ms  0.393 ms
```

```
nabsd [/home/lwhsu] -lwhsu- sudo tcpdump -i sk0 -t icmp
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on sk0, link-type EN10MB (Ethernet), capture size 96 bytes
IP e3rtn.csie.nctu.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP e3rtn.csie.nctu.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP e3rtn.csie.nctu.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP ProjE27-254.NCTU.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP ProjE27-254.NCTU.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP ProjE27-254.NCTU.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP 140.113.0.58 > nabsd: ICMP time exceeded in-transit, length 36
IP 140.113.0.58 > nabsd: ICMP time exceeded in-transit, length 36
IP 140.113.0.58 > nabsd: ICMP time exceeded in-transit, length 36
IP 140.113.0.165 > nabsd: ICMP time exceeded in-transit, length 36
IP 140.113.0.165 > nabsd: ICMP time exceeded in-transit, length 36
IP 140.113.0.165 > nabsd: ICMP time exceeded in-transit, length 36
IP bsd1.cs.nctu.edu.tw > nabsd: ICMP bsd1.cs.nctu.edu.tw udp port 33447 unreachable, length 36
IP bsd1.cs.nctu.edu.tw > nabsd: ICMP bsd1.cs.nctu.edu.tw udp port 33448 unreachable, length 36
IP bsd1.cs.nctu.edu.tw > nabsd: ICMP bsd1.cs.nctu.edu.tw udp port 33449 unreachable, length 36
```

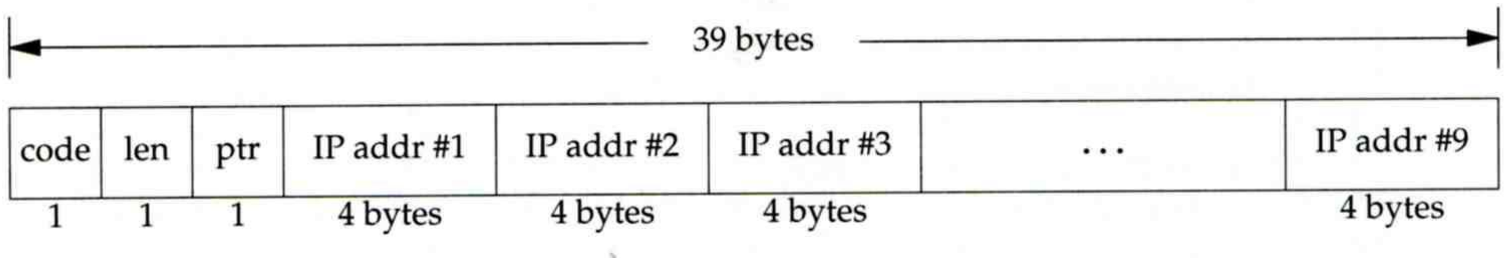
Traceroute Program (5)

- The router IP in traceroute is the interface that receives the datagram. (incoming IP)
  - Traceroute from left host to right host
    - if1, if3
  - Traceroute from right host to left host
    - if4, if2



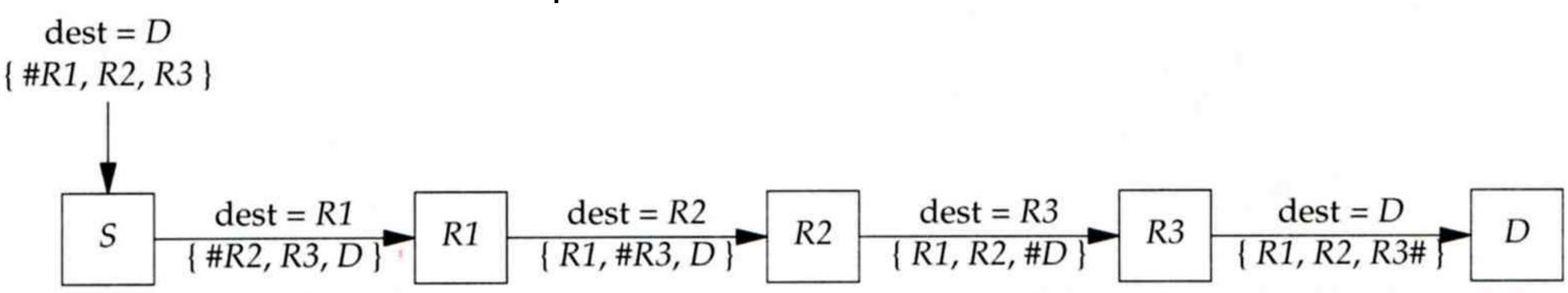
Traceroute Program – IP Source Routing Option (1)

- Source Routing
  - Sender specifies the route
- Two forms of source routing
  - Strict source routing
    - Sender specifies the exact path that the IP datagram must follow
  - Loose source routing
    - As strict source routing, but the datagram can pass through other routers between any two addresses in the list
- Format of IP header option field
  - Code = 0x89 for strict and code = 0x83 for loose SR option



Traceroute Program – IP Source Routing Option (2)

- Scenario of source routing
  - Sending host
    - Remove first entry and append destination address in the final entry of the list
  - Receiving router != destination
    - Loose source route, forward it as normal
  - Receiving router = destination
    - Next address in the list becomes the destination
    - Change source address
    - Increment the pointer

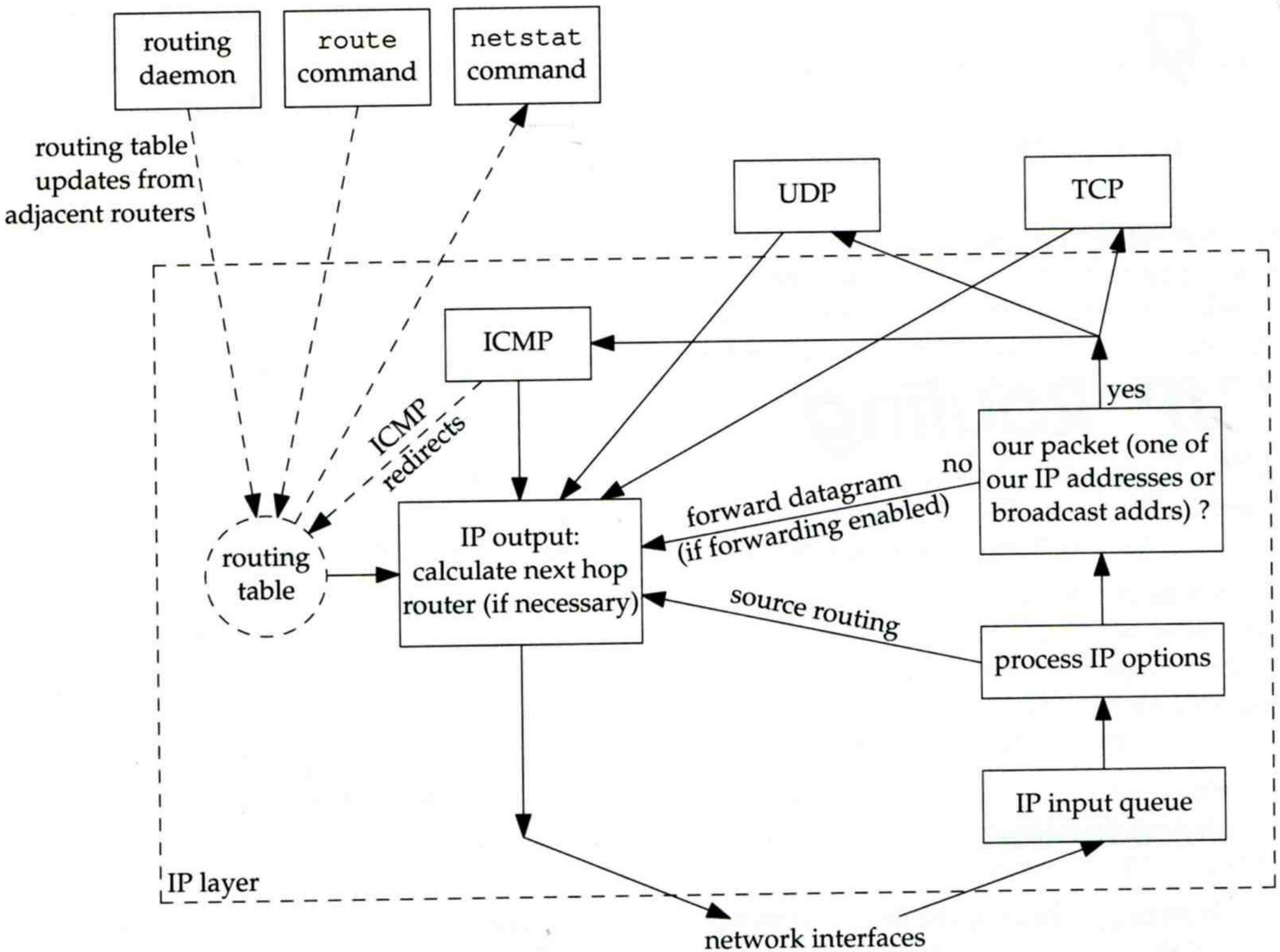


Traceroute Program – IP Source Routing Option (3)

- Traceroute using IP loose SR option
- Ex:

```
nabsd [/home/lwhsu] -lwhsu- traceroute u2.nctu.edu.tw
traceroute to u2.nctu.edu.tw (211.76.240.193), 64 hops max, 40 byte packets
 1  e3rtn-235 (140.113.235.254)  0.549 ms  0.434 ms  0.337 ms
 2  140.113.0.166 (140.113.0.166)  108.726 ms  4.469 ms  0.362 ms
 3  v255-194.NTCU.net (211.76.255.194)  0.529 ms  3.446 ms  5.464 ms
 4  v255-229.NTCU.net (211.76.255.229)  1.406 ms  2.017 ms  0.560 ms
 5  h240-193.NTCU.net (211.76.240.193)  0.520 ms  0.456 ms  0.315 ms
nabsd [/home/lwhsu] -lwhsu-  traceroute -g 140.113.0.149 u2.nctu.edu.tw
traceroute to u2.nctu.edu.tw (211.76.240.193), 64 hops max, 48 byte packets
 1  e3rtn-235 (140.113.235.254)  0.543 ms  0.392 ms  0.365 ms
 2  140.113.0.166 (140.113.0.166)  0.562 ms  9.506 ms  0.624 ms
 3  140.113.0.149 (140.113.0.149)  7.002 ms  1.047 ms  1.107 ms
 4  140.113.0.150 (140.113.0.150)  1.497 ms  6.653 ms  1.595 ms
 5  v255-194.NTCU.net (211.76.255.194)  1.639 ms  7.214 ms  1.586 ms
 6  v255-229.NTCU.net (211.76.255.229)  1.831 ms  9.244 ms  1.877 ms
 7  h240-193.NTCU.net (211.76.240.193)  1.440 ms !S  2.249 ms !S  1.737 ms !S
```

IP Routing – Processing in IP Layer



IP Routing
– Routing Table (1)

- Routing Table
  - Command to list: netstat -rn
  - Flag
    - U: the route is up
    - G: the route is to a router (indirect route)
      - Indirect route: IP is the dest. IP, MAC is the router's MAC
    - H: the route is to a host (Not to a network)
      - The dest. filed is either an IP address or network address
  - Refs: number of active uses for each route
  - Use: number of packets sent through this route

```
nabsd [/home/lwhsu] -lwhsu- netstat -rn
Routing tables

Internet:
Destination        Gateway            Flags    Refs      Use  Netif Expire
default            140.113.17.254     UGS         0   178607    sk0
127.0.0.1          127.0.0.1          UH          0      240    lo0
140.113.17/24      link#1             UC          0        0    sk0
140.113.17.5       00:02:b3:4d:44:c0  UHLW        1    12182    sk0   1058
140.113.17.212     00:90:96:23:8f:7d  UHLW        1       14    sk0   1196
140.113.17.254     00:90:69:64:ec:00  UHLW        2        4    sk0   1200
```

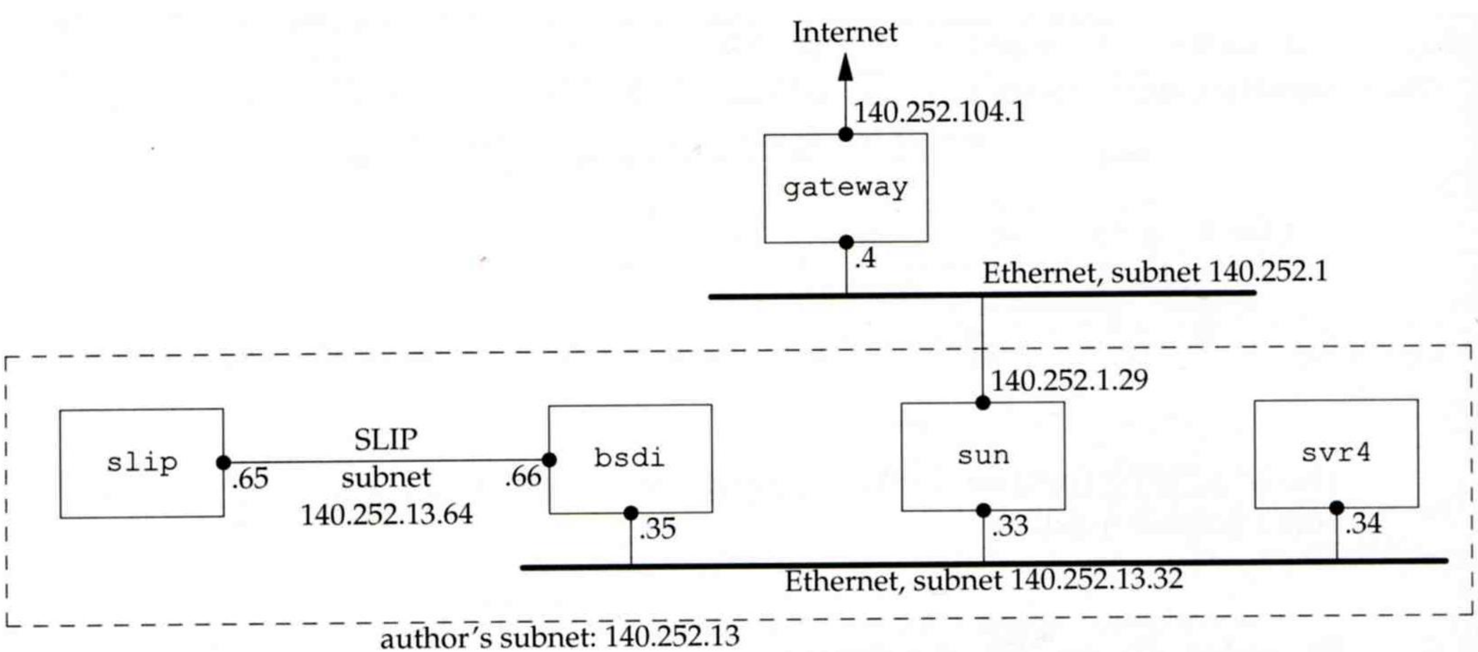
IP Routing
– Routing Table (2)

- Ex:

1. dst. = sun
2. dst. = slip
3. dst. = 192.207.117.2
4. dst. = svr4 or 140.252.13.34
5. dst. = 127.0.0.1

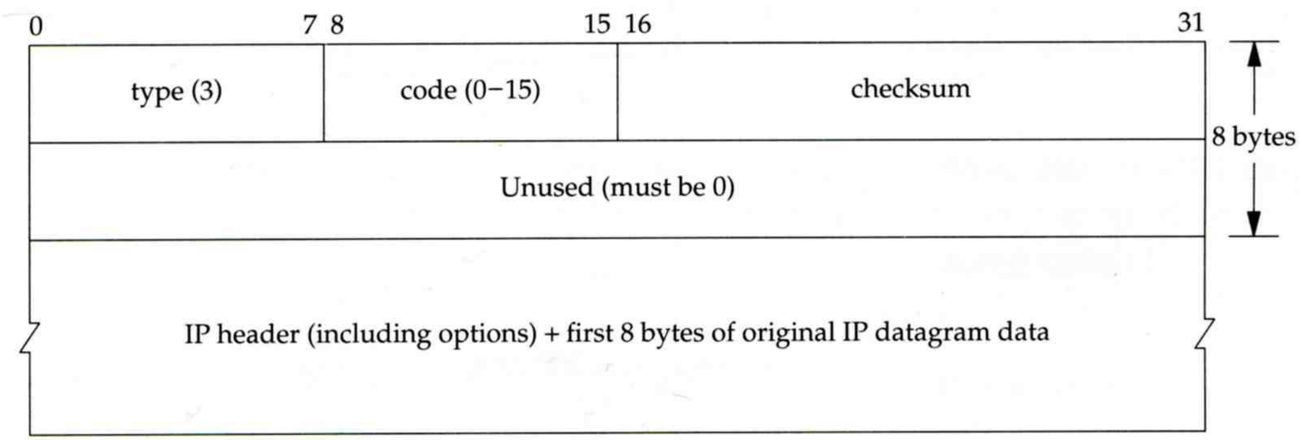
```
svr4 % netstat -rn
Routing tables
Destination      Gateway          Flags     Refcnt  Use      Interface
140.252.13.65    140.252.13.35    UGH       0       0        emd0
127.0.0.1        127.0.0.1        UH        1       0        lo0
default          140.252.13.33    UG        0       0        emd0
140.252.13.32    140.252.13.34    U         4       25043    emd0
```

loopback



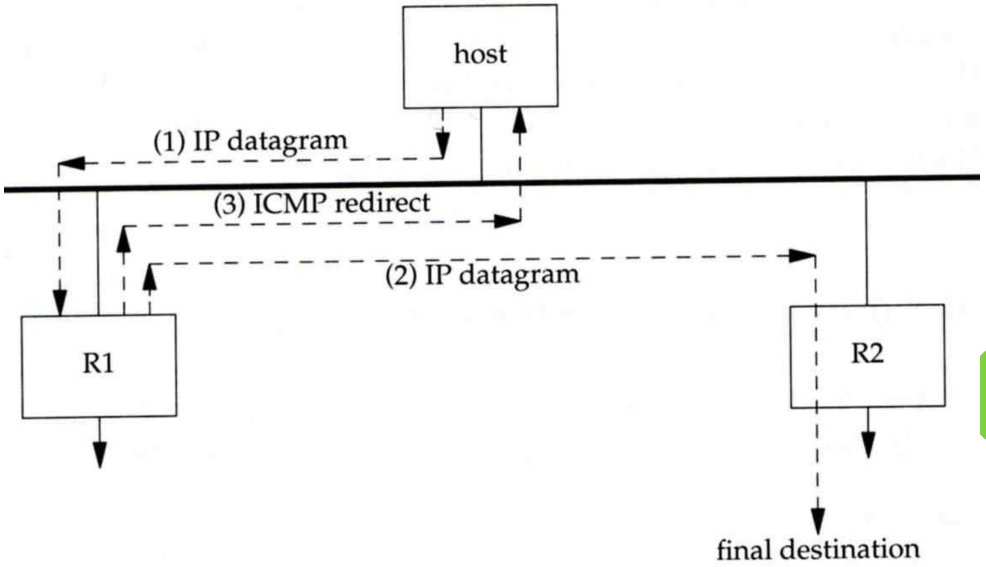
ICMP – No Route to Destination

- If there is no match in routing table
  - If the IP datagram is generated on the host
    - "host unreachable" or "network unreachable"
  - If the IP datagram is being forwarded
    - ICMP "host unreachable" error message is generated and sends back to sending host
    - ICMP message
      - Type = 3, code = 0 for host unreachable
      - Type = 3, code = 1 for network unreachable



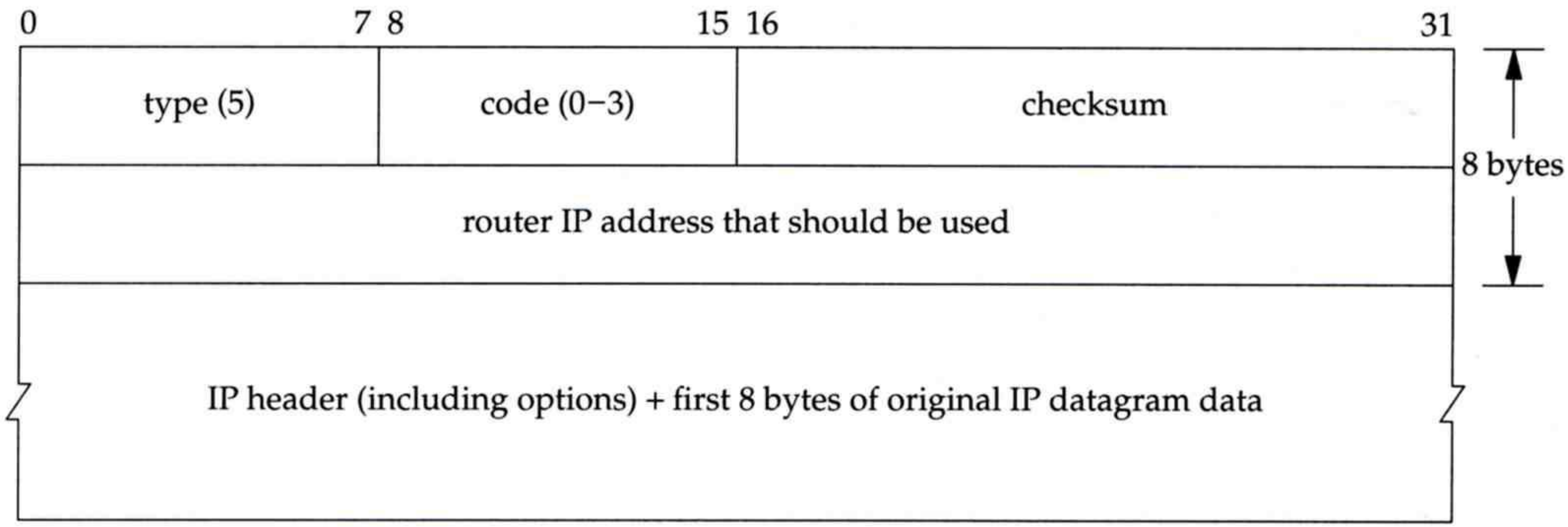
ICMP
– Redirect Error Message (1)

- Concept
  - Used by router to inform the sender that the datagram should be sent to a different router
  - This will happen if the host has a choice of routers to send the packet to
    - Ex:
      - R1 found sending and receiving interface are the same



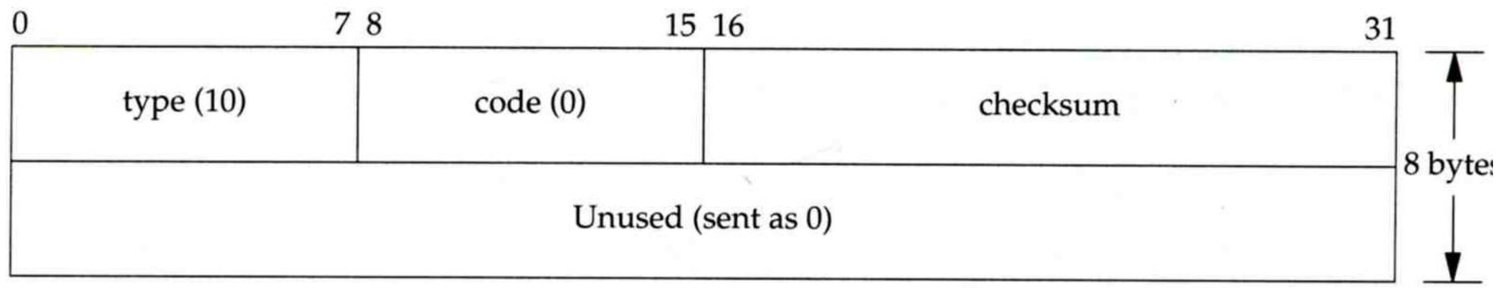
ICMP
– Redirect Error Message (2)

- ICMP redirect message format
  - Code 0: redirect for network
  - Code 1: redirect for host
  - Code 2: redirect for TOS and network (RFC 1349)
  - Code 3: redirect for TOS and hosts (RFC 1349)



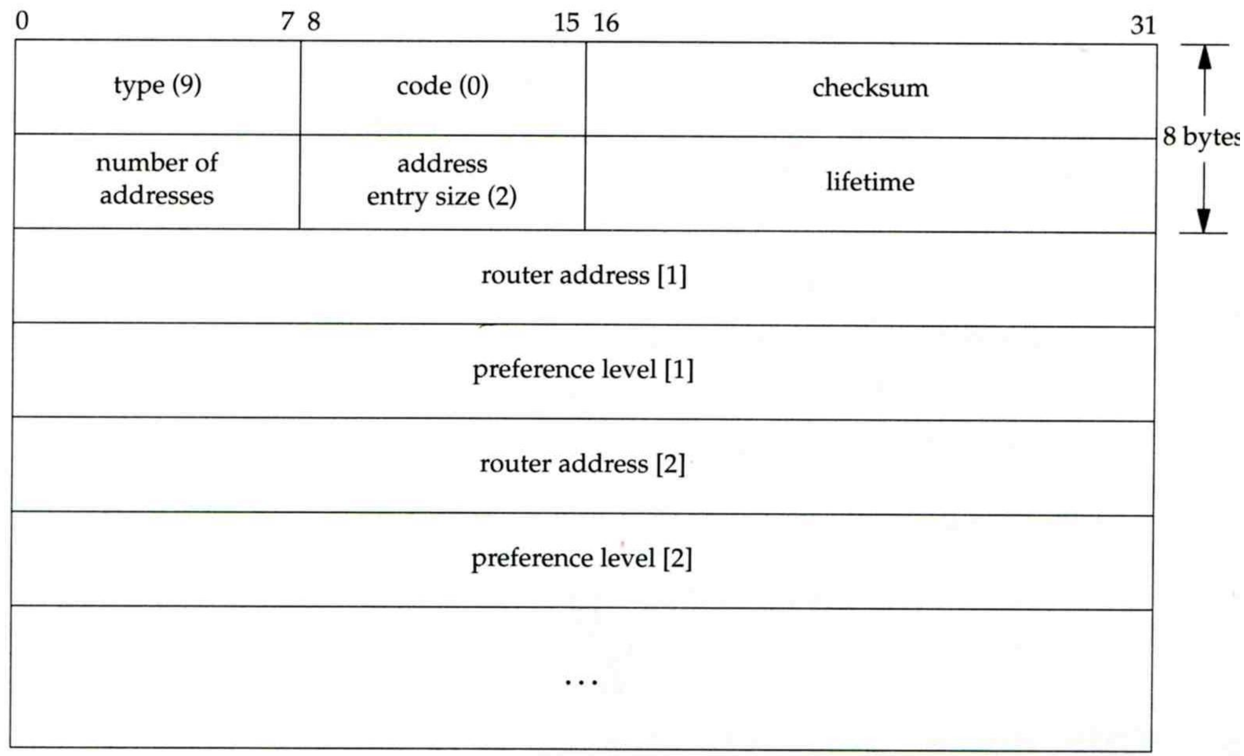
ICMP – Router Discovery Messages (1)

- Dynamic update host's routing table
  - ICMP router solicitation message (懇求)
    - Host broadcast or multicast after bootstrapping
  - ICMP router advertisement message
    - Router response
    - Router periodically broadcast or multicast
- Format of ICMP router solicitation message



ICMP
– Router Discovery Messages (2)

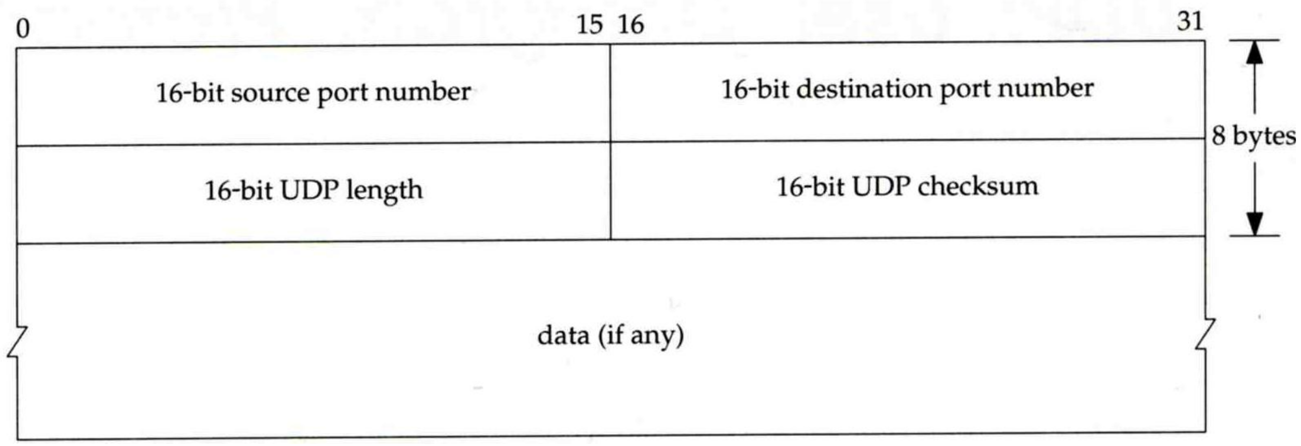
- Format of ICMP router advertisement message
  - Router address
    - Must be one of the router’s IP address
  - Preference level
    - Preference as a default router address



UDP – User Datagram Protocol

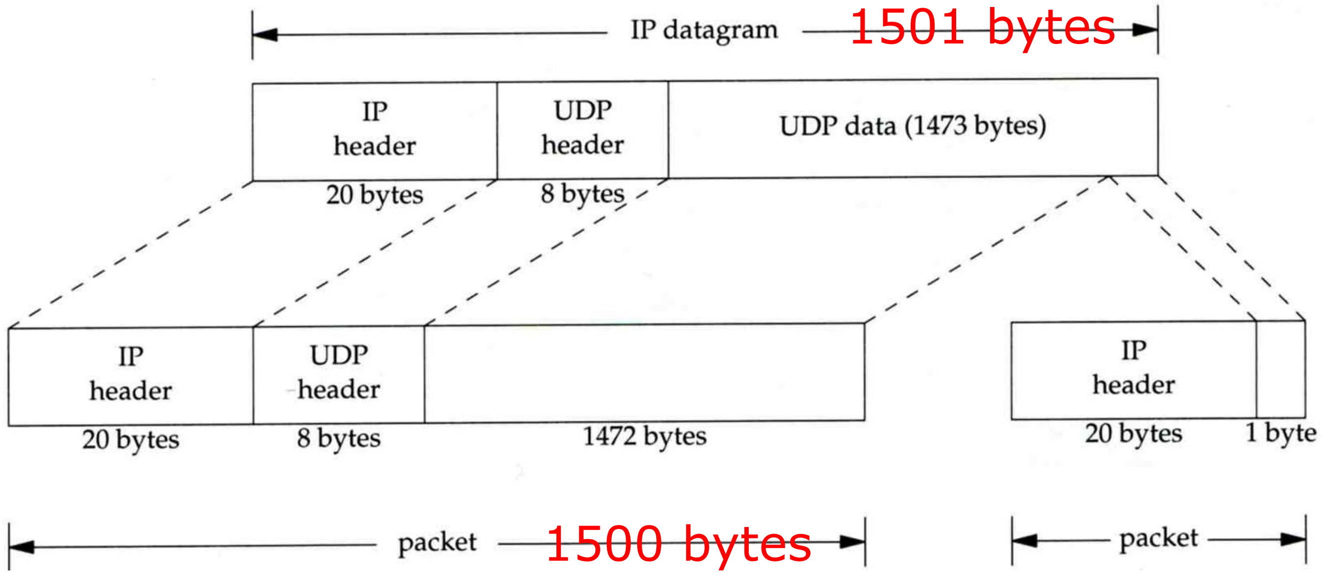
UDP

- No reliability
  - Datagram-oriented, not stream-oriented protocol
- UDP header
  - 8 bytes
    - Source port and destination port
      - Identify sending and receiving process
    - UDP length: ≧ 8



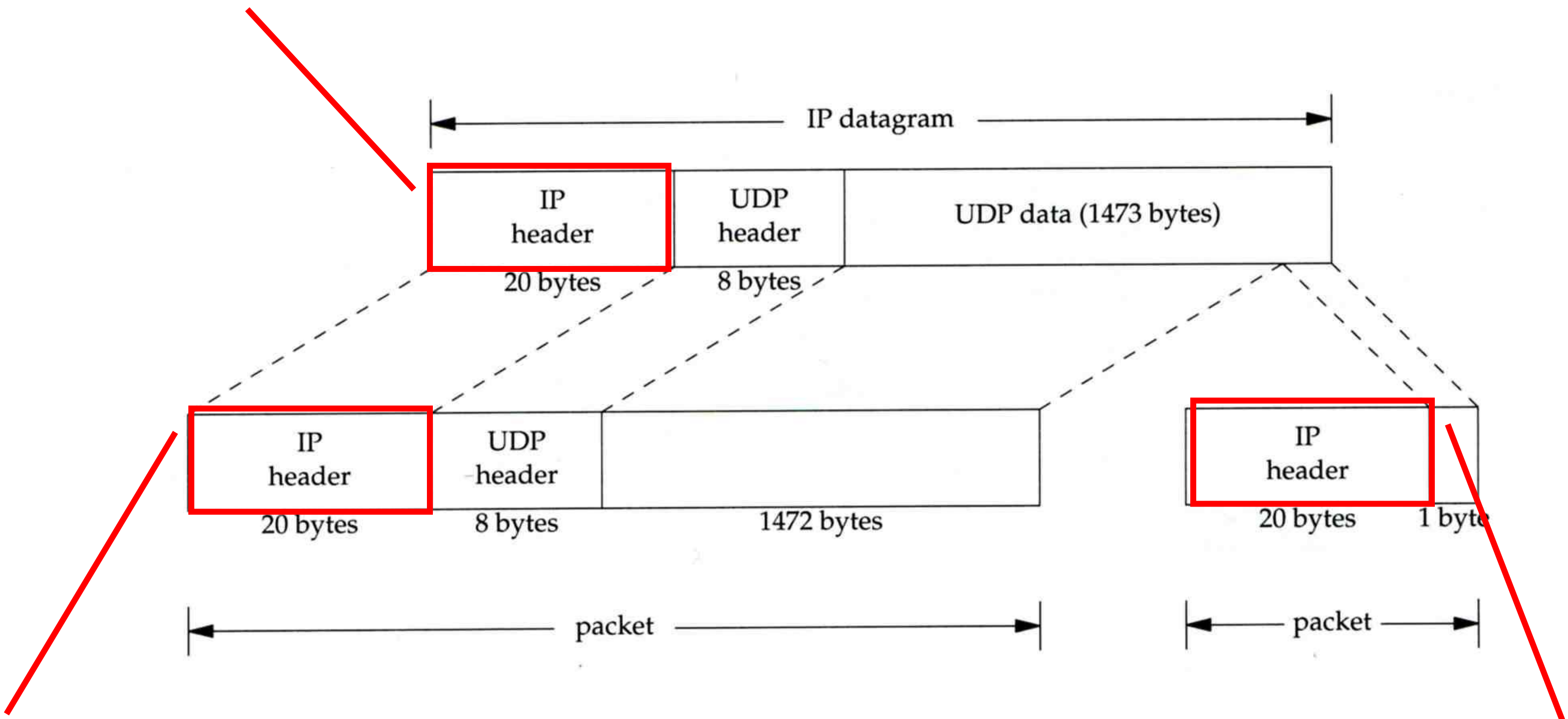
IP Fragmentation (1)

- MTU limitation
  - Before network-layer to link-layer
    - IP will check the size and link-layer MTU
    - Do fragmentation if necessary
  - Fragmentation may be done at sending host or routers
  - Reassembly is done only in receiving host



IP Fragmentation (2)

identification:	which unique IP datagram
flags:	more fragments?
fragment offset	offset of this datagram from the beginning of original datagram



identification:	the same
flags:	more fragments
fragment offset	0

identification:	the same
flags:	end of fragments
fragment offset	1480

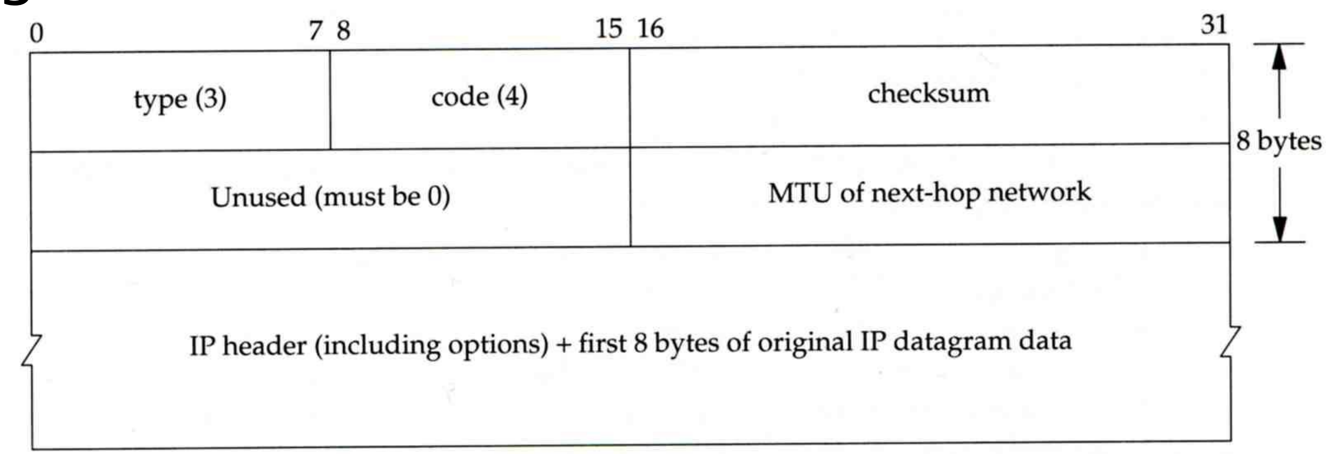
IP Fragmentation (3)

- Issues of fragmentation
  - One fragment lost, entire datagram must be retransmitted
  - If the fragmentation is performed by intermediate router, there is no way for sending host how fragmentation did

  - Fragmentation is often avoided
    - There is a "don't fragment" bit in flags of IP header

ICMP Unreachable Error – Fragmentation Required

- Type=3, code=4
  - Router will generate this error message if the datagram needs to be fragmented, but the “don’t fragment” bit is turn on in IP header
- Message format



ICMP
– Source Quench Error

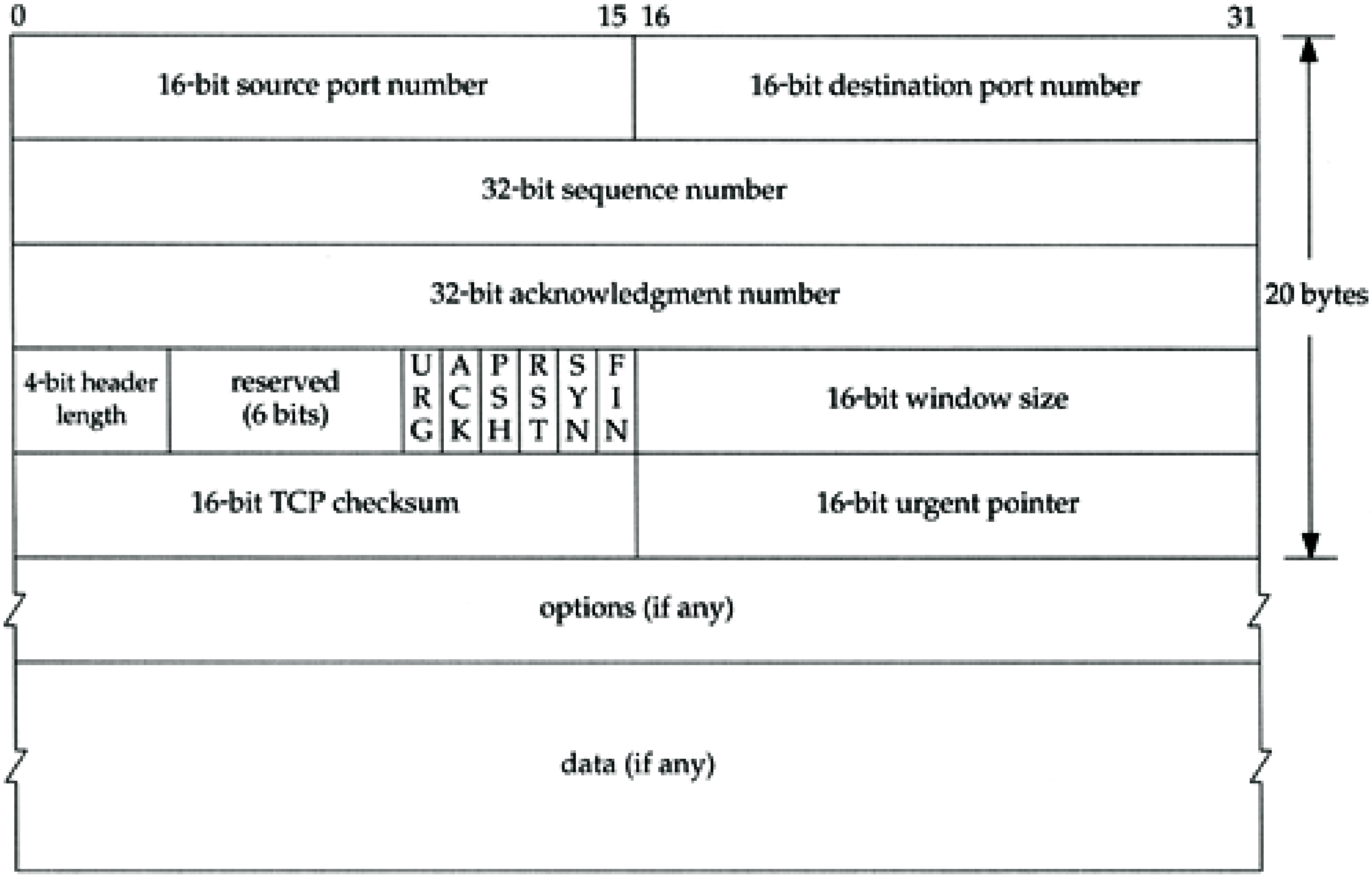
- Type=4, code=0
  - May be generated by system when it receives datagram at a rate that is too fast to be processed
  - Host receiving more than it can handle datagram
    - Send ICMP source quench or
    - Throw it away
  - Host receiving UDP source quench message
    - Ignore it or
    - Notify application

TCP – Transmission Control Protocol

TCP

- Services
  - Connection-oriented
    - Establish TCP connection before exchanging data
  - Reliability
    - Acknowledgement when receiving data
    - Retransmission when timeout
    - Ordering
    - Discard duplicated data
    - Flow control

TCP
– Header (1)

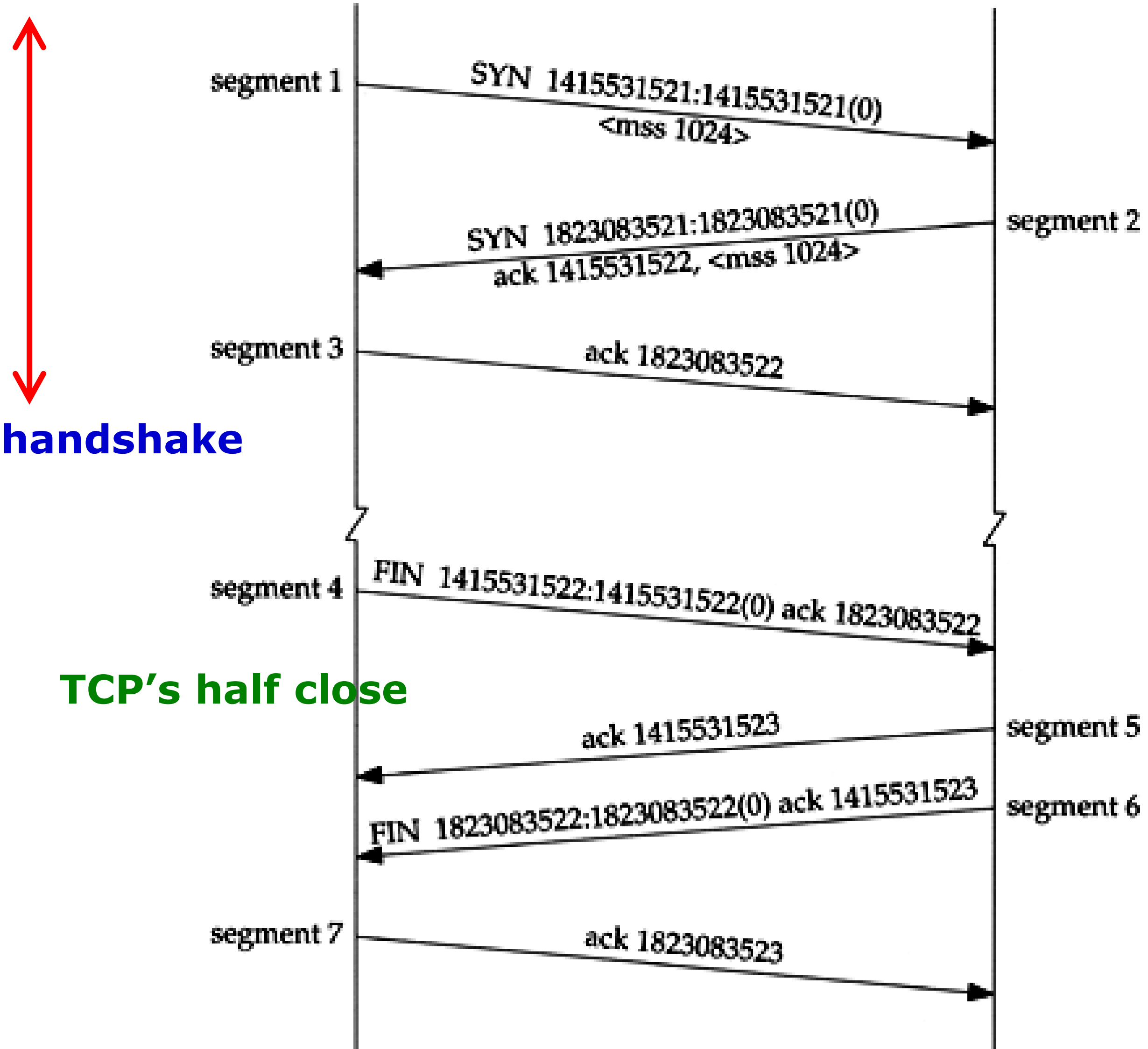


0
15
16
31
16-bit source port number
16-bit destination port number
32-bit sequence number
32-bit acknowledgment number
4-bit header length
reserved (6 bits)
URG
ACK
PSH
RST
SYN
FIN
16-bit window size
16-bit TCP checksum
16-bit urgent pointer
20 bytes
options (if any)
data (if any)

TCP – Header (2)

- Flags
  - SYN
    - Establish new connection
  - ACK
    - Acknowledgement number is valid
    - Used to ack previous data that host has received
  - RST
    - Reset connection
  - FIN
    - The sender is finished sending data

TCP CONNECTION ESTABLISHMENT AND TERMINATION



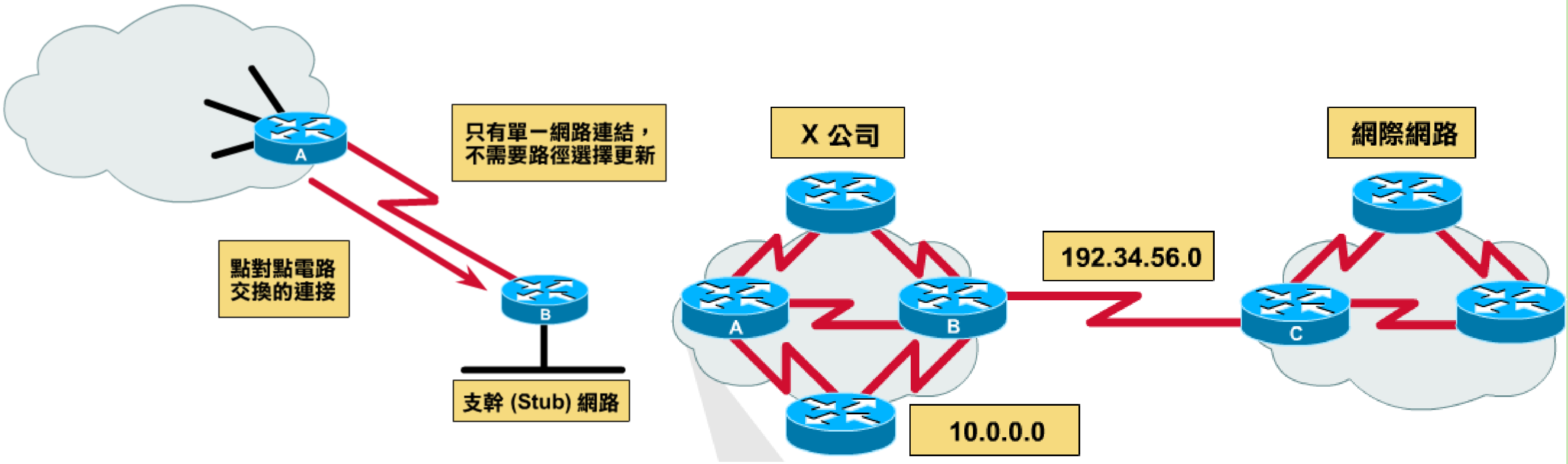
Three-way handshake

TCP's half close

Routing

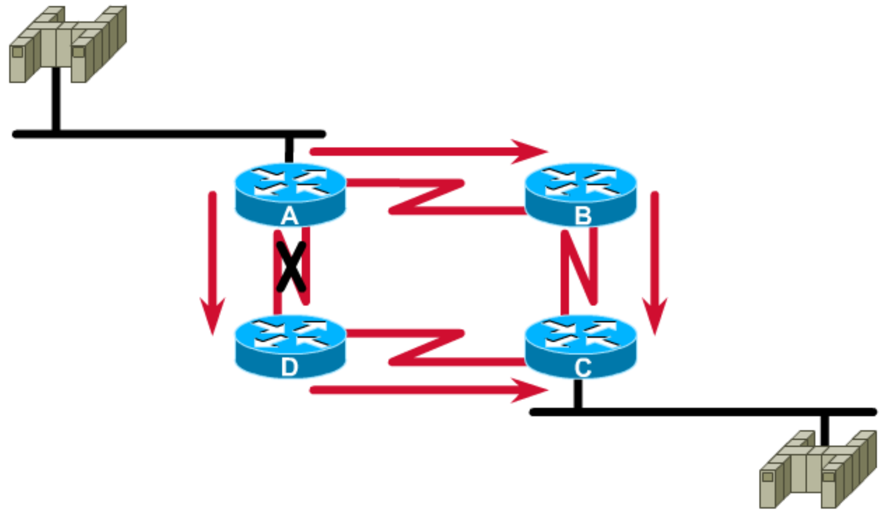
Why dynamic route ? (1)

- Static route is ok only when
  - Network is small
  - There is a single connection point to other network
  - No redundant route



Why dynamic route ? (2)

- Dynamic Routing
  - Routers update their routing table with the information of adjacent routers
  - Dynamic routing need a routing protocol for such communication
  - Advantage:
    - They can react and adapt to changing network condition

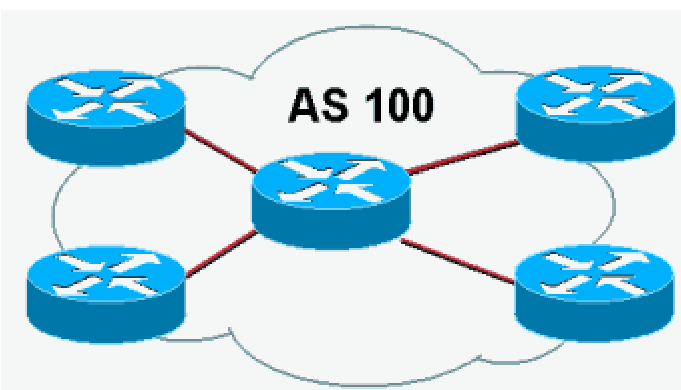


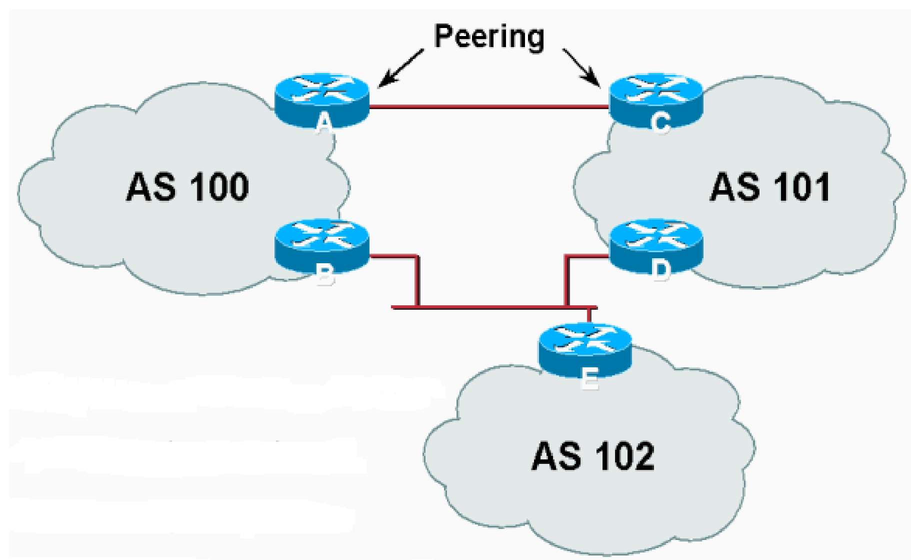
Routing Protocol

- Used to change the routing table according to various routing information
  - Specify detail of communication between routers
  - Specify information changed in each communication,
    - Network reachability
    - Network state
    - Metric
- Metric
  - A measure of how good a particular route
    - Hop count, bandwidth, delay, load, reliability, ...
- Each routing protocol may use different metric and exchange different information

Autonomous System

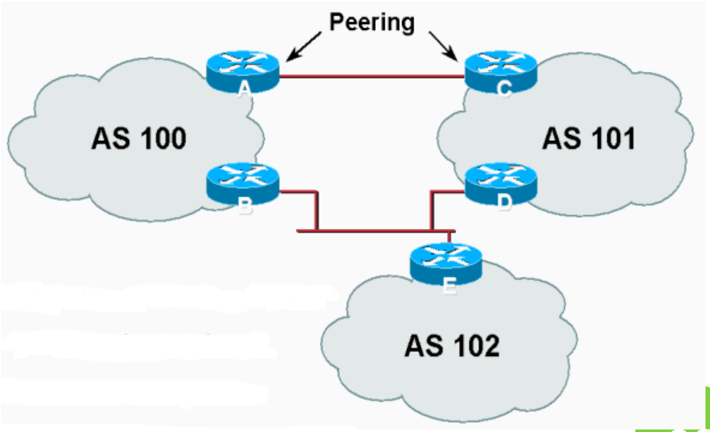
- Autonomous System (AS)
  - Internet is organized in to a collection of autonomous system
  - An AS is a collection of networks with same routing policy
    - Single routing protocol
    - Normally administered by a single entity
      - Corporation or university campus
    - All depend on how you want to manage routing





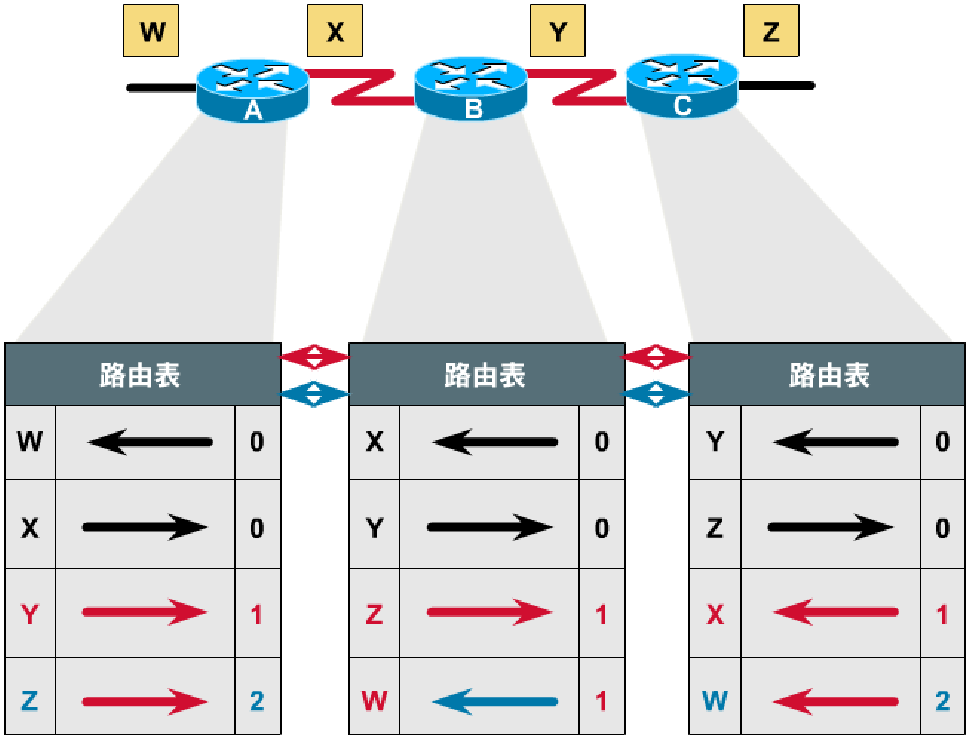
Category of Routing Protocols – by AS

- AS-AS communication
  - Communications between routers in different AS
  - Interdomain routing protocols
  - Exterior gateway protocols (EGP)
  - Ex:
    - BGP (Border Gateway Protocol)
- Inside AS communication
  - Communication between routers in the same AS
  - Intradomain routing protocols
  - Interior gateway protocols (IGP)
  - Ex:
    - RIP (Routing Information Protocol)
    - IGRP (Interior Gateway Routing Protocol)
    - OSPF (Open Shortest Path First Protocol)



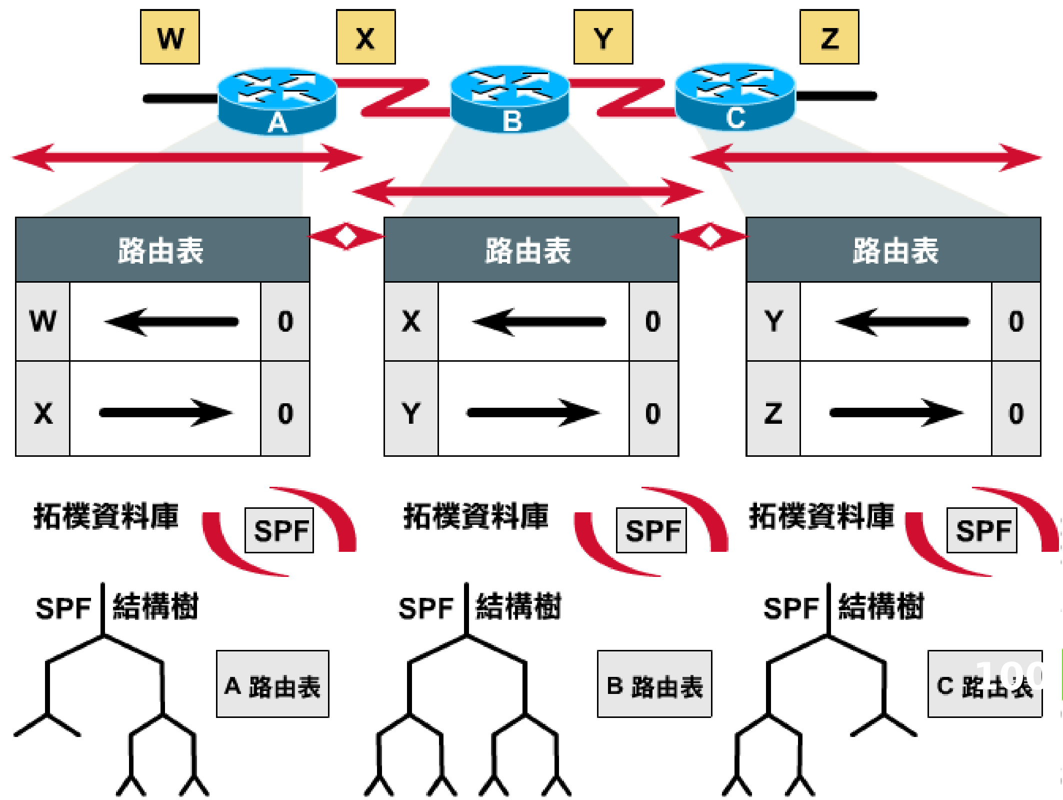
Category of Routing Protocols – by information changed (1)

- Distance-Vector Protocol
  - Message contains a vector of distances, which is the cost to other network
  - Each router updates its routing table based on these messages received from neighbors
  - Protocols:
    - RIP
    - IGRP
    - BGP



Category of Routing Protocols – by information changed (2)

- Link-State Protocol
  - Broadcast their link state to neighbors and build a complete network map at each router using Dijkstra algorithm
  - Protocols:
    - OSPF

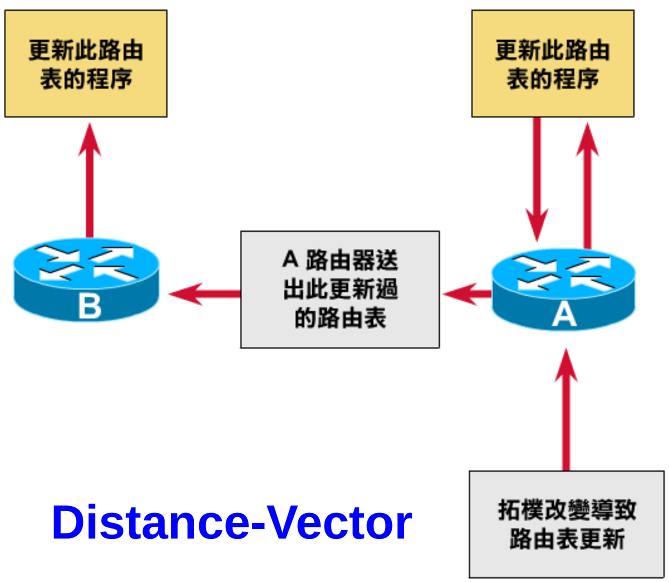


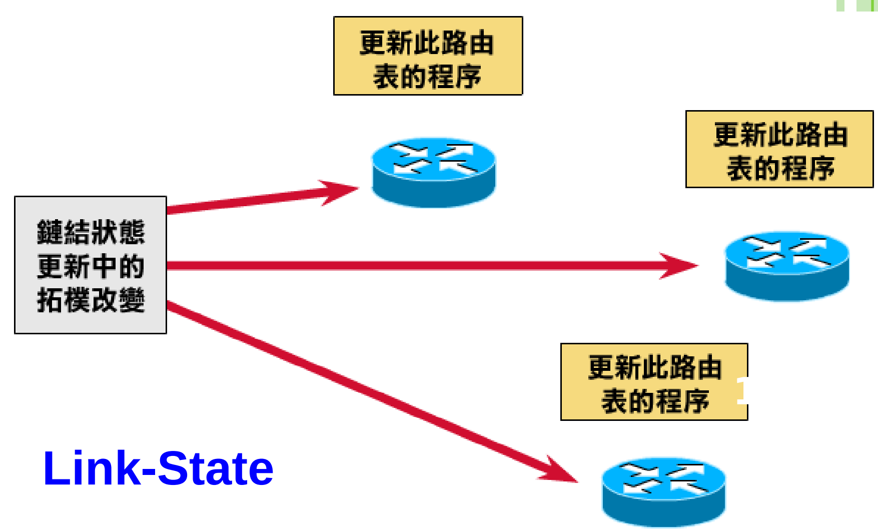
Difference between Distance-Vector and Link-State

- Difference

	Distance-Vector	Link-State
Update	updates neighbor (propagate new info.)	update all nodes
Convergence	Propagation delay cause slow convergence	Fast convergence
Complexity	simple	Complex

- Information update sequence





Routing Protocols

RIP	IGP, DV
IGRP	IGP, DV
OSPF	IGP, LS
BGP	EGP

RIP

- RIP
  - Routing Information Protocol
- Category
  - Interior routing protocol
  - Distance-vector routing protocol
    - Using “hop-count” as the cost metric
- Example of how RIP advertisements work

Destination network	Next router	# of hops to destination
1	A	2
20	B	2
30	B	7

Routing table in router before Receiving advertisement

Destination network	Next router	# of hops to destination
30	C	4
1	--	1
10	--	1

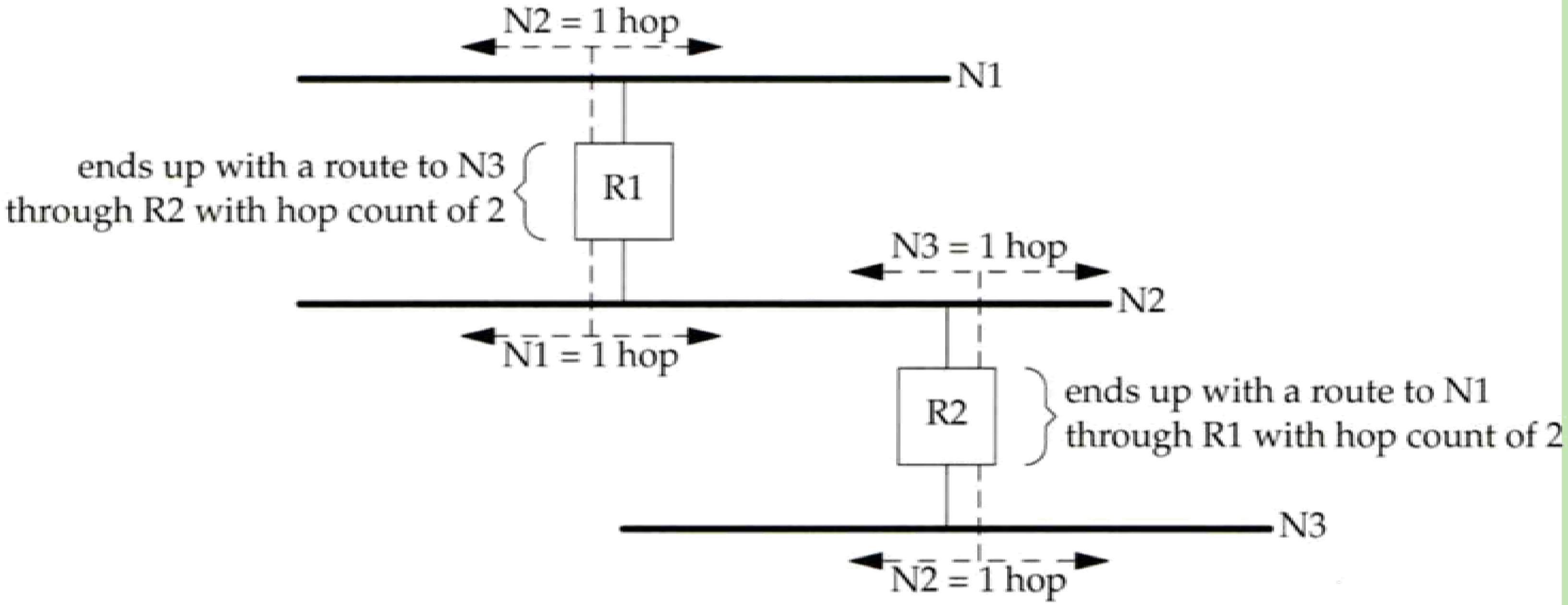
Advertisement from router A

Destination network	Next router	# of hops to destination
1	A	2
20	B	2
30	A	5

Routing table after receiving advertisement

RIP
– Example

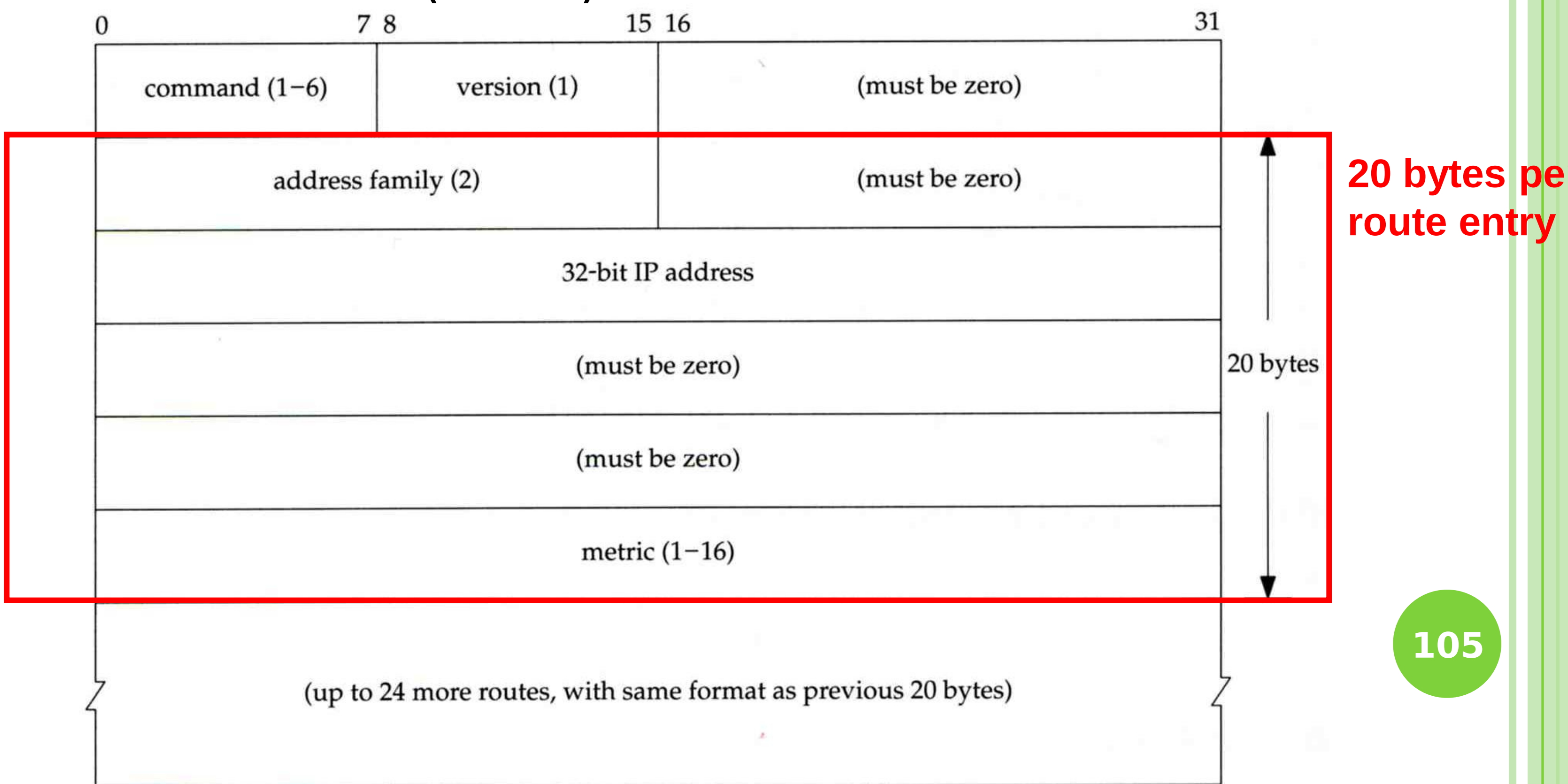
- Another example



RIP

– Message Format

- RIP message is carried in UDP datagram
  - Command: 1 for request and 2 for reply
  - Version: 1 or 2 (RIP-2)



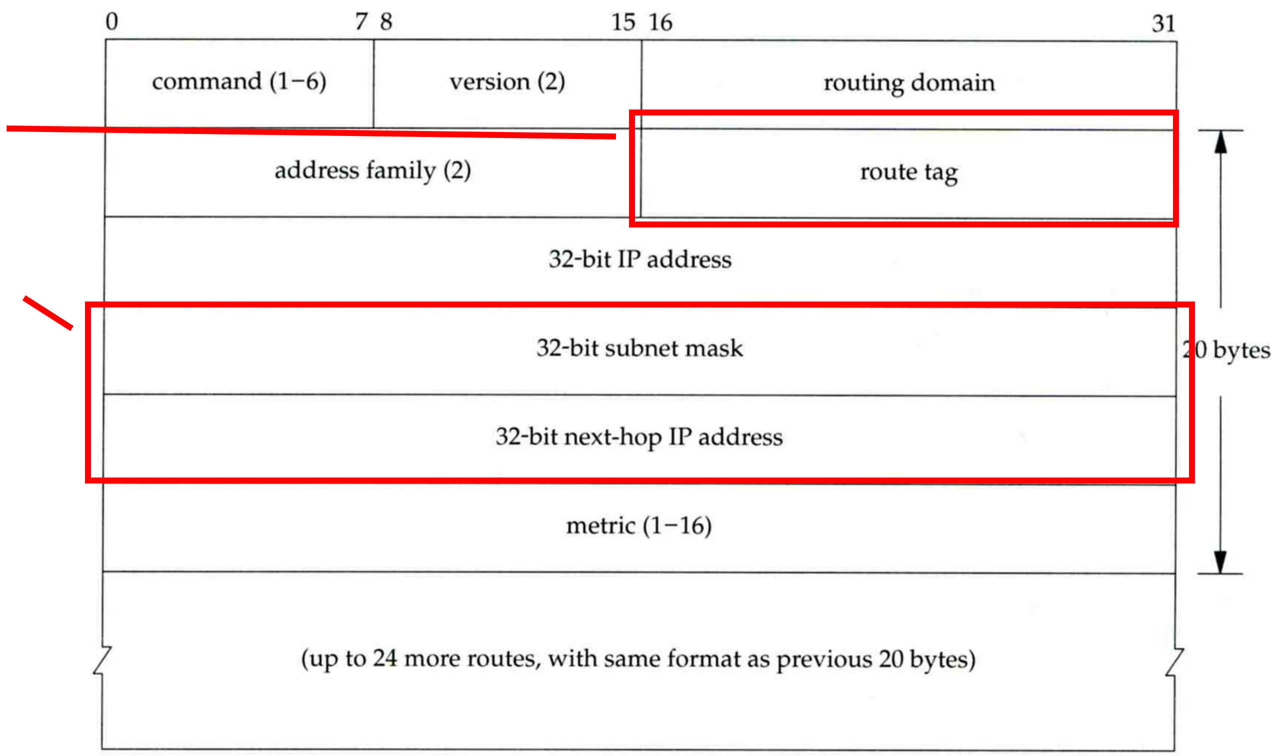
RIP – Operation

- routed – RIP routing daemon
  - Operated in UDP port 520
- Operation
  - Initialization
    - Probe each interface
    - send a request packet out each interface, asking for other router's complete routing table
  - Request received
    - Send the entire routing table to the requestor
  - Response received
    - Add, modify, delete to update routing table
  - Regular routing updates
    - Router sends out their routing table to every neighbor every 30 minutes
  - Triggered updates
    - Whenever a route entry's metric change, send out those changed part routing table

RIP

– Problems of RIP

- Issues
  - 15 hop-count limits
  - Take long time to stabilize after the failure of a router or link
  - No CIDR
- RIP-2
  - EGP support
    - AS number
  - CIDR support



IGRP (1)

- IGRP – Interior Gateway Routing Protocol
- Similar to RIP
  - Interior routing protocol
  - Distance-vector routing protocol
- Difference between RIP
  - Complex cost metric other than hop count
    - delay time, bandwidth, load, reliability
    - The formula

$$\left(\frac{bandwith\_weight}{bandwith*(1-load)}+\frac{delay\_weight}{delay}\right)*reliability$$

  - Use TCP to communicate routing information
  - Cisco System’s proprietary routing protocol

IGRP (2)

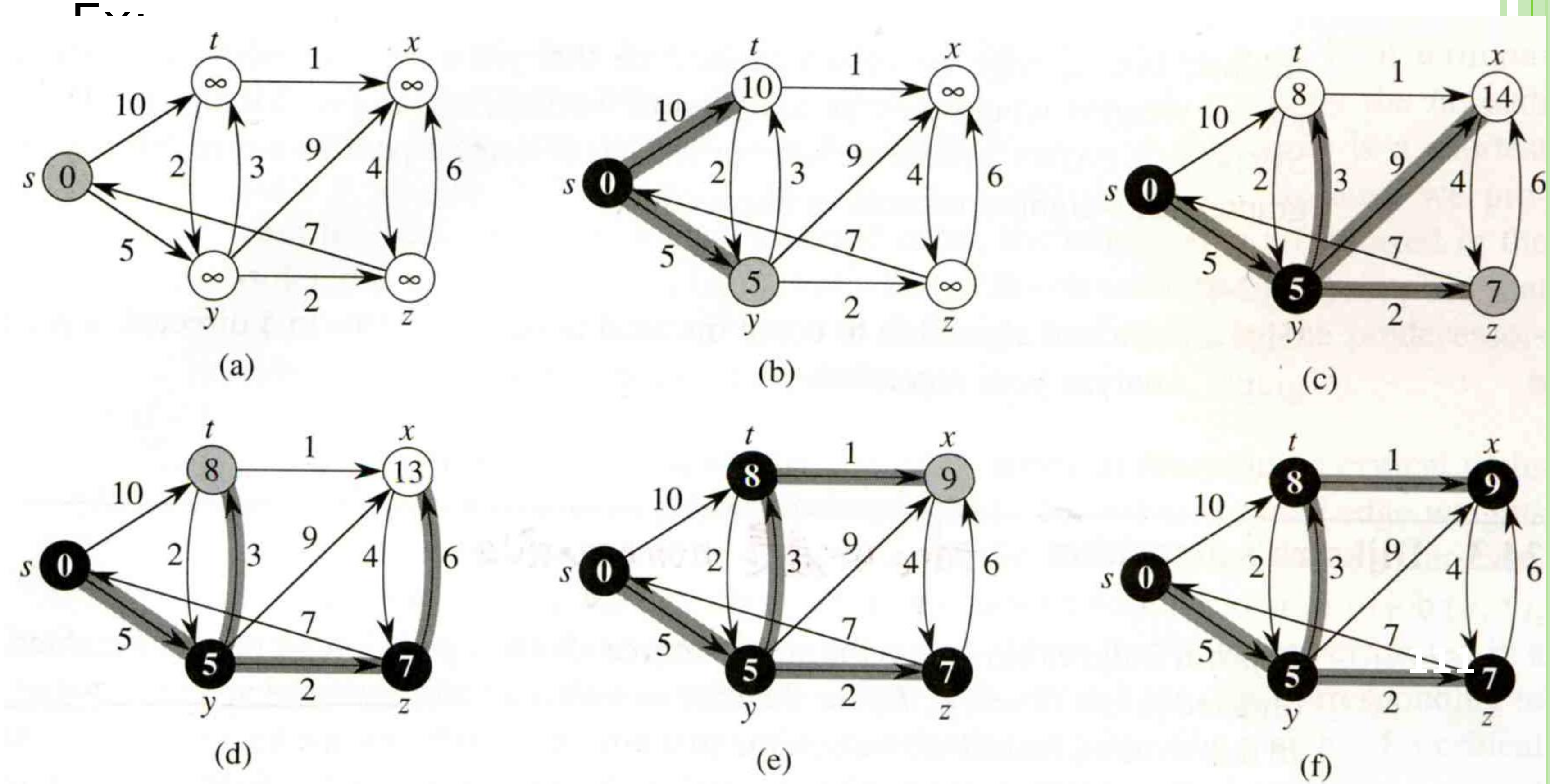
- Advantage over RIP
  - Control over metrics
- Disadvantage
  - Still classful and has propagation delay

OSPF (1)

- OSPF
  - Open Shortest Path First
- Category
  - Interior routing protocol
  - Link-State protocol
- Each interface is associated with a cost
  - Generally assigned manually
  - The sum of all costs along a path is the metric for that path
- Neighbor information is broadcast to all routers
  - Each router will construct a map of network topology
  - Each router run Dijkstra algorithm to construct the shortest path tree to each routers

OSPF
– Dijkstra Algorithm

- Single Source Shortest Path Problem
  - Dijkstra algorithm use “greedy” strategy
  - Ex:

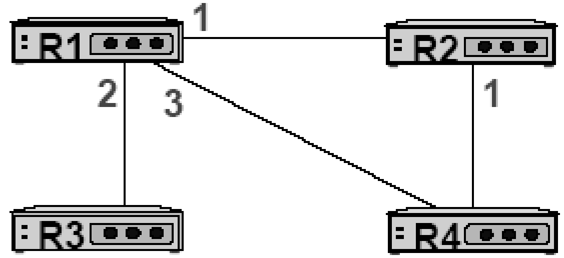


OSPF

– Routing table update example (1)

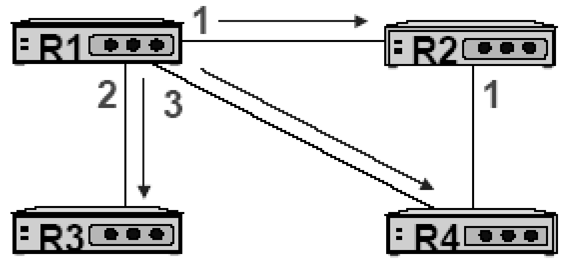
R1

D	Path	M
R1	?	
R2		
R3		
R4		



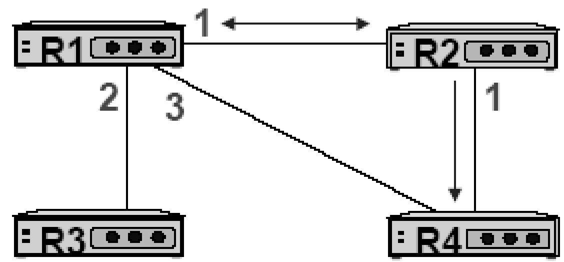
R1

D	Path	M
R1	direct	0
R2	*R1-R2*	*1*
R3	*R1-R3*	*2*
R4	*R1-R4*	*3*



R1

D	Path	M
R1	direct	0
R2	R1-R2	1
R3	*R1-R3*	*2*
R4	*R1-R4*	*3*

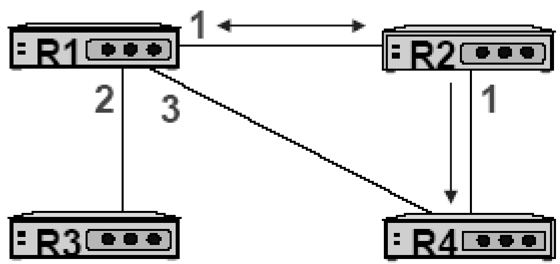


OSPF

– Routing table update example (2)

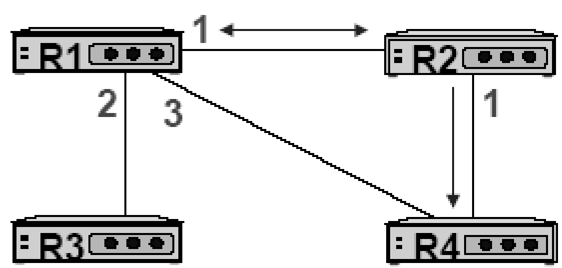
R1

D	Path	M	
R1	direct	0	✓
R2	R1-R2	1	✓
R3	*R1-R3*	*2*	
R4	*R1-R4*	*3*	



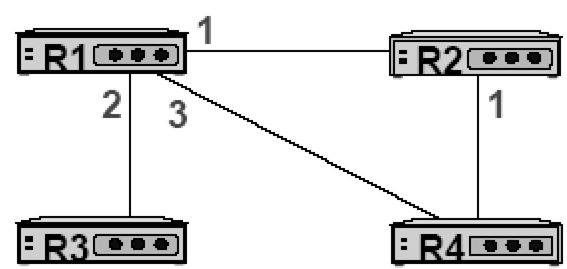
R1

D	Path	M	
R1	direct	0	✓
R2	R1-R2	1	✓
R3	*R1-R3*	*2*	
R4	*R1-R2-R4*	*2*	



R1

D	Path	M	
R1	direct	0	✓
R2	R1-R2	1	✓
R3	R1-R3	2	✓
R4	R1-R2-R4	2	✓



OSPF
– Summary

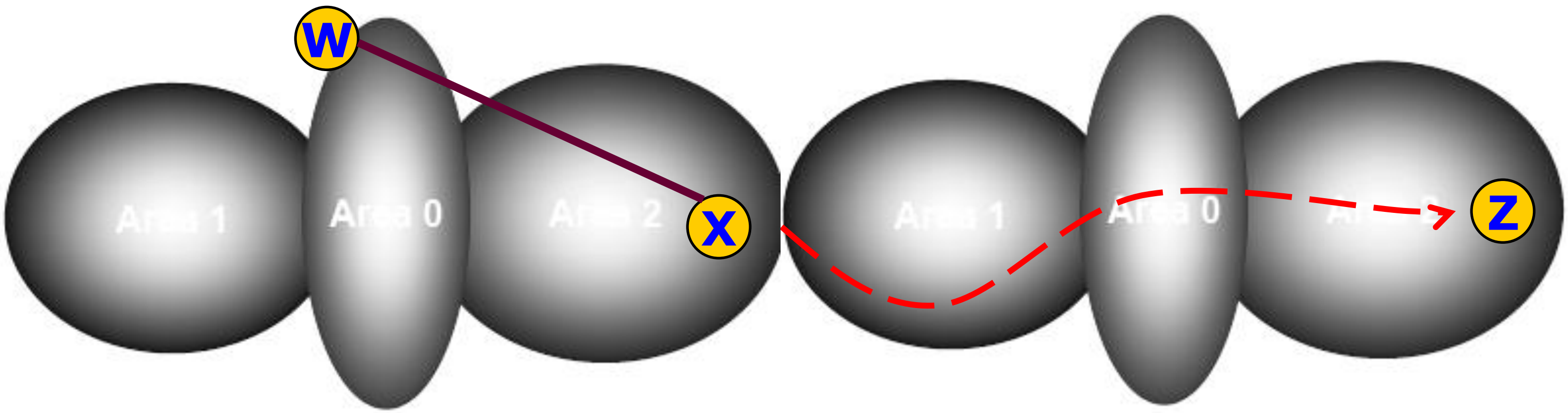
- Advantage
  - Fast convergence
  - CIDR support
  - Multiple routing table entries for single destination, each for one type-of-service
    - Load balancing when cost are equal among several routes
- Disadvantage
  - Large computation

BGP

- BGP
  - Border Gateway Protocol
- Exterior routing protocol
  - Now BGP-4
  - Exchange network reachability information with other BGP systems
- Routing information exchange
  - Message:
    - Full path of autonomous systems that traffic must transit to reach destination
    - Can maintain multiple route for a single destination
  - Exchange method
    - Using TCP
    - Initial: entire routing table
    - Subsequent update: only sent when necessary
    - Advertise only optimal path
- Route selection
  - Shortest AS path

BGP
– Operation Example

- How BGP work
  - The whole Internet is a graph of autonomous systems
  - X→Z
    - Original: X→A→B→C→Z
    - X advertise this best path to his neighbor W
  - W→Z
    - W→X→A→B→C→Z



Routing Protocols Comparison

	RIP	IGRP	OSPF	BGP4
DV or LS	DV	DV	LS	Path Vec
TCP/UDP & Port	U - 520	IP - 9	T - 89	T - 179
Classless	No	No	Yes	Yes
Updates	Per.	Per.	Both	Trig.
Load Balance	No	Yes	Yes	No
Internal / External	Int.	Int.	Int.	Ext.
Metric	Hop Count	Load Errors Delay Bdwth	Sum of Int. Cost	Short. AS Path

routed

routed

- Routing daemon
  - Speak RIP (v1 and v2)
  - Supplied with most every version of UNIX
  - Two modes
    - Server mode (-s) & Quiet mode (-q)
    - Both listen for broadcast, but server will distribute their information
  - routed will add its discovered routes to kernel's routing table
  - Support configuration file - /etc/gateways
    - Provide static information for initial routing table

```
net Nname[/mask] gateway Gname metric value <passive | active | extern>

host Hname gateway Gname metric value <passive | active | extern>
```

Network Hardware

Network Performance Issues

- Three major factors
  - Selection of high-quality hardware
  - Reasonable network design
  - Proper installation and documentation

Hardware Selection – Classification of market

- LAN
  - Local Area Network
  - Networks that exist within a building or group of buildings
  - High-speed, low-cost media
- WAN
  - Wide Area Network
  - Networks that endpoints are geographically dispersed
  - High-speed, high-cost media
- MAN
  - Metropolitan Area Network
  - Networks that exist within a city or cluster of cities
  - High-speed, medium-cost media

Hardware Selection – LAN Media (1)

- Evolution of Ethernet

Year	Speed	Common name	IEEE#	Dist	Media
1973	3 Mb/s	Xerox Ethernet	–	?	Coax
1980	10 Mb/s	Ethernet 1	–	500m	RG-11 coax
1982	10 Mb/s	DIX Ethernet (Ethernet II)	–	500m	RG-11 coax
1985	10 Mb/s	10Base5 ("Thicknet")	802.3	500m	RG-11 coax
1985	10 Mb/s	10Base2 ("Thinnet")	802.3	180m	RG-58 coax
1989	10 Mb/s	10BaseT	802.3	100m	Category 3 UTP[a] copper
1993	10 Mb/s	10BaseF	802.3	2km 25km	MM[b] Fiber SM Fiber
1994	100 Mb/s	100BaseTX ("100 meg")	802.3u	100m	Category 5 UTP copper
1994	100 Mb/s	100BaseFX	802.3u	2km 20km	MM fiber SM fiber
1998	1 Gb/s	1000BaseSX	802.3z	260m 550m	62.5-μm MM fiber 50-μm MM fiber
1998	1 Gb/s	1000BaseLX	802.3z	440m 550m 3km	62.5-μm MM fiber 50-μm MM fiber SM fiber
1998	1 Gb/s	1000BaseCX	802.3z	25m	Twinax
1999	1 Gb/s	1000BaseT ("Gigabit")	802.3ab	100m	Cat 5E and 6 UTP copper

a. Unshielded twisted pair

b. Multimode and single-mode fiber

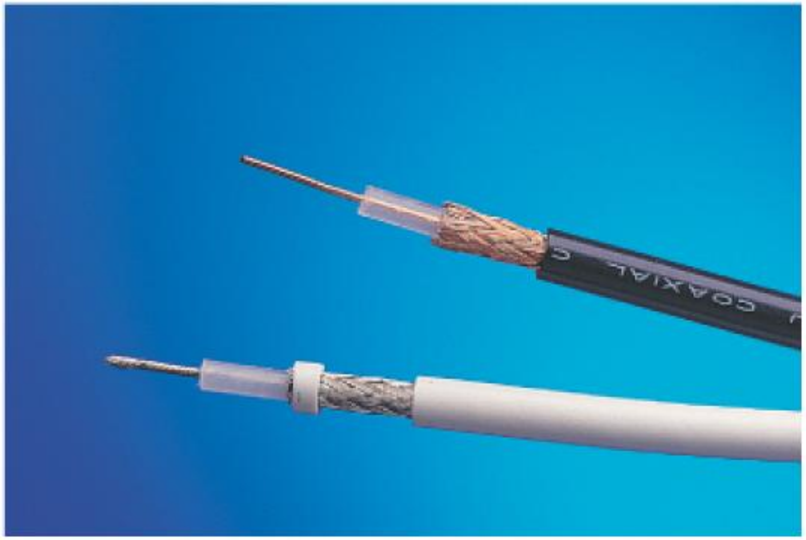
Coaxial cable

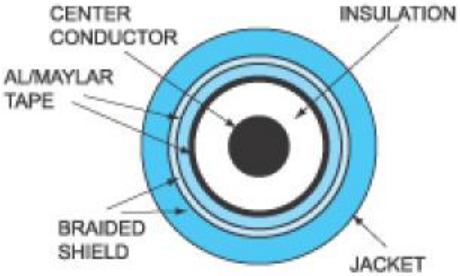
UTP

Fiber

Hardware Selection – LAN Media (2)

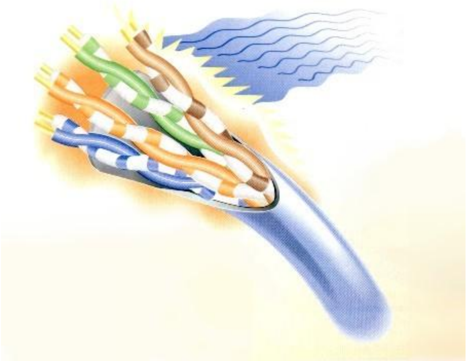
- Coaxial cable
  - Cooperated with BNC connector
  - Speed: 10 Mbps
  - Coaxial cable used in LAN
    - RG11 (10Base5, 500m)
    - RG58 (10Base2, 200m)

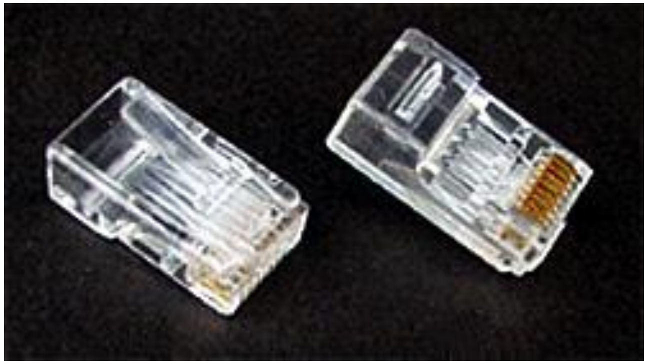




Hardware Selection – LAN Media (3)

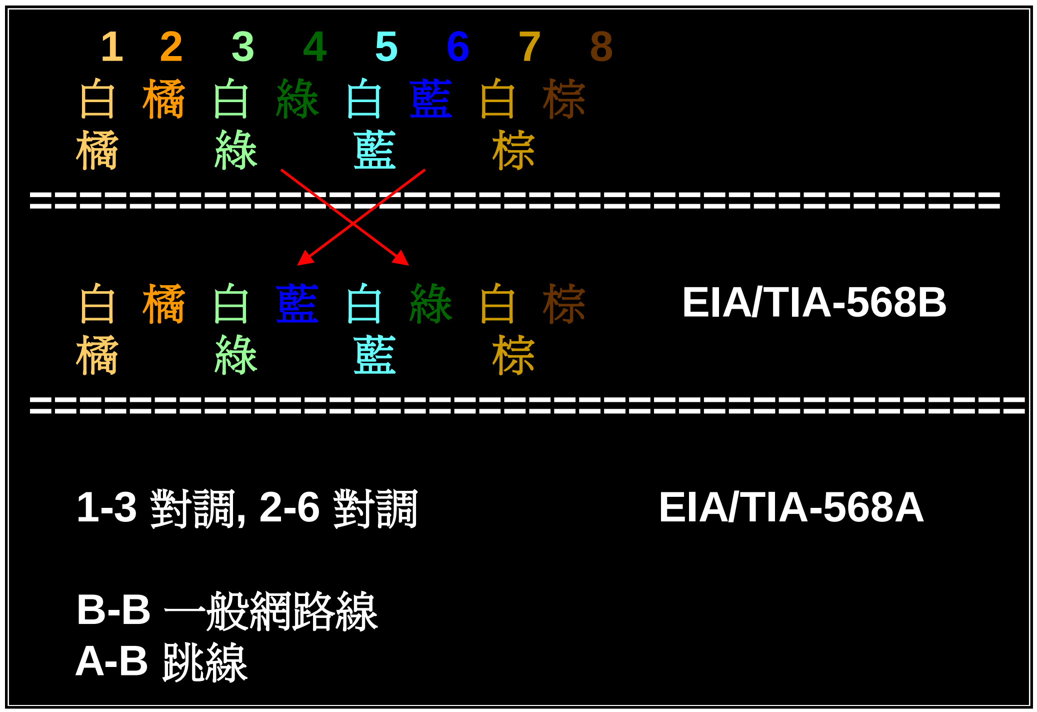
- Twisted Pair Cable
  - UTP (Unshielded) and STP (Shielded)
    - STP has conductive shield
      - More expensive but good in resisting cross talk
  - Cooperated with RJ45 connector
  - Categories
    - From CATEGORY-1 ~ CATEGORY-7, CATEGORY-5E
      - Cat3 up to 10Mbps (10BaseT, 100m)
      - Cat5 up to 100Mbps (100BaseTX, 100m)
      - Cat5e / Cat6 up to 1000Mbps (1000BaseT, 100m)





Hardware Selection – LAN Media (4)

- UTP cable wiring standard
  - TIA/EIA-568A, 568B

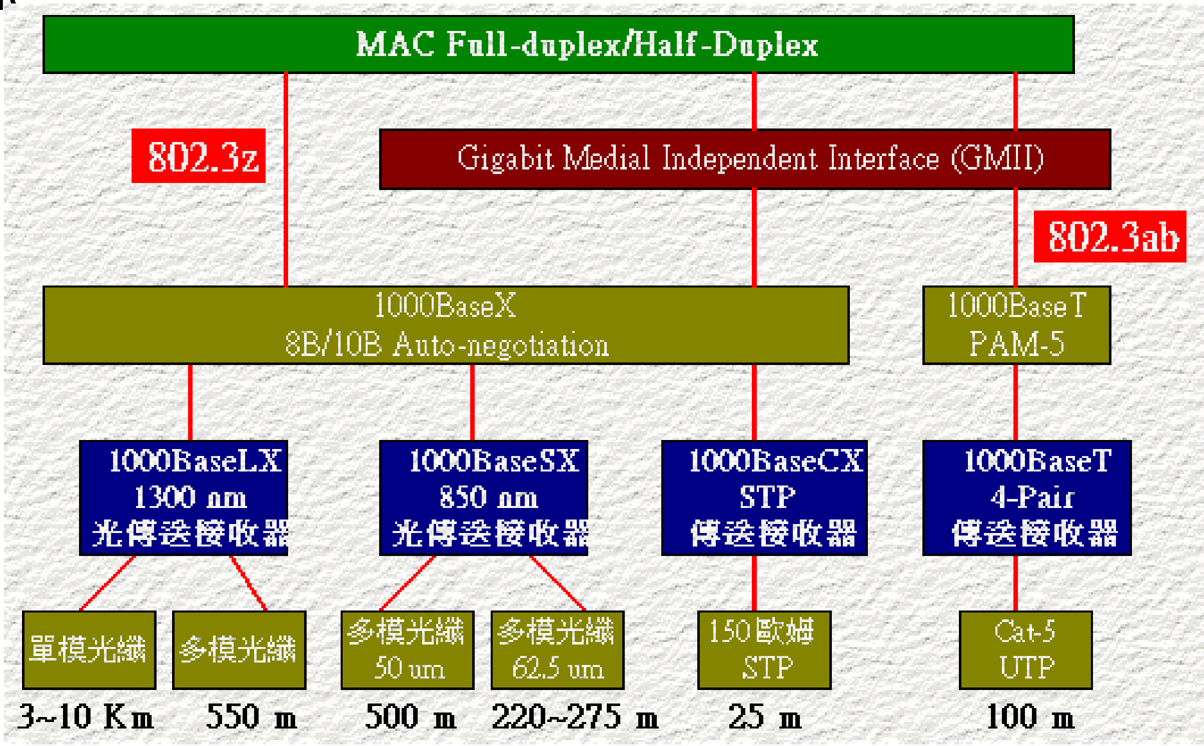


Hardware Selection – LAN Media (5)

- Fiber Optical Cable
  - Mode
    - Bundle of light rays that enter the fiber at particular angle
  - Two mode
    - Single-mode (exactly one frequency of light)
      - One stream of laser-generated light
      - Long distance, cheaper
    - Multi-mode (allow multiple path in fiber)
      - Multiple streams of LED-generated light
      - Short distance, more expensive
  - Wavelength
    - 0.85, 1.31, 1.55 μm
- Connector
  - ST, SC, MT-RJ

Hardware Selection – LAN Media (6)

- 1000BaseLX (Long wavelength, 1.31μm)
  - Single mode
  - Multi mode
- 1000BaseSX (Short wavelength, 0.85 μm)
  - Multimode



Hardware Selection – LAN Media (7)

- Fiber connector

Hardware Selection – LAN Media (8)

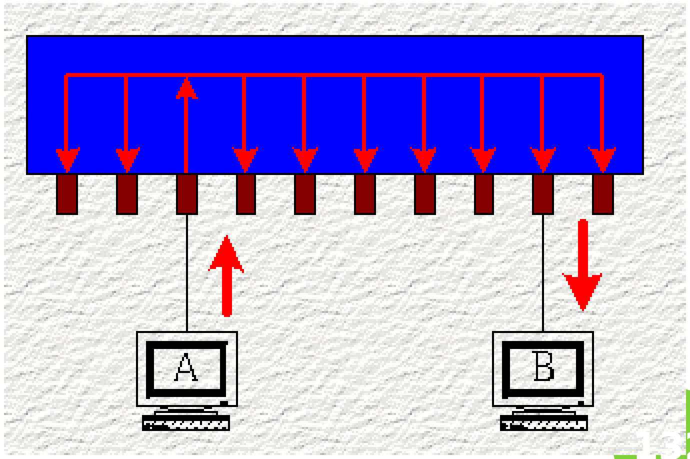
- Wireless
  - 802.11a
    - 5.4GHz
    - Up to 22Mbps
  - 802.11b
    - 2.4GHz
    - Up to 11Mbps
  - 802.11g
    - 2.4GHz
    - Up to 54Mbps
  - 802.11n
    - Draft 2.0 (~2007/1)
    - Up to 100Mbps
    - MIMO

Hardware Selection – LAN Device (1)

- Connecting and expanding Ethernet
  - Layer1 device
    - Physical layer
    - Repeater, Transceiver, HUB
      - Does not interpret Ethernet frame
  - Layer2 device
    - Data-link layer
    - Switch, Bridge
      - Transfer Ethernet frames based on hardware address
  - Layer3 device
    - Network layer
    - Router
      - Route message based on IP address

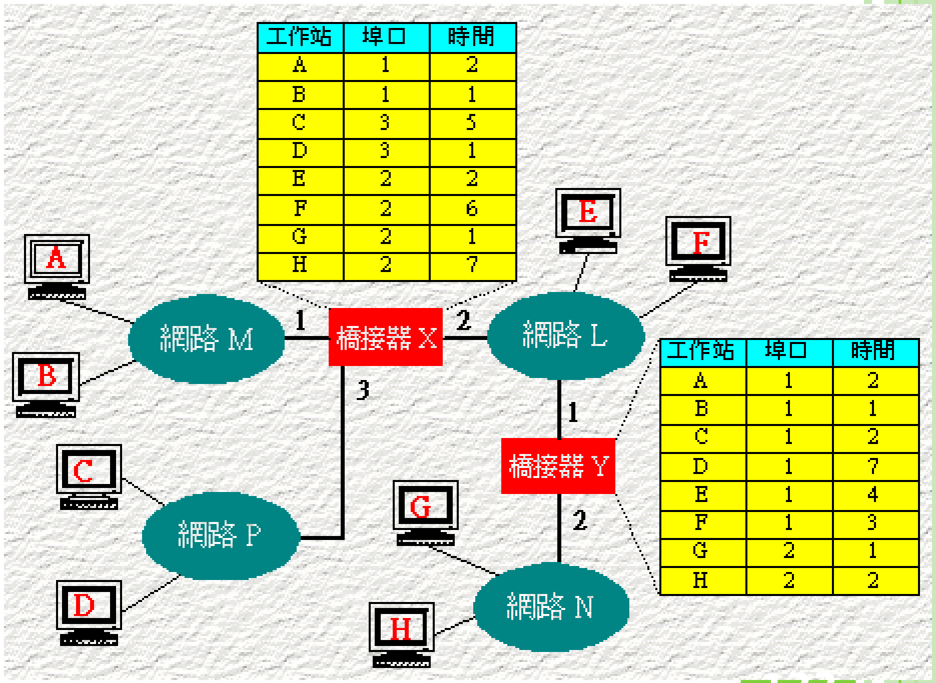
Hardware Selection – LAN Device (2)

- HUB
  - Layer1 device
  - Multi-port repeater
  - Increasing collision domain size
  - MDI and MDI-X ports
    - (Media Dependent Interface Crossover)
    - Auto-sense now
  - 5-4-3 rules in 10Mbps
    - More severe in 100Mbps ~
- Switching HUB
  - Layer1 device but forward to required port



Hardware Selection –
LAN Device (3)

- Bridge
  - Layer2 device
  - Forward Ethernet frames among different segments
  - Bridge table
    - Fewer collisions
  - STP (Spanning Tree Protocol)
    - Loop avoidances
    - Including
      - STA (Spanning Tree Algorithm)
      - BPDUs (Bridge Protocol Data Units)



工作站	埠口	時間
A	1	2
B	1	1
C	3	5
D	3	1
E	2	2
F	2	6
G	2	1
H	2	7

工作站	埠口	時間
A	1	2
B	1	1
C	1	2
D	1	7
E	1	4
F	1	3
G	2	1
H	2	2

Hardware Selection – LAN Device (4)

- Switch (layer2)
  - Layer2 device
  - Multi-port bridge
    - Each port is a single collision domain
    - Learning
      - Each port can learn 1024 Ethernet Address
    - Store-and-Forward
  - Port Trunks
    - Aggregate multi-ports to form a logical one
      - Bandwidth
      - Reliability

VLAN – Virtual LAN

- VLAN
  - Spilt a physical switch into several logical switches
  - Static VLAN
    - Administratively assign which port to which VLAN
  - Trunking
    - IEEE 802.1Q Tagging
    - Cisco's Inter-Switch Link Tagging
    - 3COM’s VLT Tagging

Last Mile Solution

- xDSL
  - Digital Subscriber Line
  - ADSL for asymmetric DSL
  - Use ordinary telephone wire to transmit data
- Cable Modem
  - Use TV cable to transmit data
- Dedicated phone connection
  - T1 (DS1 line)
    - 1.544Mbps, 24 channels, each channel 64Kbps
  - T2 (DS2 line)
    - 6.1Mpbs, 96 channels, each channel 64Kbps
  - T3 (DS3 line)
    - 43Mbps, 672 channels, each channel 64Kbps
- FTTx (Fiber To The Home)
  - FTTH for home, FTTB for building, FTTC for Curb