

TCP/IP Protocols

TCP/IP and the Internet

- In 1969
 - ARPA funded and created the “ARPAnet” network
 - 美國高級研究計劃署 (Advanced Research Project Agency)
 - NCP – network control protocol
 - Two disadvantages
- In 1973
 - How to connect ARPAnet with SAT Net and ALOHAnet
 - TCP/IP begun to be developed
- In 1983
 - TCP/IP protocols replaced NCP as the ARPANET’s principal protocol
 - 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

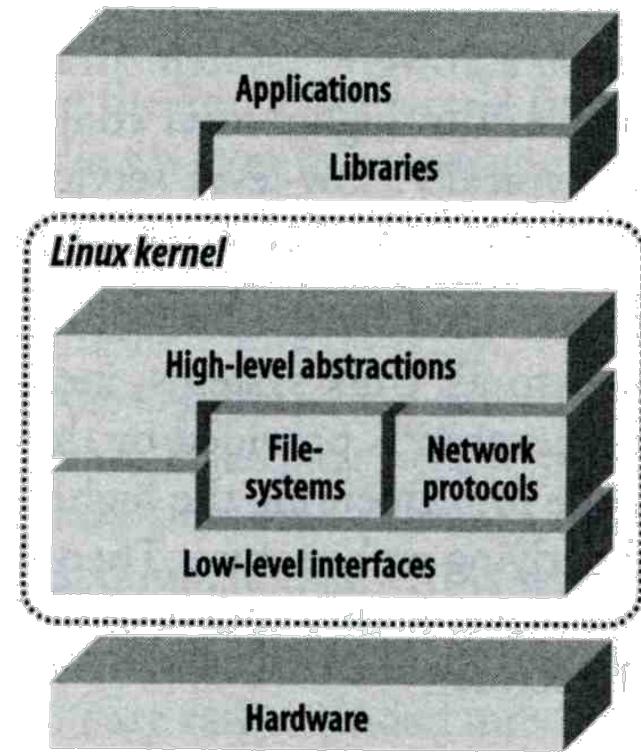
ARPA = Advanced Research Project Agency
NSF = National Science Foundation

Introduction

– Why TCP/IP ?

□ The gap between applications and Network

- Network
 - 802.3 Ethernet
 - 802.4 Token bus
 - 802.5 Token Ring
 - 802.11 Wireless
- Application
 - Reliable
 - Performance



**We need something to do the translating work!
TCP/IP it is!!**

Introduction

– Layers of TCP/IP (1)

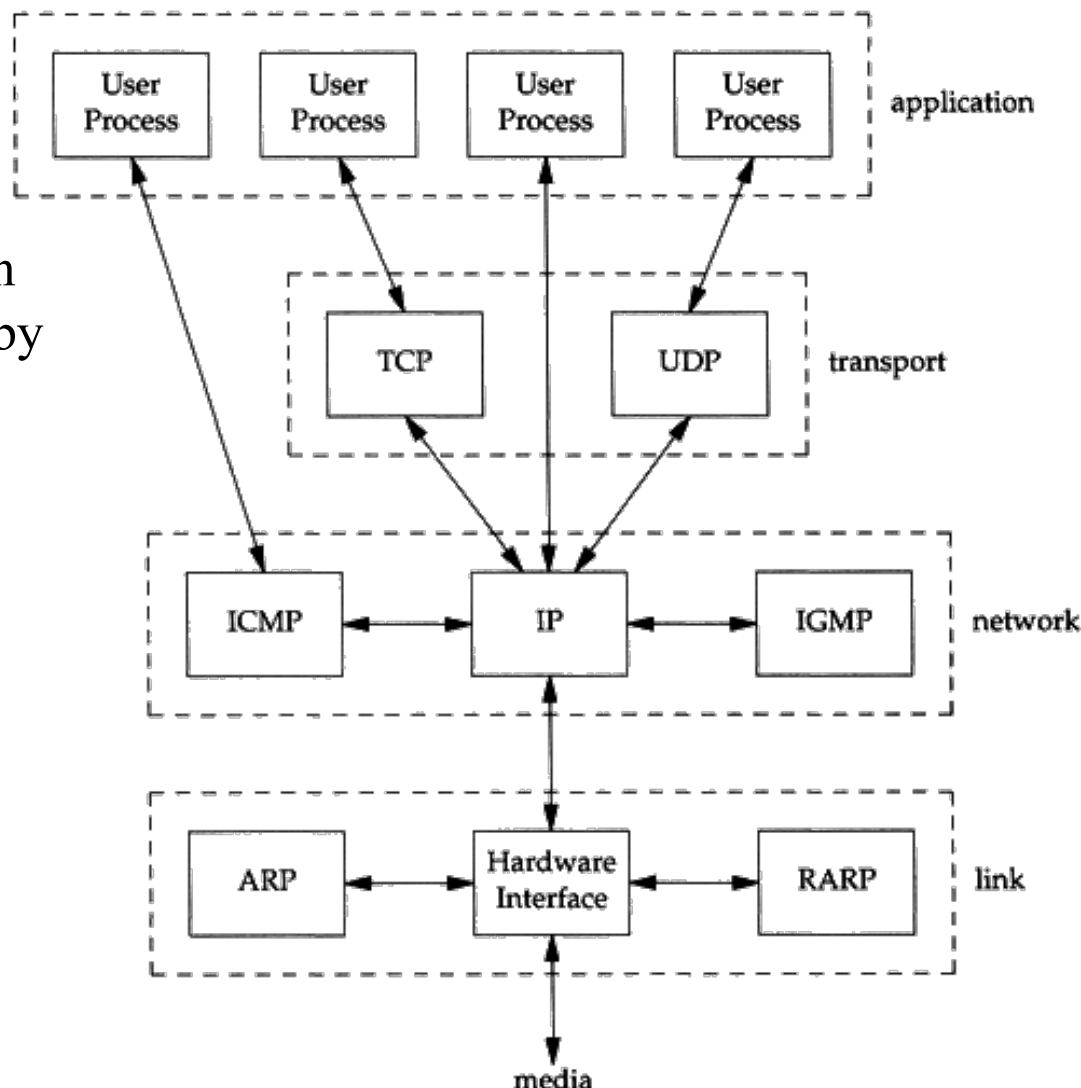
- TCP/IP is a suite of networking protocols
 - 4 layers Layering architecture
 - Link layer (data-link layer)
 - Include device drivers to handle hardware details
 - Network layer (IP)
 - Handle the movement of packets around the network
 - Transport layer (Port)
 - Handle flow of data between hosts
 - Application

Introduction

– Layers of TCP/IP (2)

- Each layer has several protocols

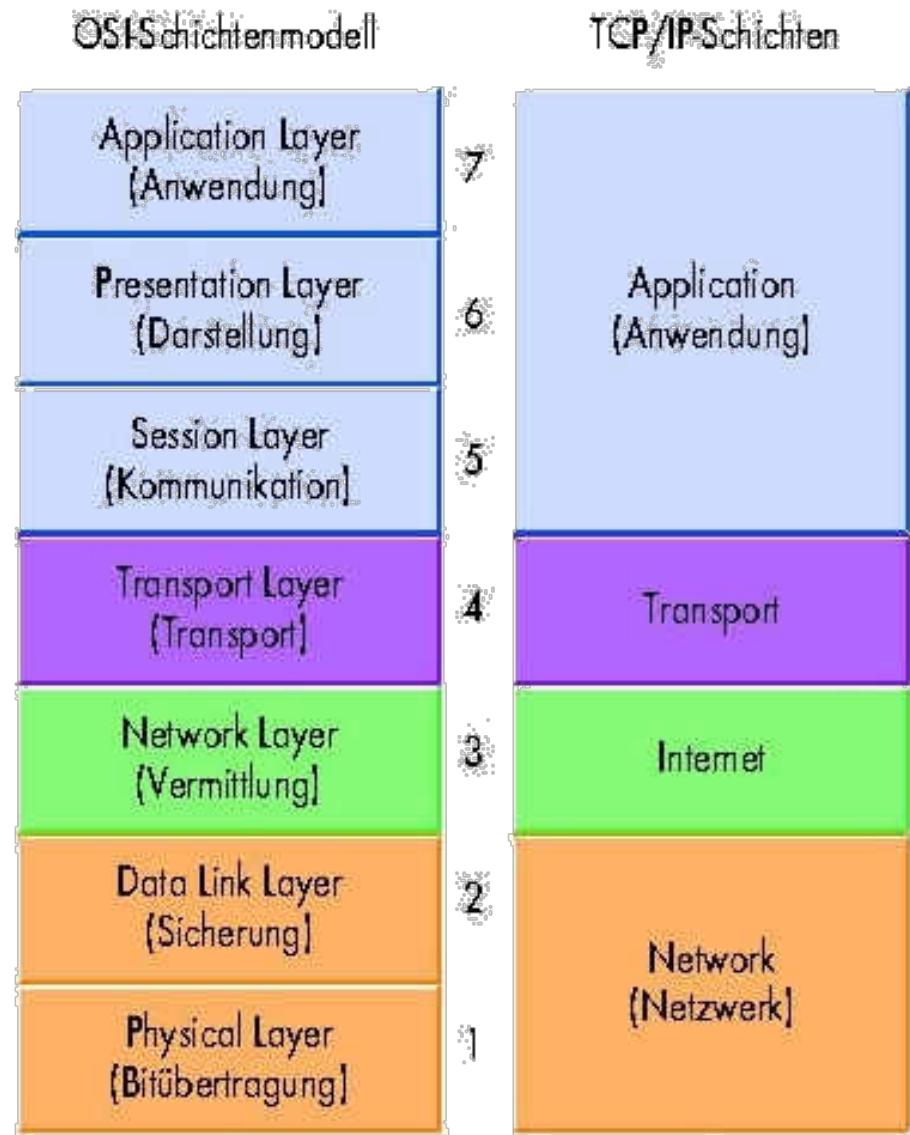
- A layer define a data communication function that may be performed by certain protocols
- A protocol provides a service suitable to the function of that layer



Introduction

– Layers of TCP/IP (3)

- ISO/OSI Model and TCP/IP Model



Introduction

□ TCP/IP

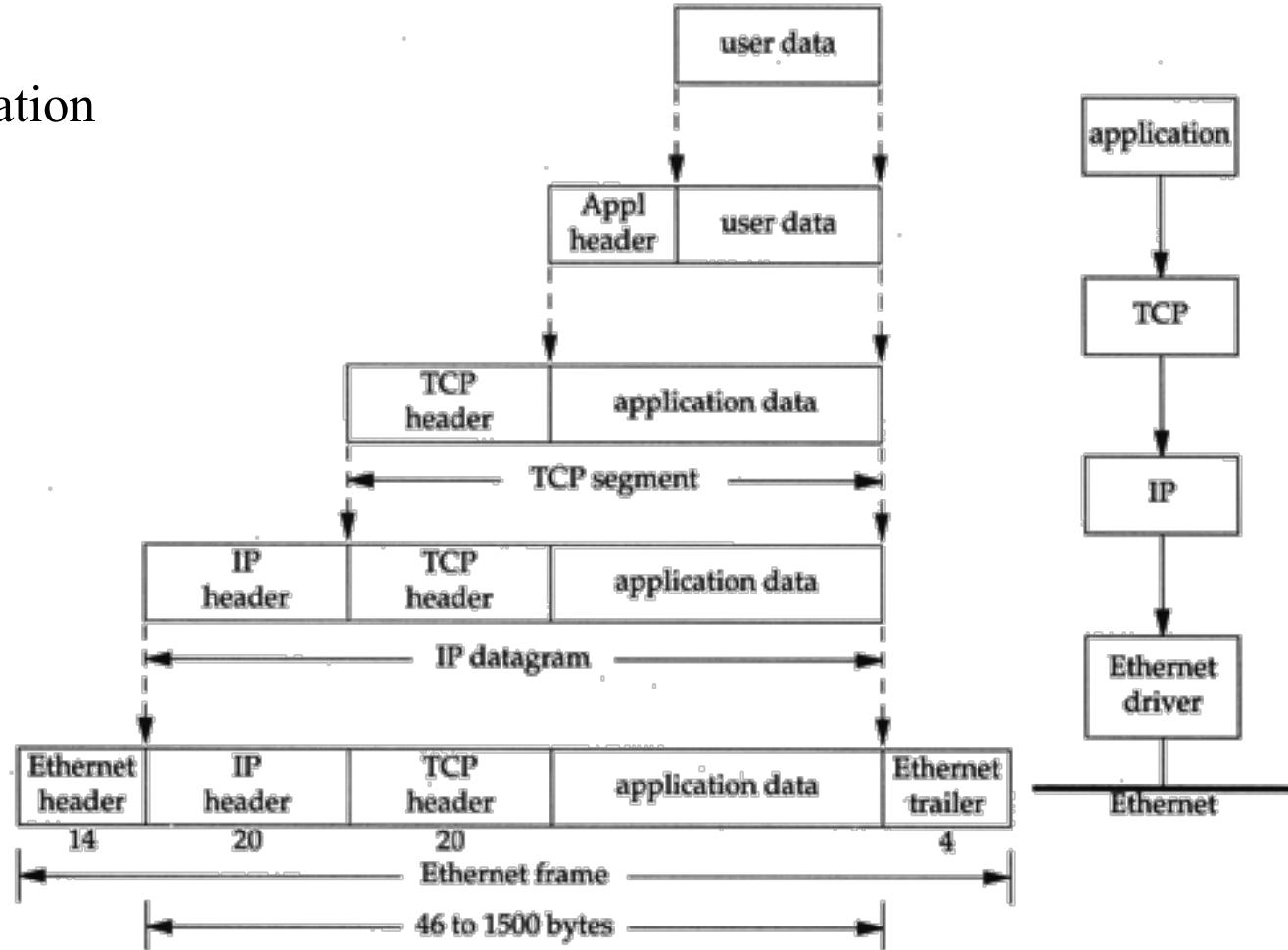
- Used to provide data communication between hosts
 - How to delivery data reliably
 - How to address remote host on the network
 - How to handle different type of hardware device

Introduction

– Encapsulation

□ Send data

- encapsulation



Introduction

– Demultiplex

□ Demultiplexing

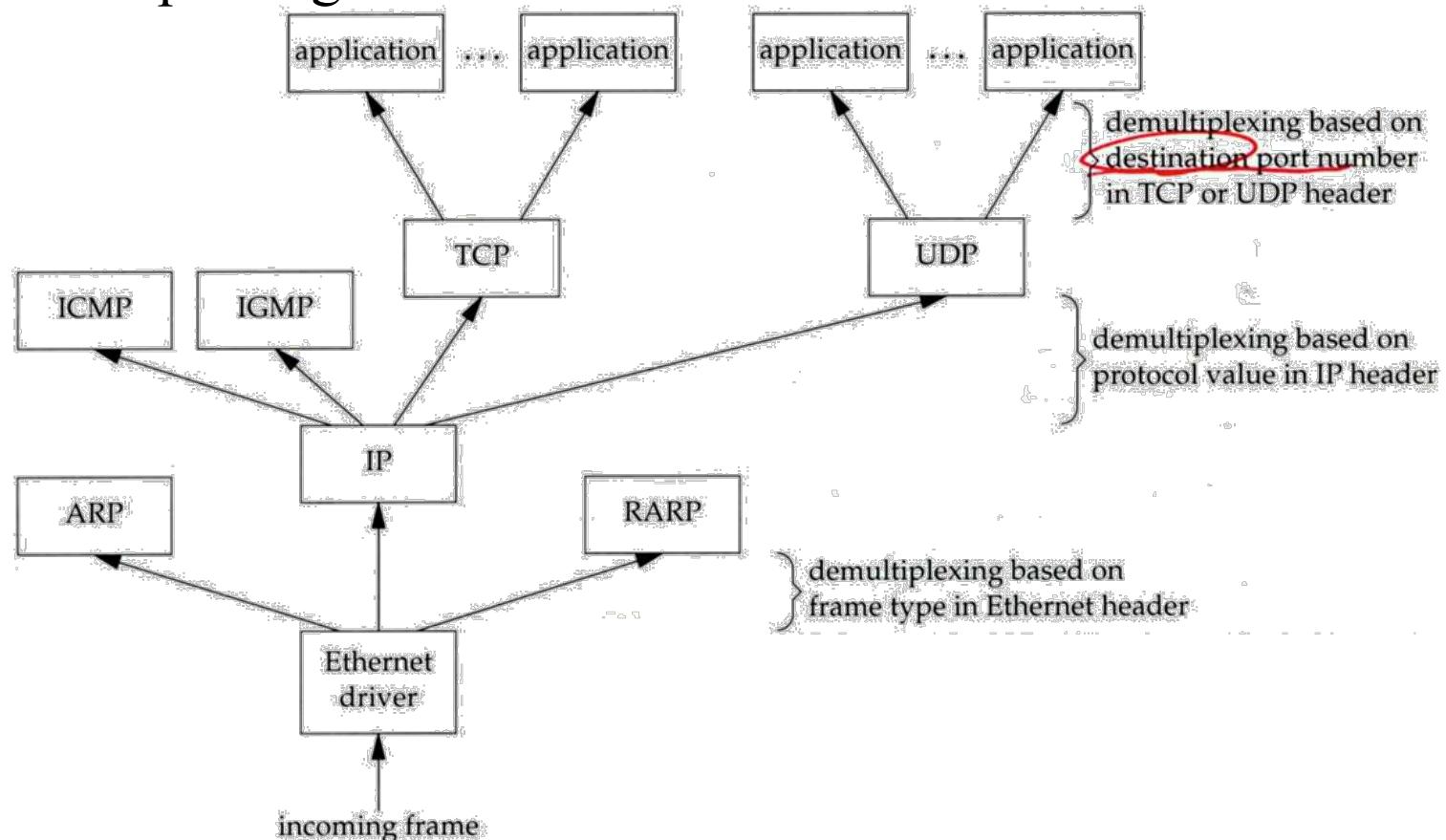


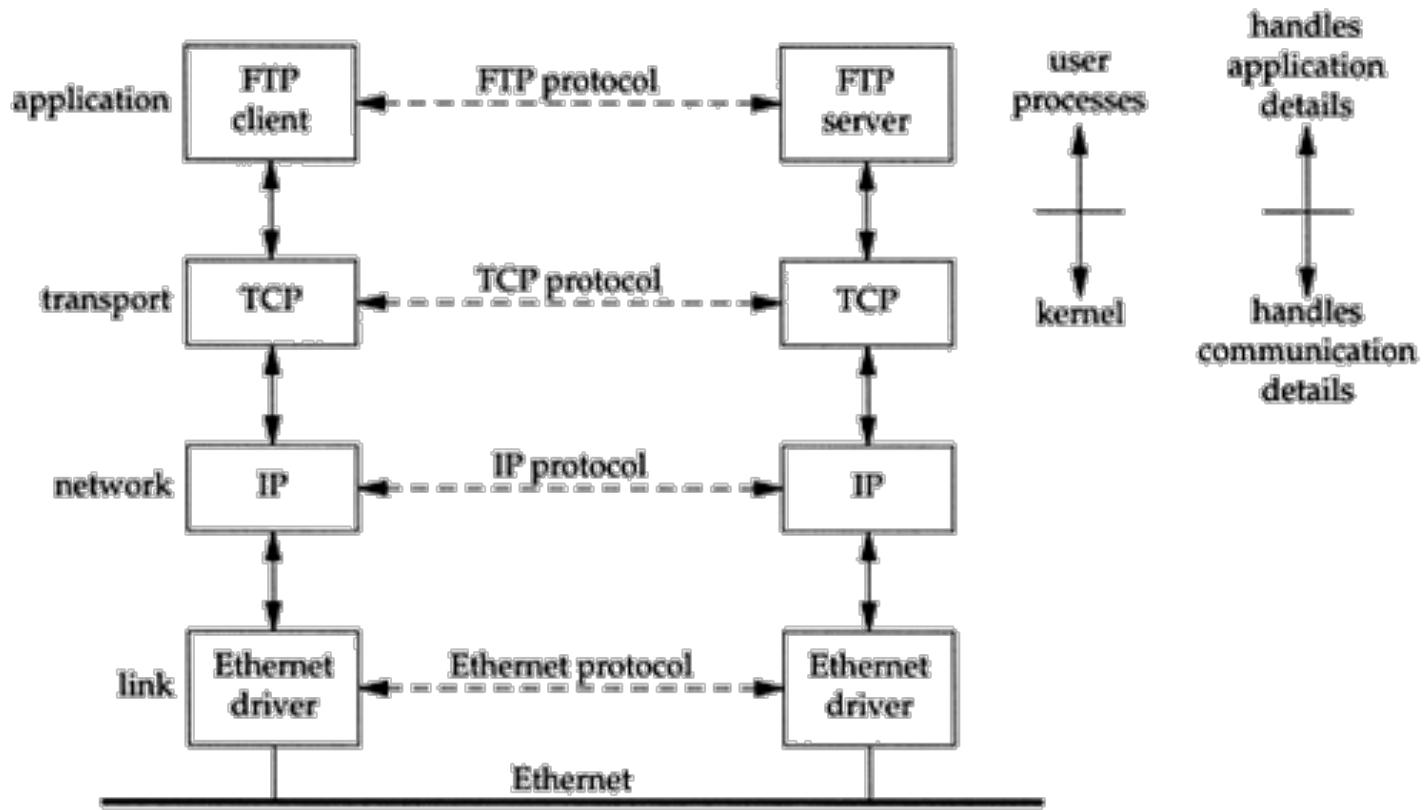
Figure 1.8 The demultiplexing of a received Ethernet frame.

Introduction

– Addressing

□ Addressing

- Nearby (same network)

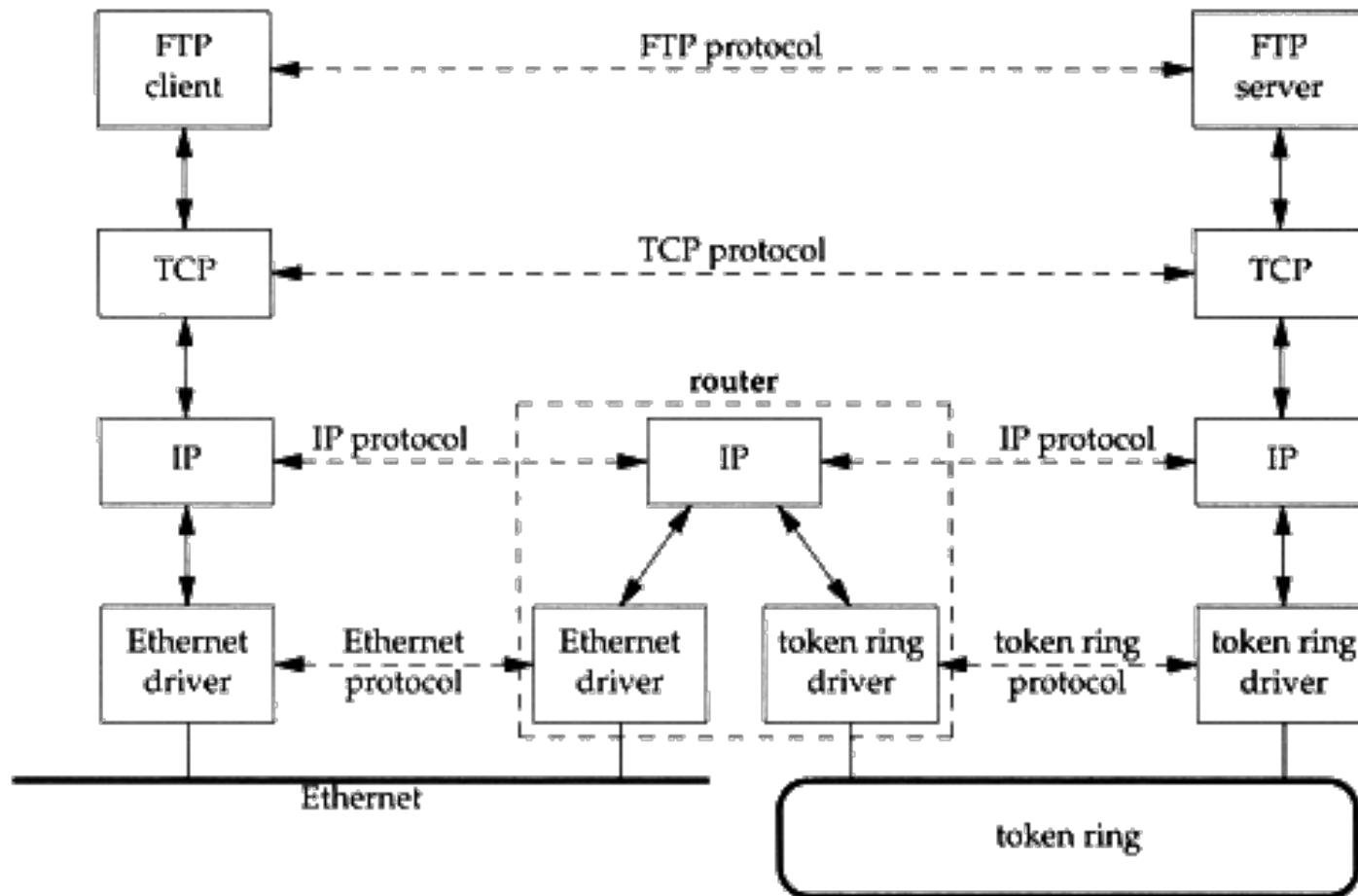


Introduction

– Addressing

□ Addressing

- Faraway (across network)



Introduction

– Addressing

□ 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

```
sabsd [/home/chwong] -chwong- ifconfig
sk0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        options=b<RXCSUM,TXCSUM,VLAN_MTU>
        inet 140.113.17.215 netmask 0xffffffff broadcast 140.113.17.255
        inet 140.113.17.221 netmask 0xffffffff broadcast 140.113.17.221
        ether 00:11:d8:06:1e:81
        media: Ethernet autoselect (100baseTX <full-duplex,flag0,flag1>)
        status: active
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> mtu 16384
        inet 127.0.0.1 netmask 0xff000000
```

Link Layer

Link Layer

– Introduction of Link Layer

□ Purpose of the link layer

- Send and receive IP datagram form 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

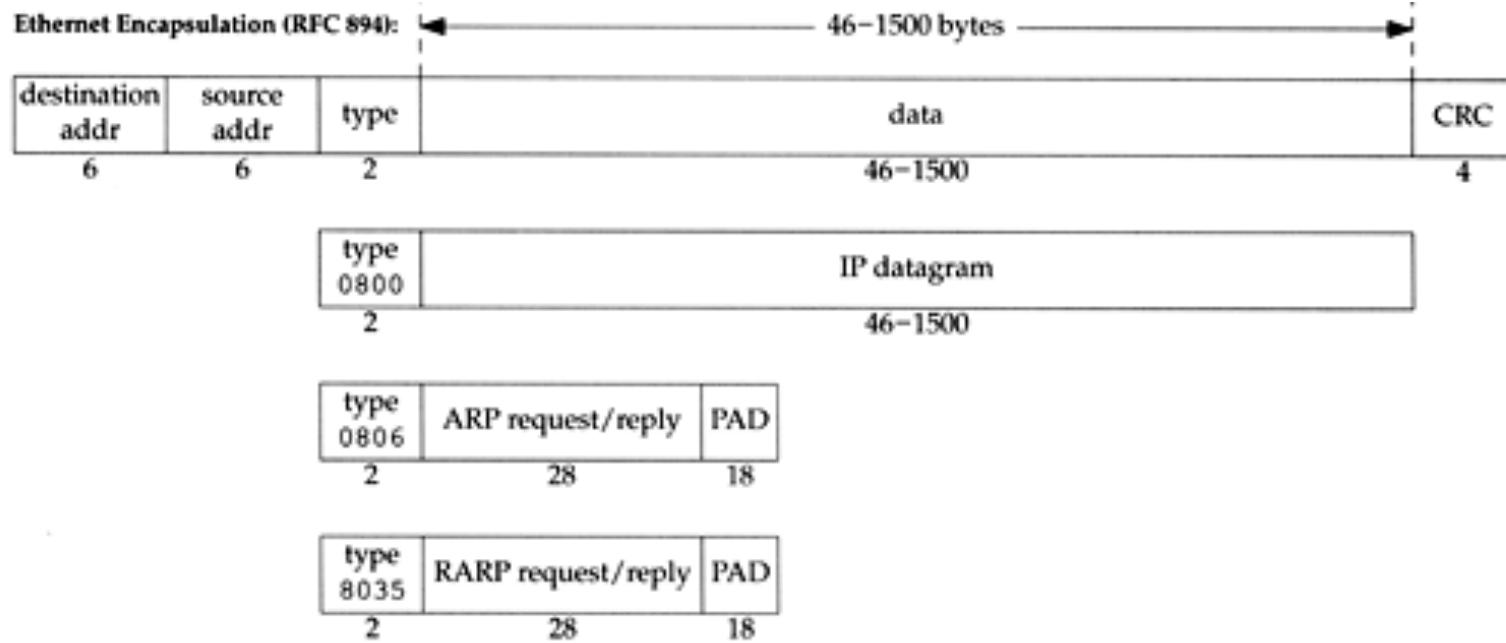
□ Features

- 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

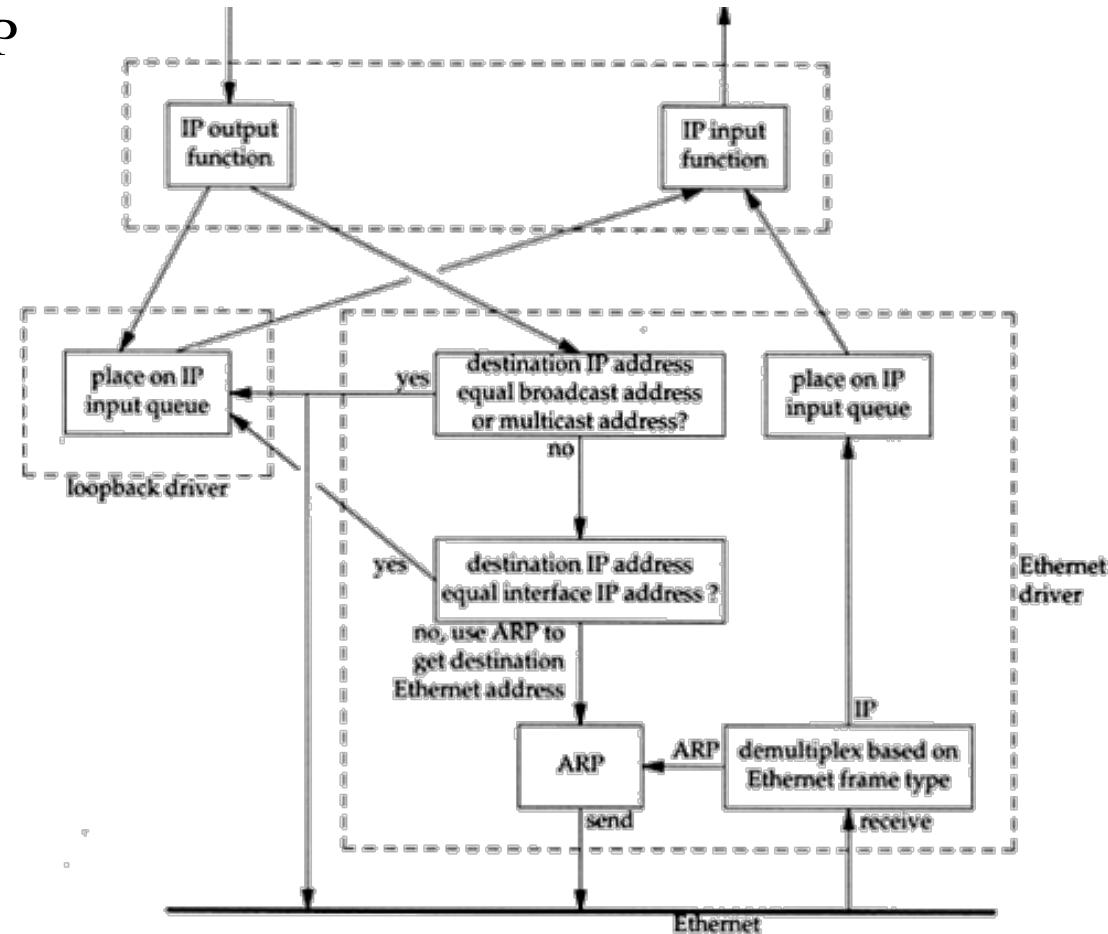


Link Layer

– 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

- To get MTU info

```
% ifconfig  
em0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 9000
```

options=b<RXCSUM,TXCSUM,VLAN_MTU>

inet 192.168.7.1 netmask 0xffffffff broadcast 192.168.7.255

ether 00:0e:0c:01:d7:c8

media: Ethernet autoselect (1000baseTX <full-duplex>)

status: active

```
fpx0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
```

options=b<RXCSUM,TXCSUM,VLAN_MTU>

inet 140.113.17.24 netmask 0xffffffff broadcast 140.113.17.255

ether 00:02:b3:99:3e:71

media: Ethernet autoselect (100baseTX <full-duplex>)

status: active

Network Layer

Network Layer

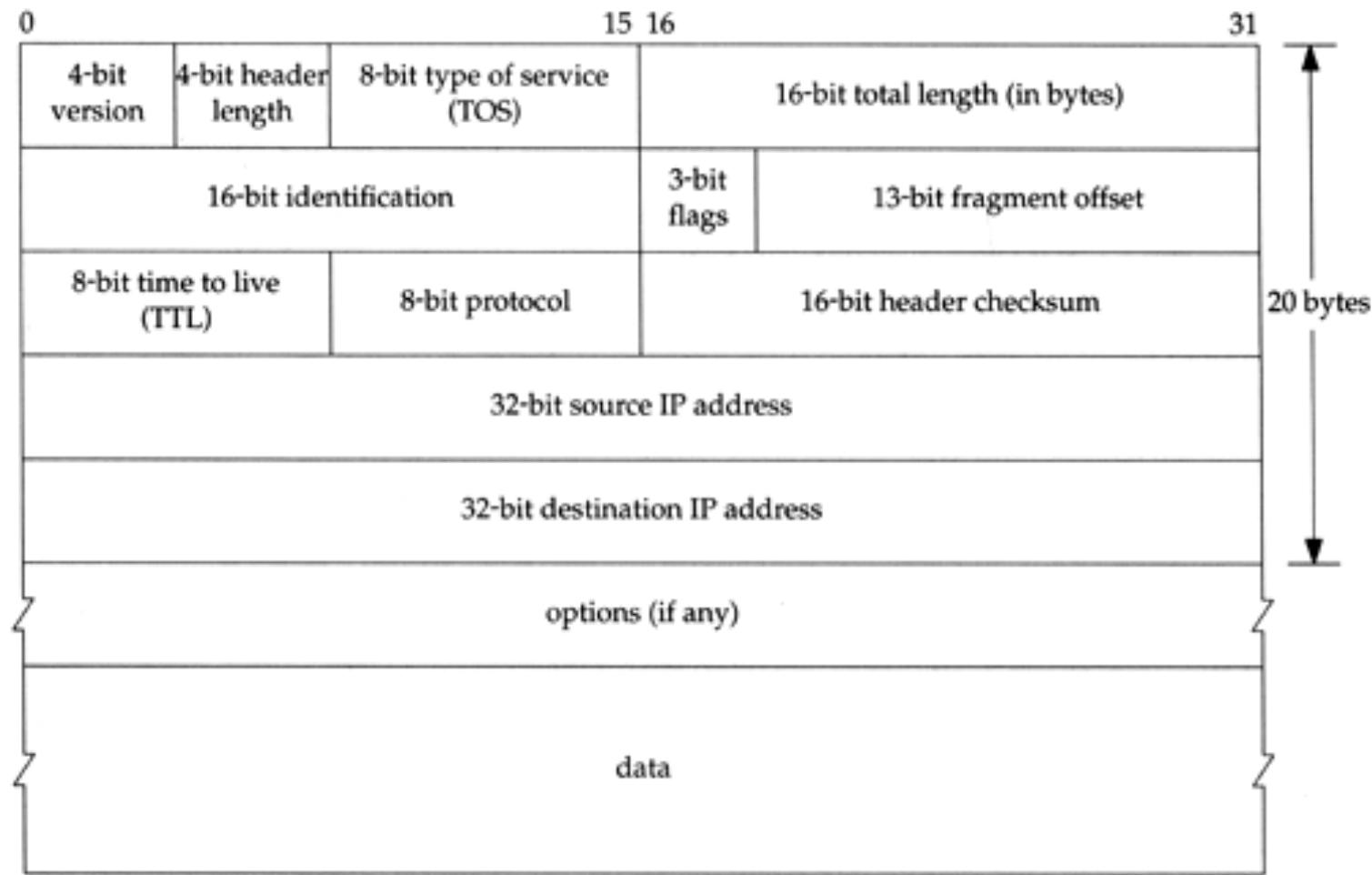
– Introduction to Network Layer

- 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

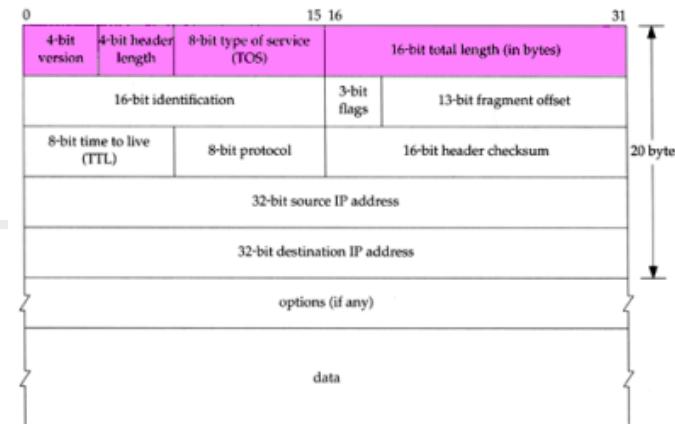
– IP Header (1)

- 20 bytes in total length, excepts options



Network Layer

– IP Header (2)



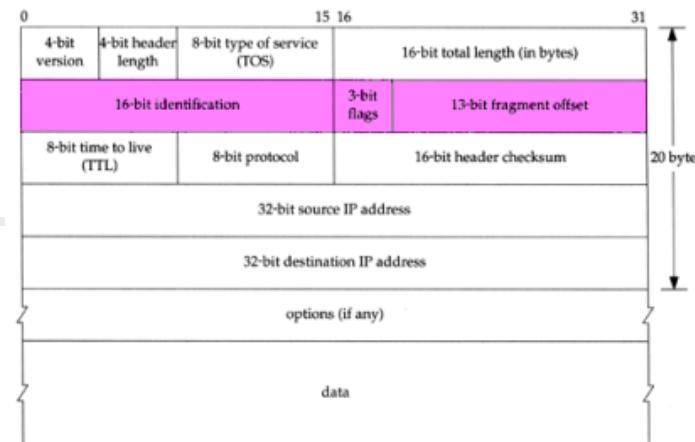
- Version (4bit)
 - 4 for IPv4 and 6 for IPv6
- Header length (4bit)
 - The number of 32bit words in the header ($15*4=60$ bytes)
 - Normally, the value is 5 (no option)
- TOS-Type of Service (8bit)
 - 3bit precedence + 4bit TOS + 1bit unused
- Total length (16bit)
 - Total length of the IP datagram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

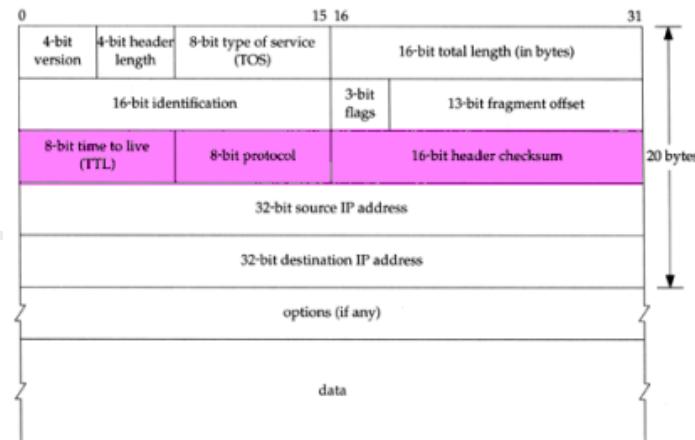
- Limit of next hop count of routers

□ 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 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: $255 \times 255 = 65535$
- IP address category

Class	1 st 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

- $255 \times 255 \times 255$ 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	Netmask 255.255.255.252 211.23.188.78/29
140.113.209.0 → network ID 140.113.209.255 → broadcast address 1 ~ 254, total 254 IPs are usable	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

```
chbsd [/usr/ports/net-mgmt/ipcalc] -chwong- ipcalc 140.113.209.78/28
Address: 140.113.209.78          10001100.01110001.11010001.0100 1110
Netmask: 255.255.255.240 = 28 11111111.11111111.11111111.1111 0000
Wildcard: 0.0.0.15              00000000.00000000.00000000.0000 1111
⇒
Network: 140.113.209.64/28    10001100.01110001.11010001.0100 0000
HostMin: 140.113.209.65      10001100.01110001.11010001.0100 0001
HostMax: 140.113.209.78      10001100.01110001.11010001.0100 1110
Broadcast: 140.113.209.79    10001100.01110001.11010001.0100 1111
Hosts/Net: 14                  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	0xFFFFFFF00
/25	7	126	255.255.255.128	0xFFFFFFF80
/26	6	62	255.255.255.192	0xFFFFFFC00
/27	5	30	255.255.255.224	0xFFFFFFFEO
/28	4	14	255.255.255.240	0xFFFFFFF00
/29	3	6	255.255.255.248	0xFFFFFFF80
/30	2	2	255.255.255.252	0xFFFFFFFFC00

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

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
 - `net.inet.ip.forwarding=1`

□ 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

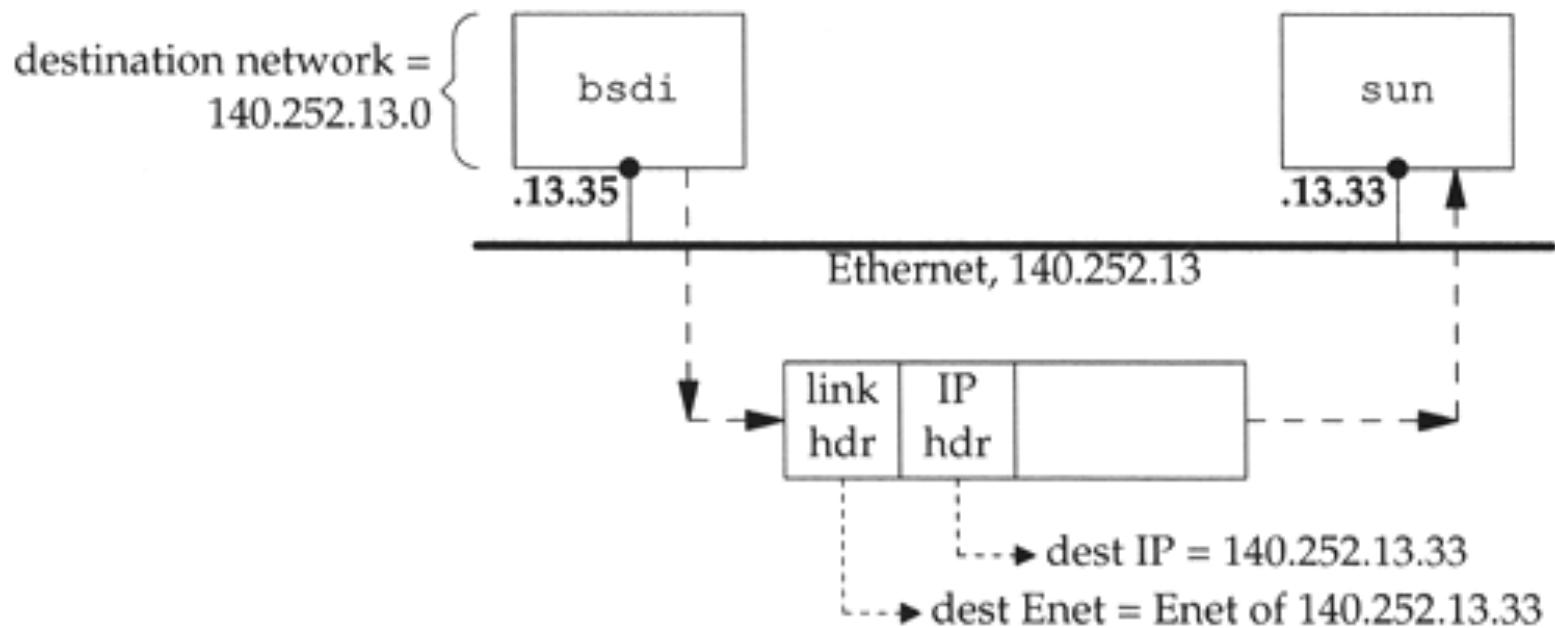
- Done on a hop-by-hop basis
- It assumes that the next-hop router is closer to the destination
- Steps:
 - Search routing table for complete matched IP address
 - Send to next-hop router or to the directly connected NIC
 - Search routing table for matched network ID
 - Send to next-hop router or to 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



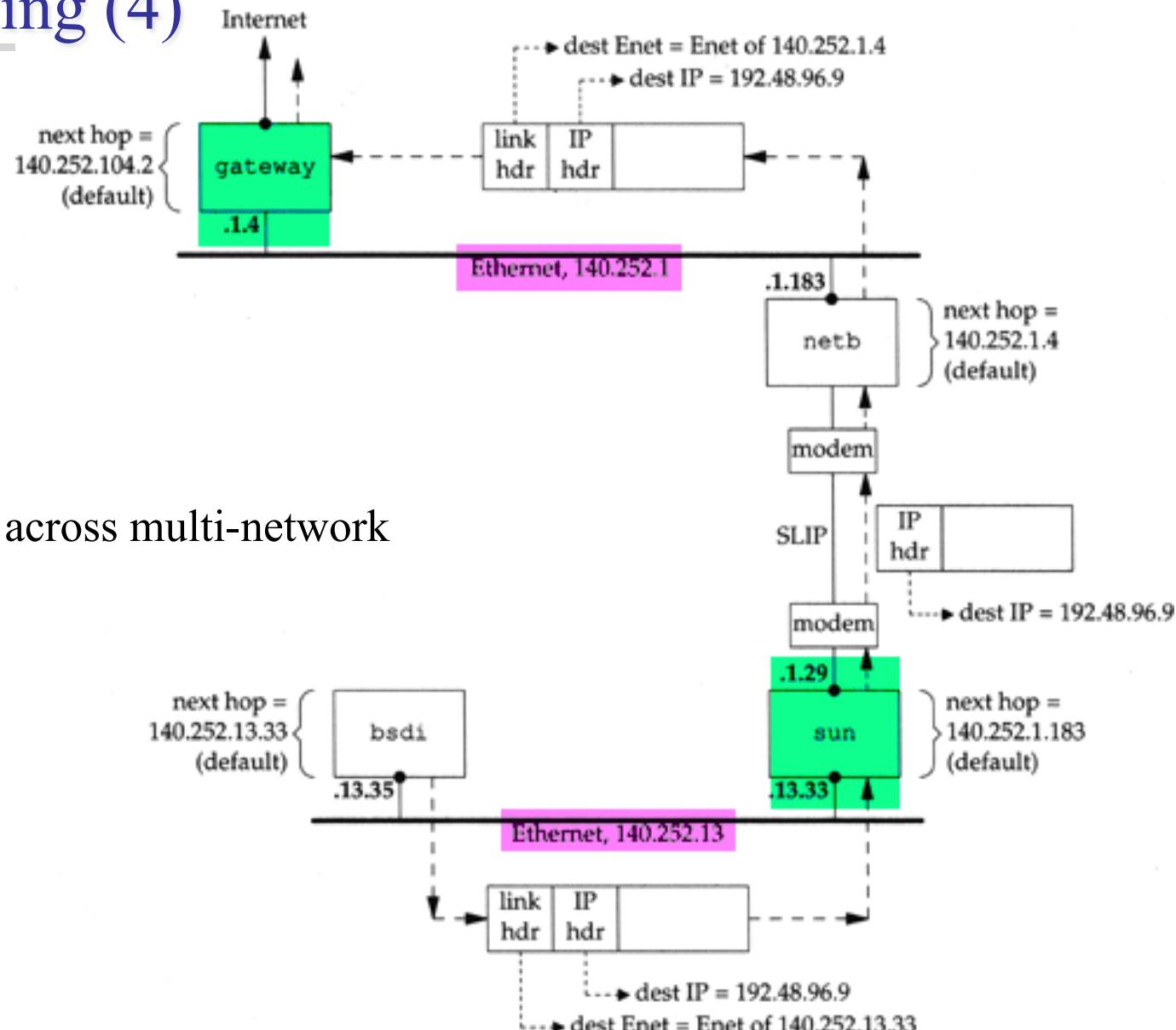
Ex Routing table:

140.252.13.33

00:d0:59:83:d9:16

UHLW fxp1

Network Layer – IP Routing (4)



□ Ex2:

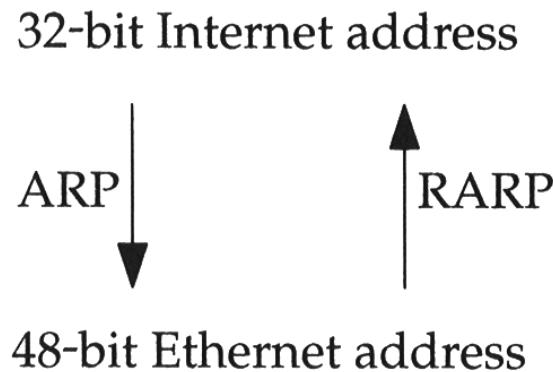
- routing across multi-network

ARP and RARP

Something between
MAC (link layer)
And
IP (network layer)

ARP and RARP

- ARP
 - Address Resolution Protocol and
 - 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

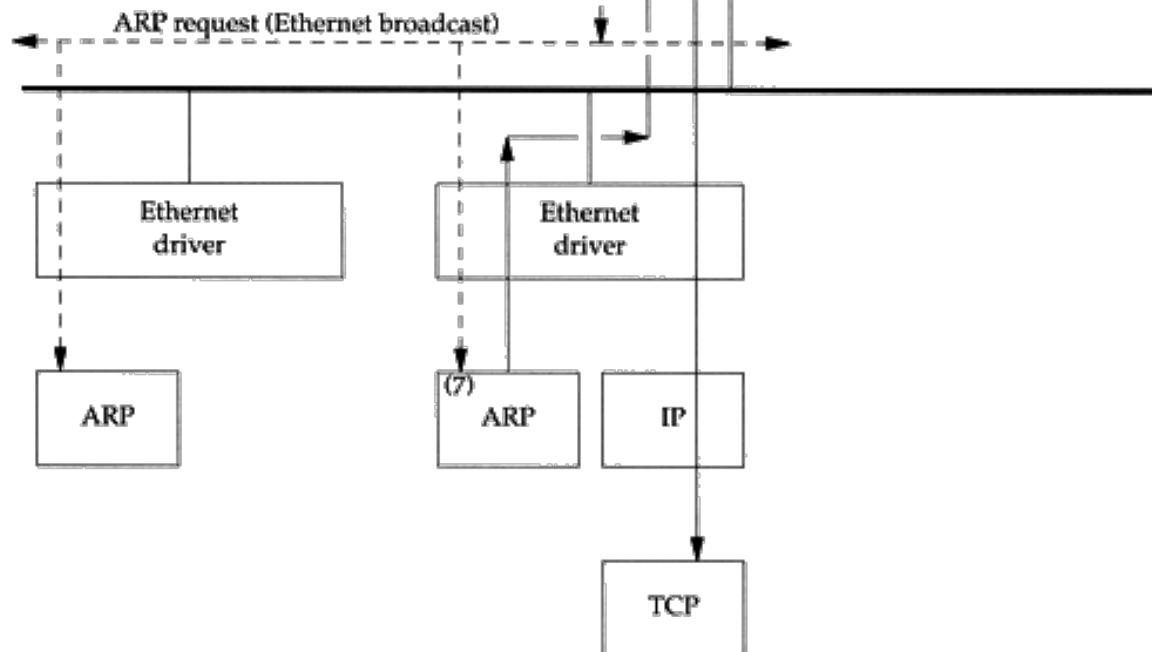
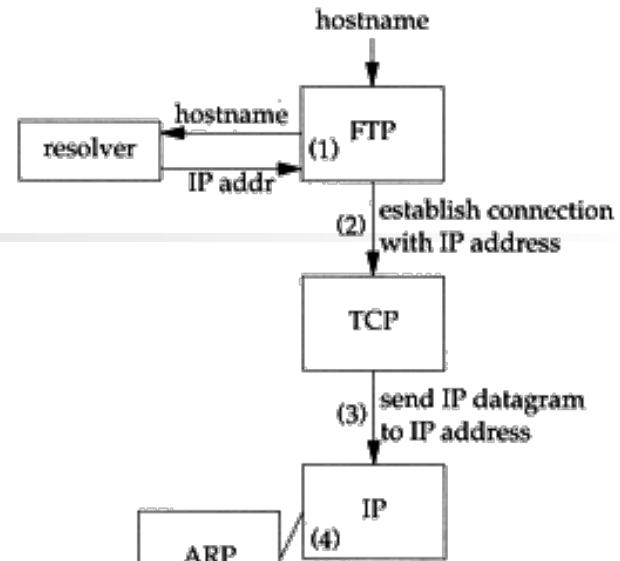
ARP and RARP

– 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

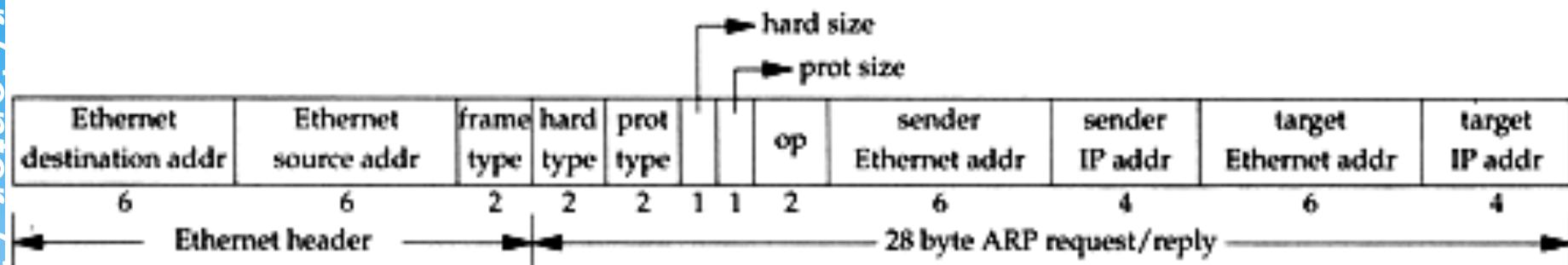
□ Maintain recent ARP results

- come from both ARP request and reply
 - 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/chwong] -chwong- 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 chbsd.csie.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
```

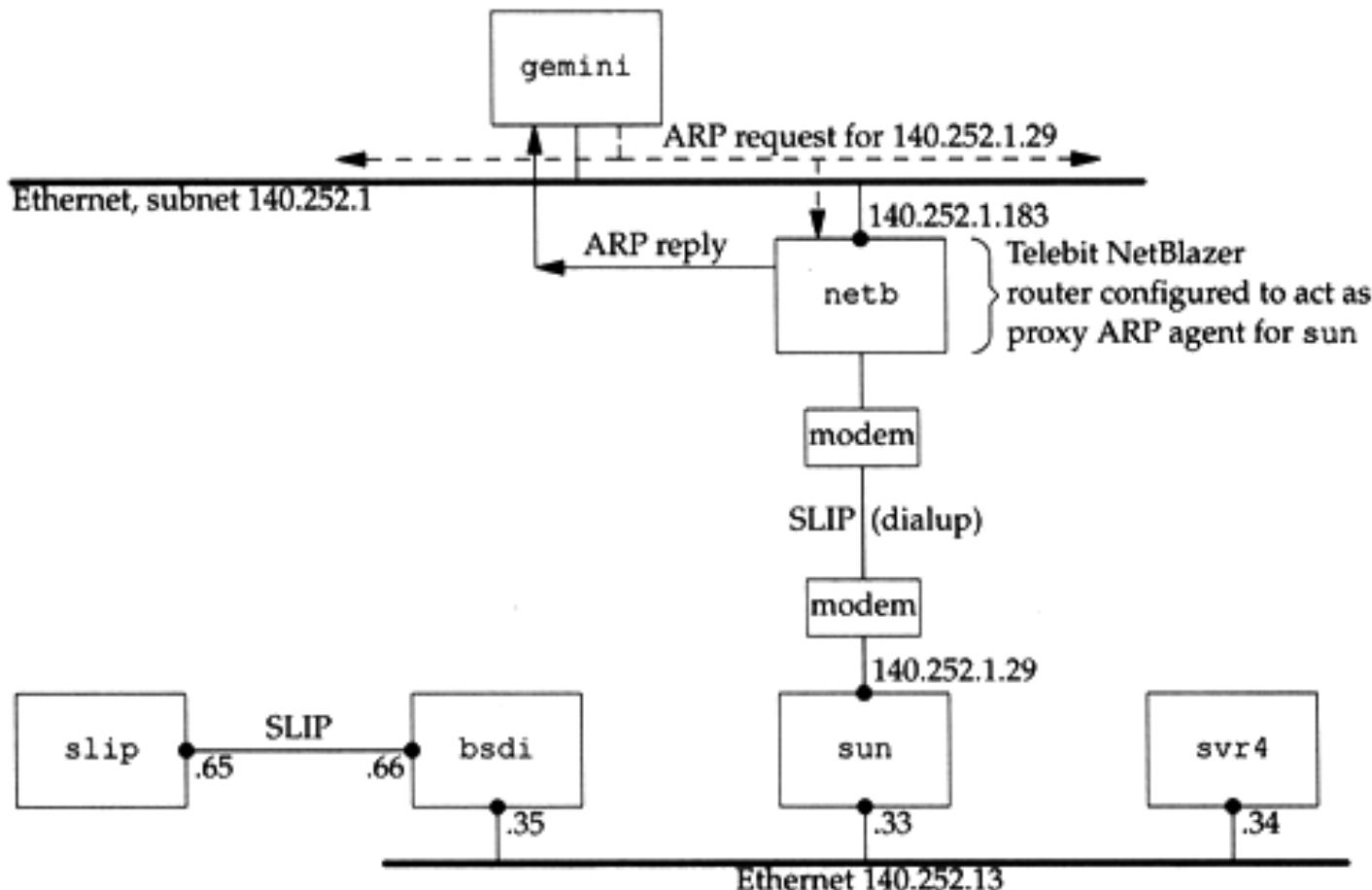
```
00:90:96:23:8f:7d > ff:ff:ff:ff:ff:ff, ethertype ARP (0x0806), length 60:  
arp who-has 140.113.17.215 tell 140.113.17.212
```

```
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

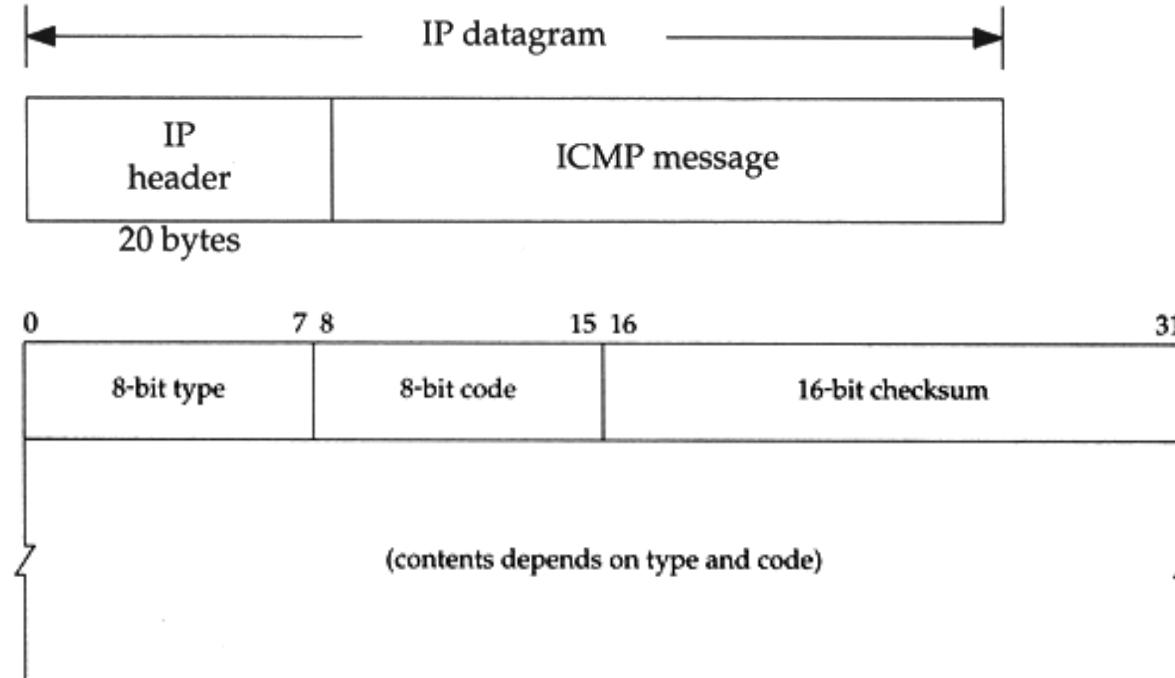
ICMP

– 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)

<i>type</i>	<i>code</i>	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:

```
chbsd [/home/chwong] -chwong- 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

chbsd [/home/chwong] -chwong- icmpquery -m sun1
sun1 : 0xFFFFFFF00
```

※ 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:

```
chbsd [/home/chwong] -chwong- ping -M time nbsd  
ICMP_TSTAMP  
PING nbsd.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  
  
chbsd [/home/chwong] -chwong- icmpquery -t nbsd  
nbsd : 14:54:47
```

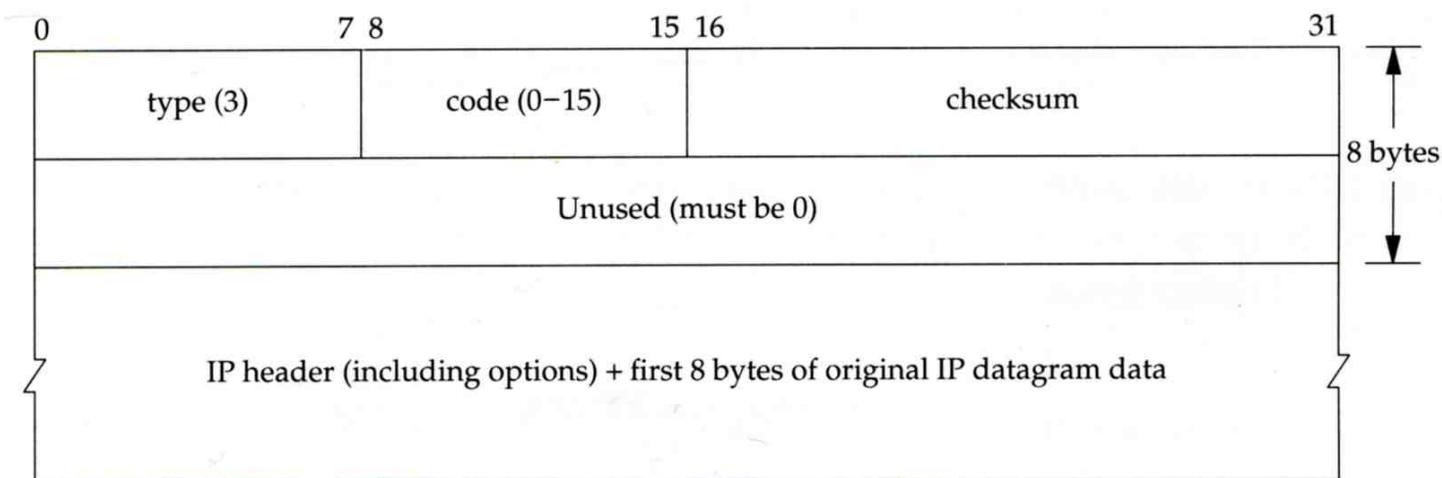
```
nbsd [/home/chwong] -chwong- sudo tcpdump -i sk0 -e icmp  
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode  
listening on sk0, link-type EN10MB (Ethernet), capture size 96 bytes  
14:48:24.999106 00:90:96:23:8f:7d > 00:11:d8:06:1e:81, ethertype IPv4 (0x0800), length 110:  
    chbsd.csie.nctu.edu.tw > nbsd: 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:  
    nbsd > chbsd.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:  
    chbsd.csie.nctu.edu.tw > nbsd: 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:  
    nbsd > chbsd.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
 - 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

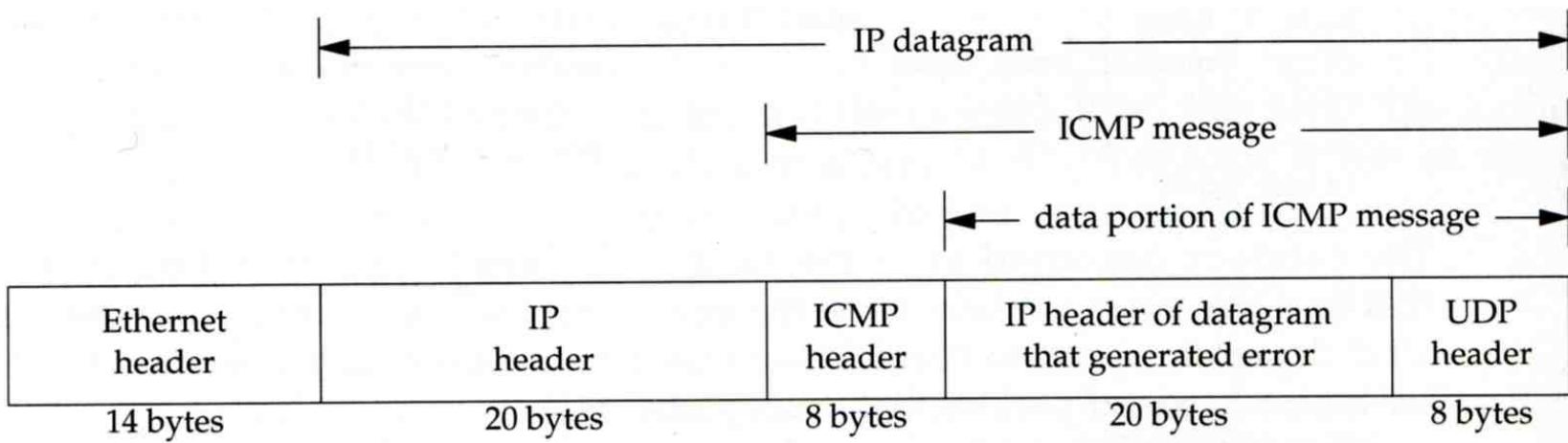


ICMP – Error Message

– 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

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

tftp>
```

```
chbsd [/home/chwong] -chwong- 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

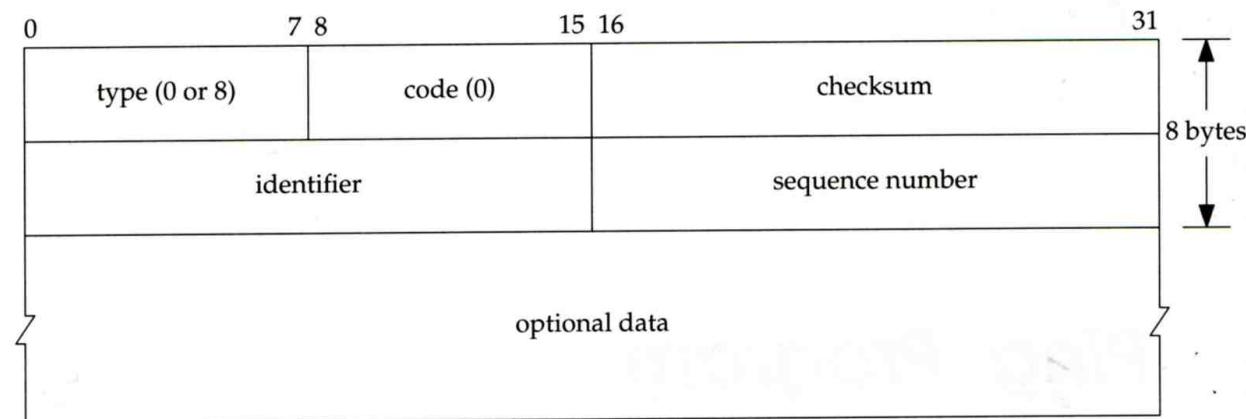
– Ping Program (1)

□ 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:

- chbsd ping nabsd
- execute “tcpdump -i sk0 -X -e icmp” on nabsd

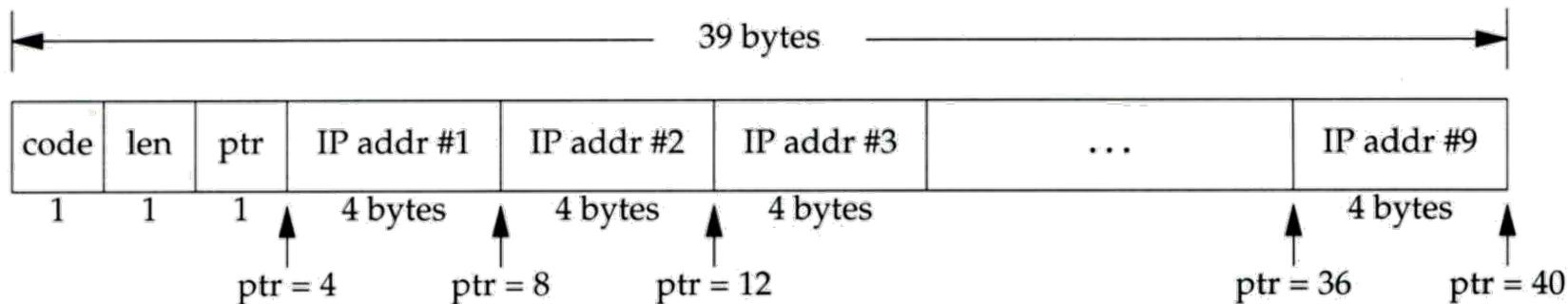
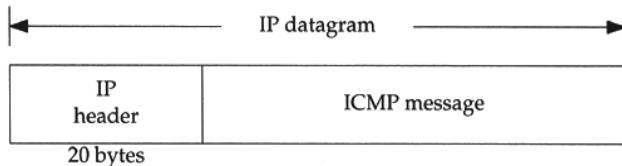
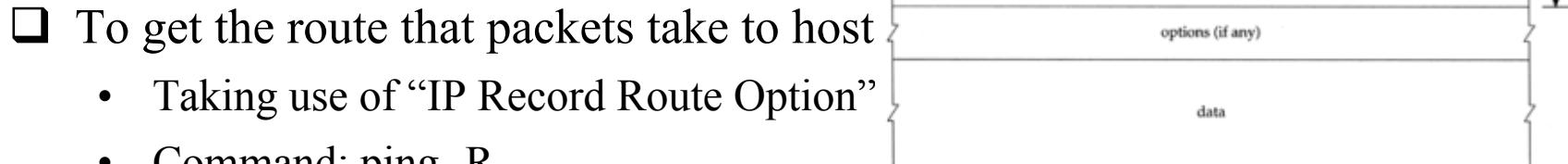
```
chbsd [/home/chwong] -chwong- ping nabsd
PING nabsd.cs.nctu.edu.tw (140.113.17.215) : 56 data bytes
64 bytes from 140.113.17.215: icmp_seq=0 ttl=64 time=0.520 ms
```

```
15:08:12.631925 00:90:96:23:8f:7d > 00:11:d8:06:1e:81, ethertype IPv4 (0x0800), length 98:
    chbsd.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 > chbsd.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

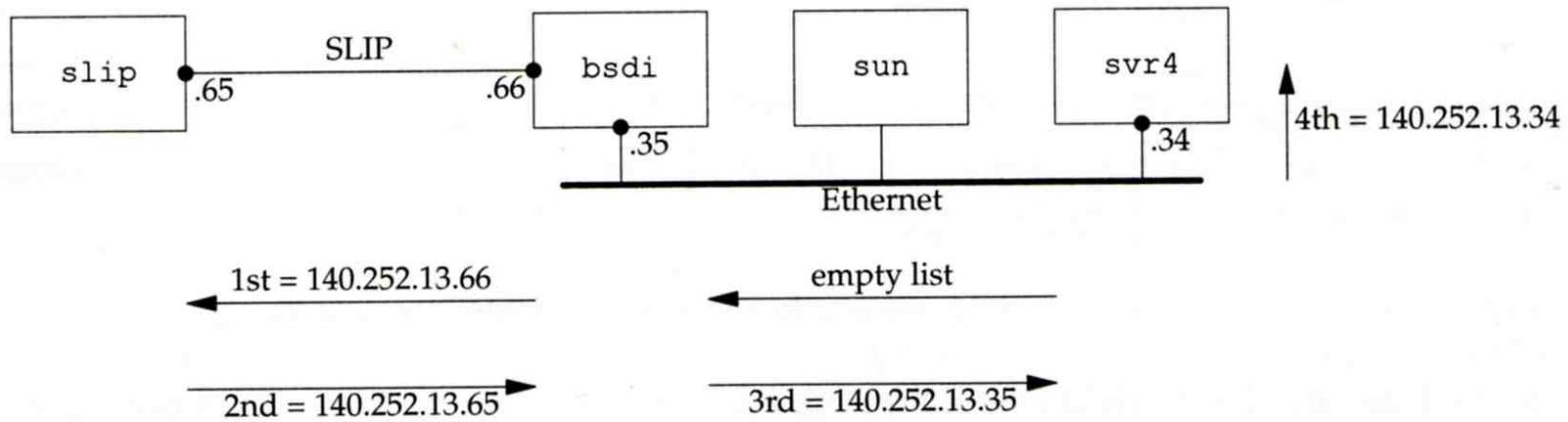
– Ping Program (3)



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

```
chbsd [/home/chwong] -chwong- 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)
       chbsd.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)
```

```
chbsd [/home/chwong] -chwong- 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 390.0.0.00.0.00.0.0.00.0.00.0.0.00.0.0.00.0.0.00.0.0.00.0.0.0.0.0.0.0EOL
(0) len 1 )) 140.113.17.212 > 140.113.250.5: ICMP echo request, id 45561, seq 0, length 64
22:57:04.509521 00:90:96:64: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

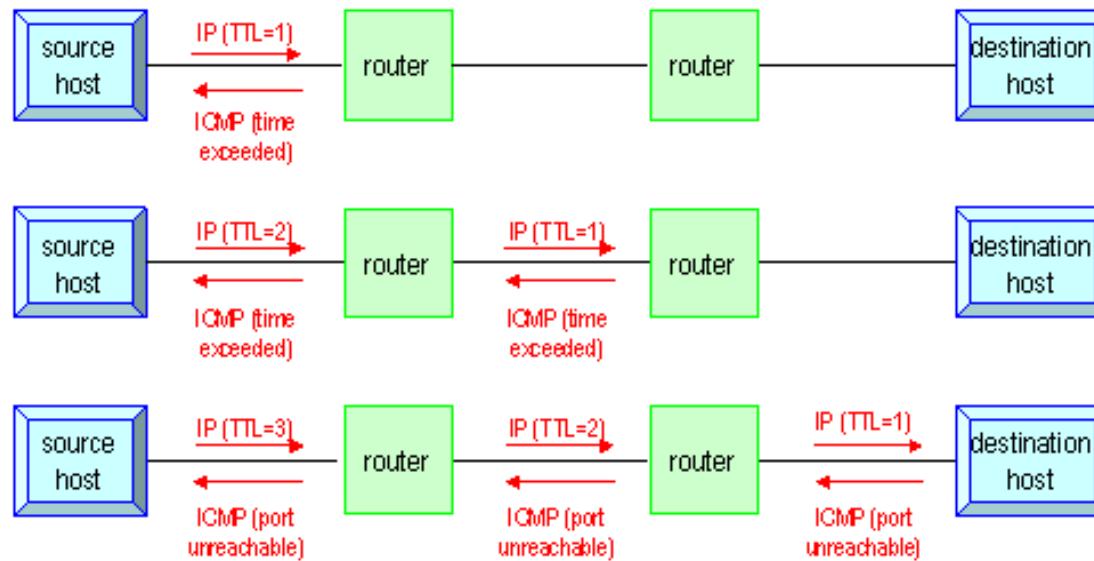
- Drawbacks of IP RR options (ping -R)
 - Not all routers have supported the IP RR option
 - Limitation of IP header length

- 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

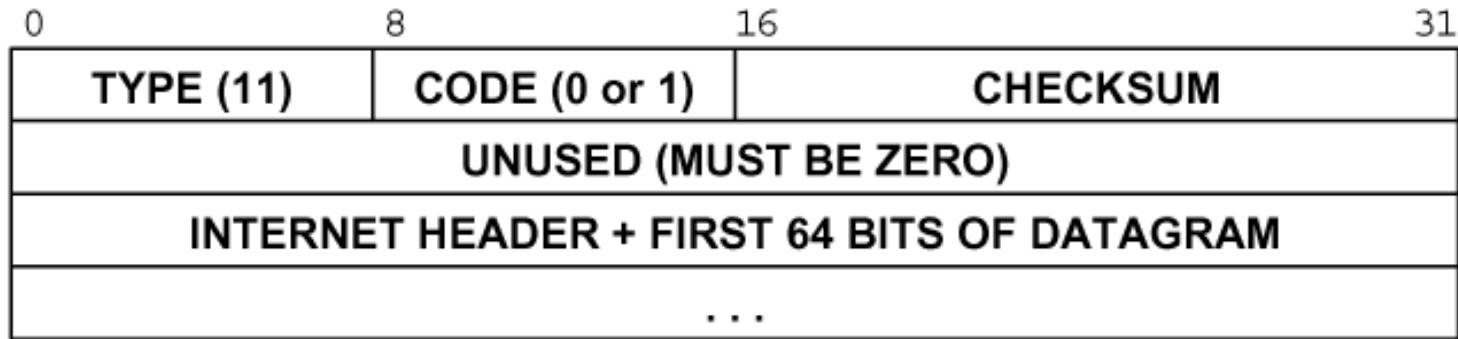
- Send UDP with port > 30000, encapsulated with IP header with TTL = 1, 2, 3, ... continuously
- When router receives the datagram and TTL = 1, it returns a “Time exceed” ICMP message
- When destination host receives the datagram and TTL = 1, it returns a “Port unreachable” ICMP message



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



Traceroute Program (4)

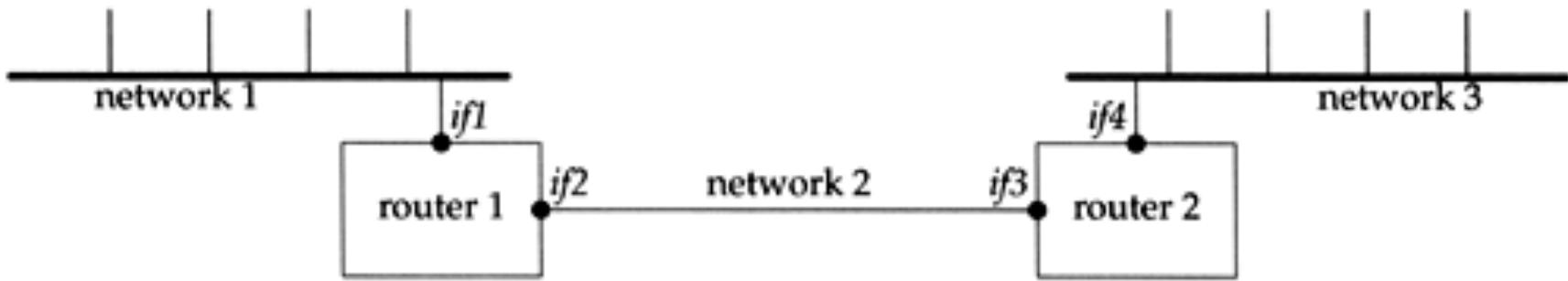
□ Ex:

```
nabsd [/home/chwong] -chwong- traceroute bsd1.cs.nctu.edu.tw
traceroute to bsd1.cs.nctu.edu.tw (140.113.235.131), 64 hops max, 40 byte packets
  1 e3 rtn.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/chwong] -chwong- 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 e3 rtn.csie.nctu.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP e3 rtn.csie.nctu.edu.tw > nabsd: ICMP time exceeded in-transit, length 36
IP e3 rtn.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
```

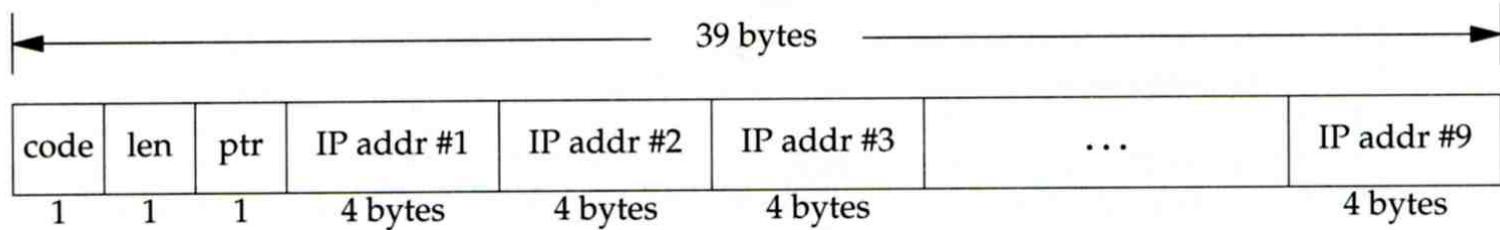
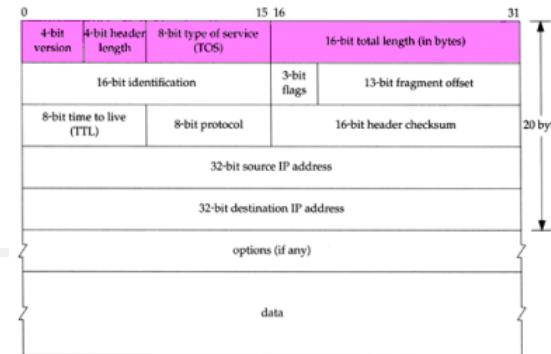
Traceroute Program (5)

- 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)

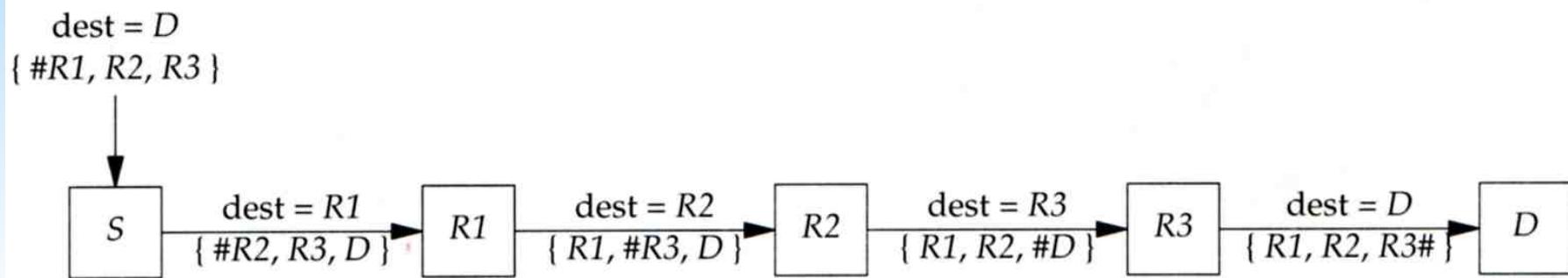
- Source Routing
 - Sender specifies the route
- Two forms of source routing
 - Strict source routing
 - Sender specifies the **exact path** that the IP datagram must follow
 - Loose source routing
 - As strict source routing, but the datagram can pass through other routers between any two addresses 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 \neq 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)

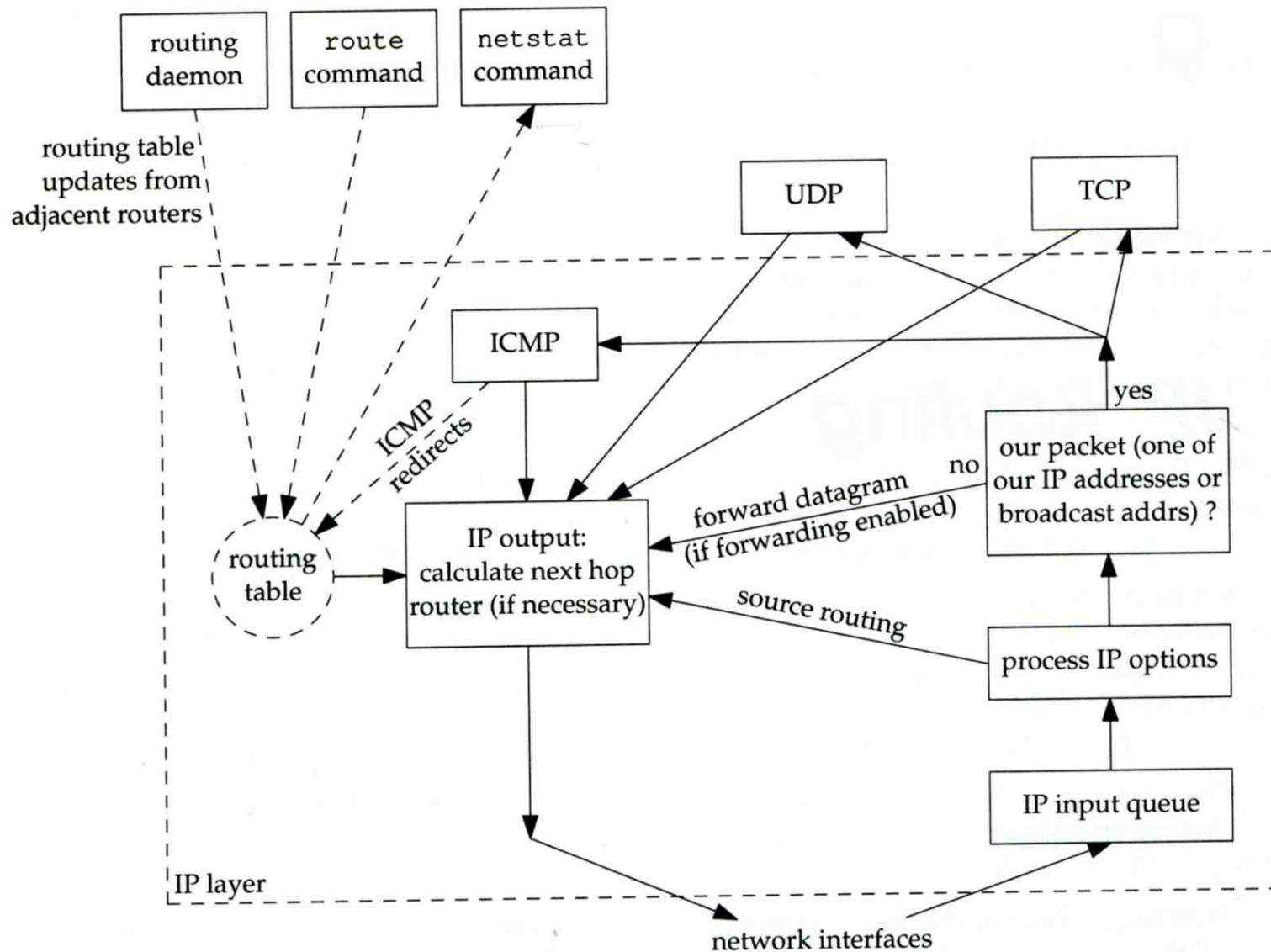
- Traceroute using IP loose SR option
- Ex:

```
nabsd [/home/chwong] -chwong- traceroute u2.nctu.edu.tw
traceroute to u2.nctu.edu.tw (211.76.240.193), 64 hops max, 40 byte packets
 1 e3 rtn-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/chwong] -chwong- 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 e3 rtn-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. field 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/chwong] -chwong- 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:

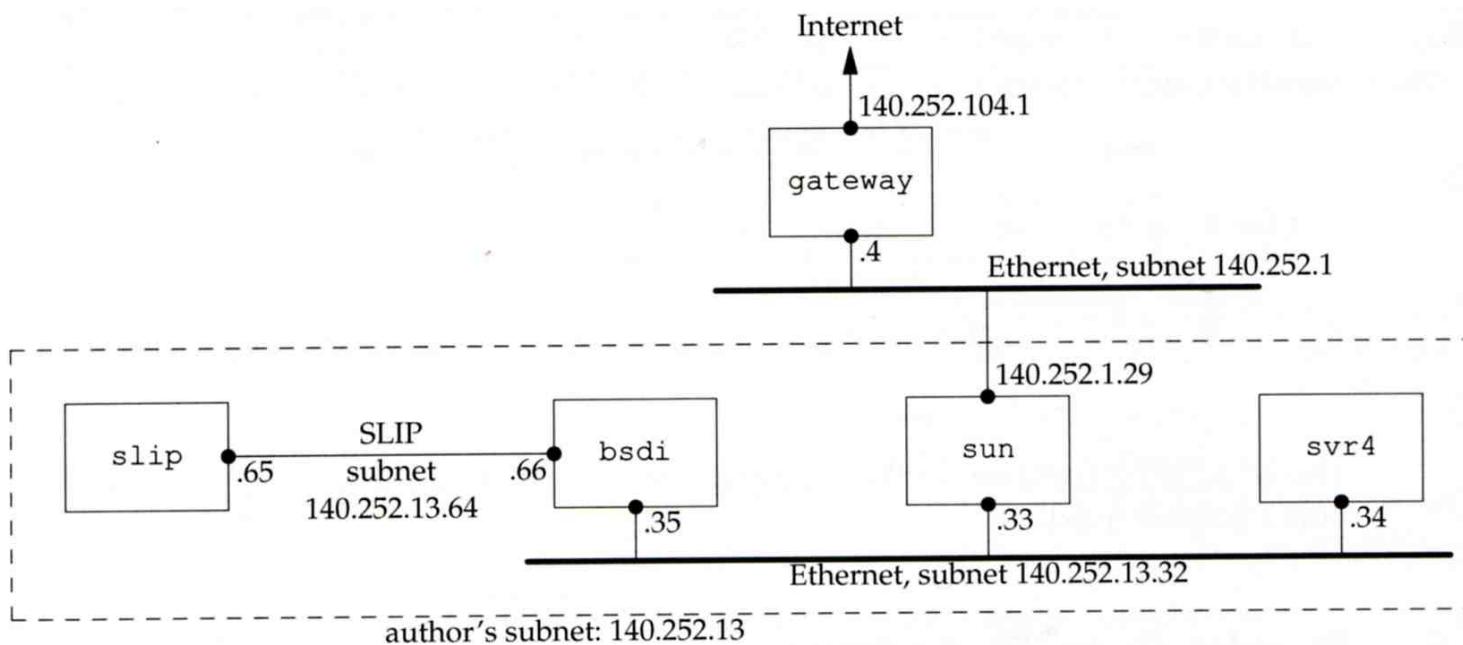
```
svr4 % netstat -rn
```

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

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

loopback

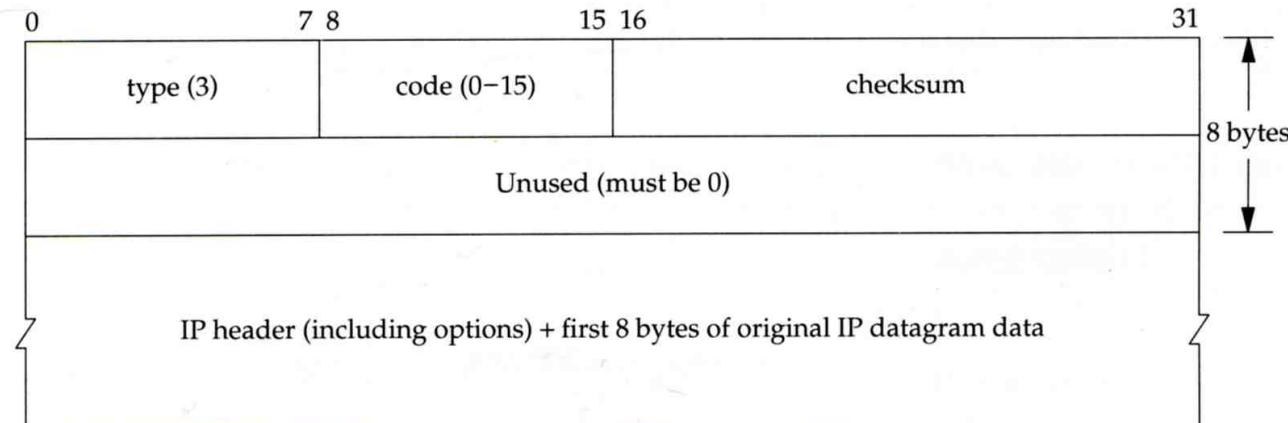


ICMP

– 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

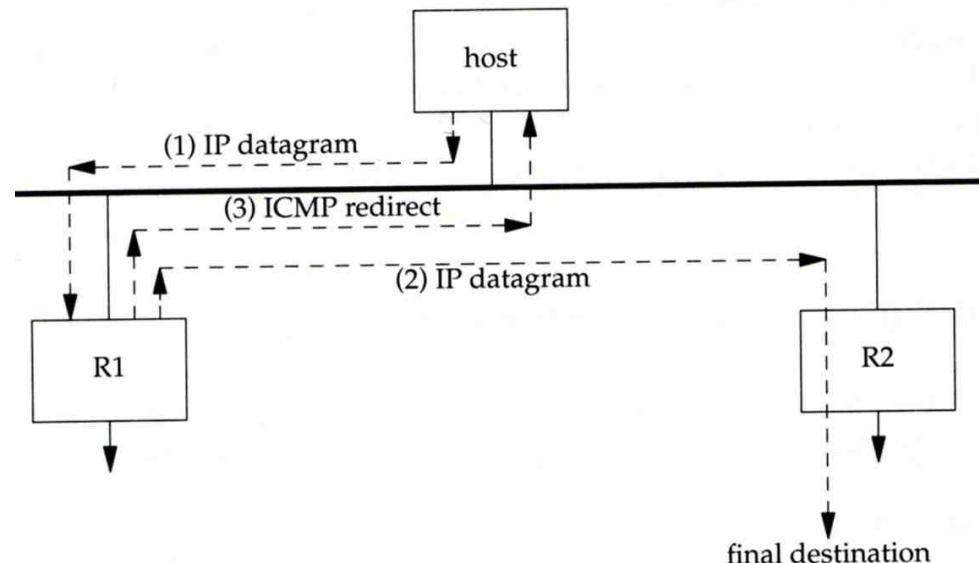


ICMP

– 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

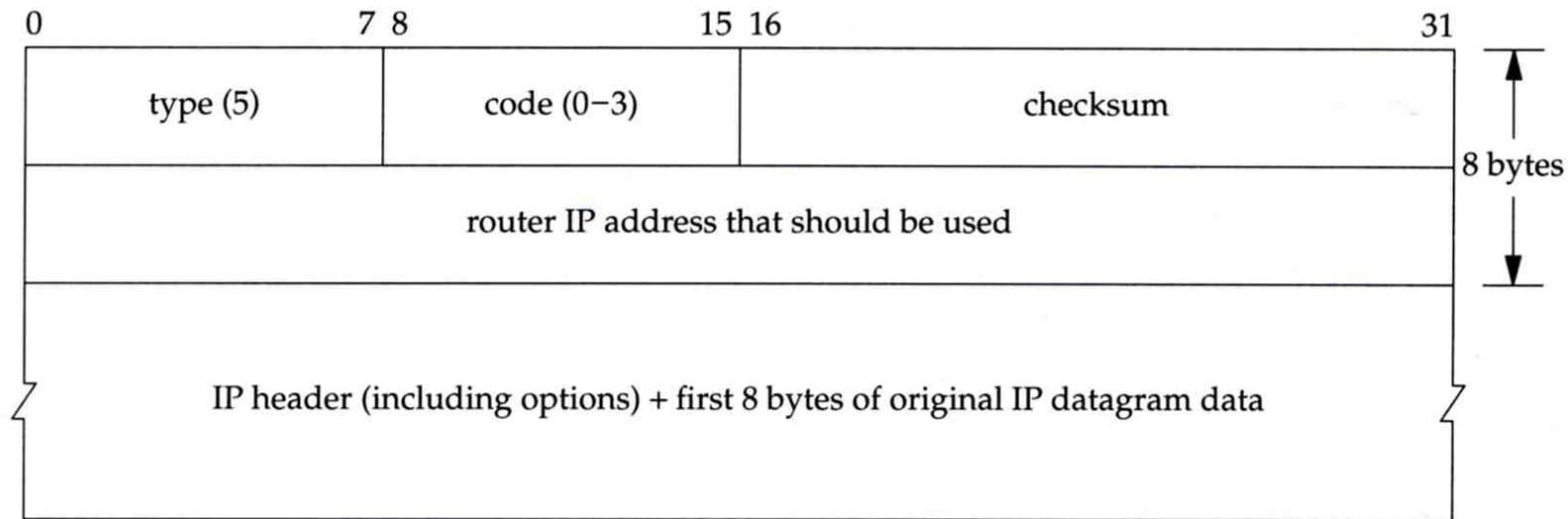


ICMP

– Redirect Error Message (2)

□ ICMP redirect message format

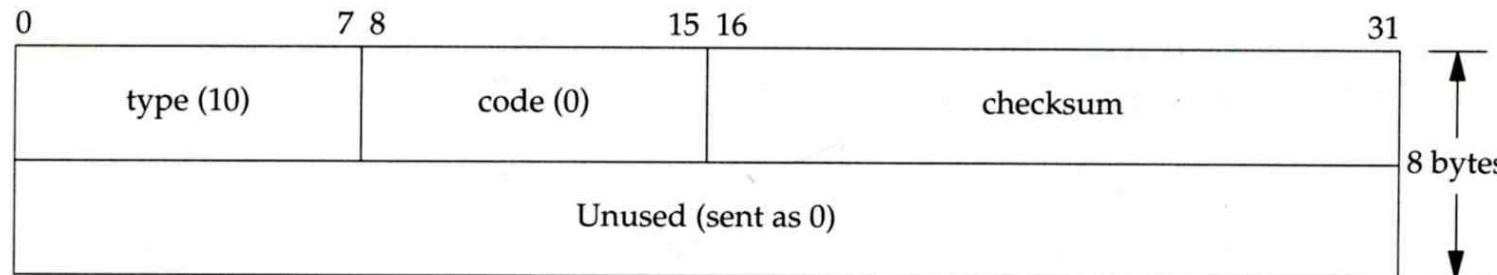
- Code 0: redirect for network
- Code 1: redirect for host
- Code 2: redirect for TOS and network (RFC 1349)
- Code 3: redirect for TOS and hosts (RFC 1349)



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

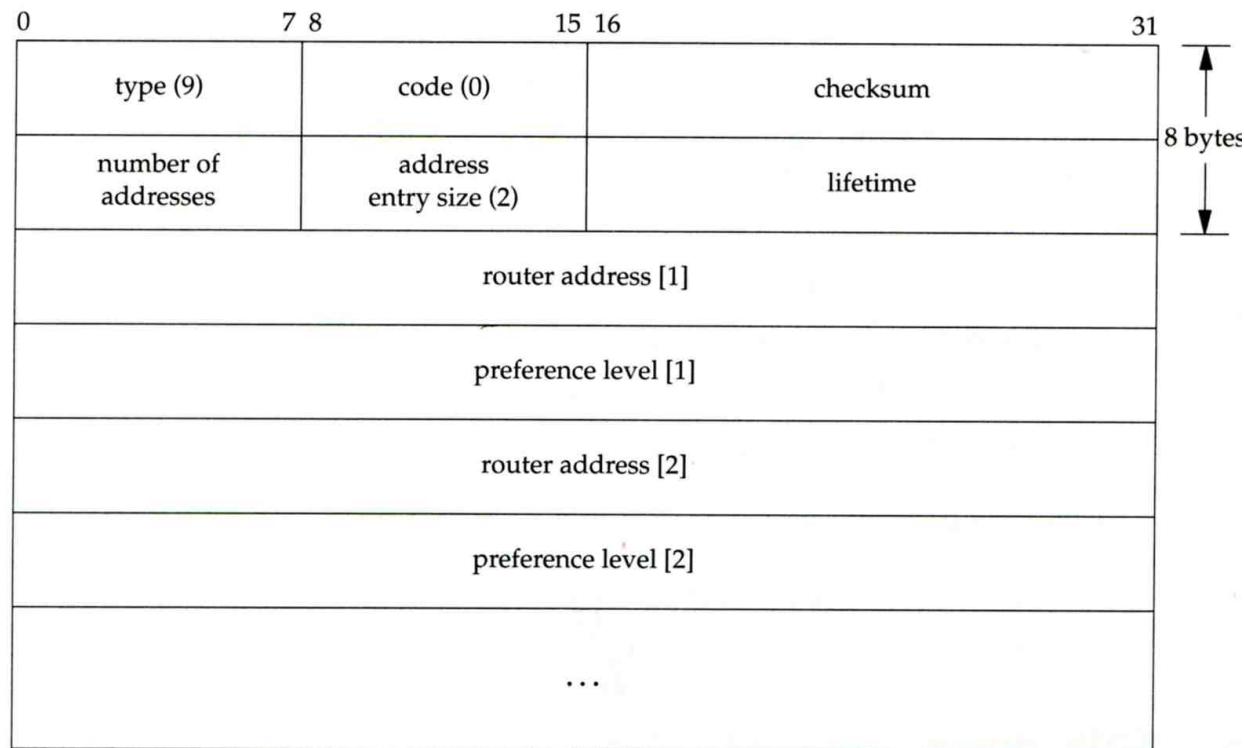


ICMP

– 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

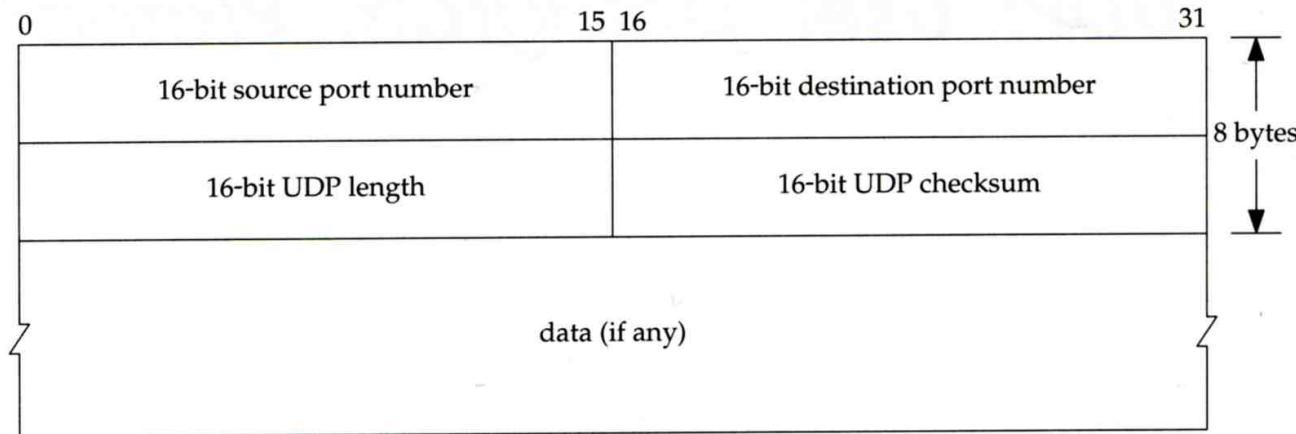
UDP

❑ No reliability

- Datagram-oriented, not stream-oriented protocol

❑ UDP header

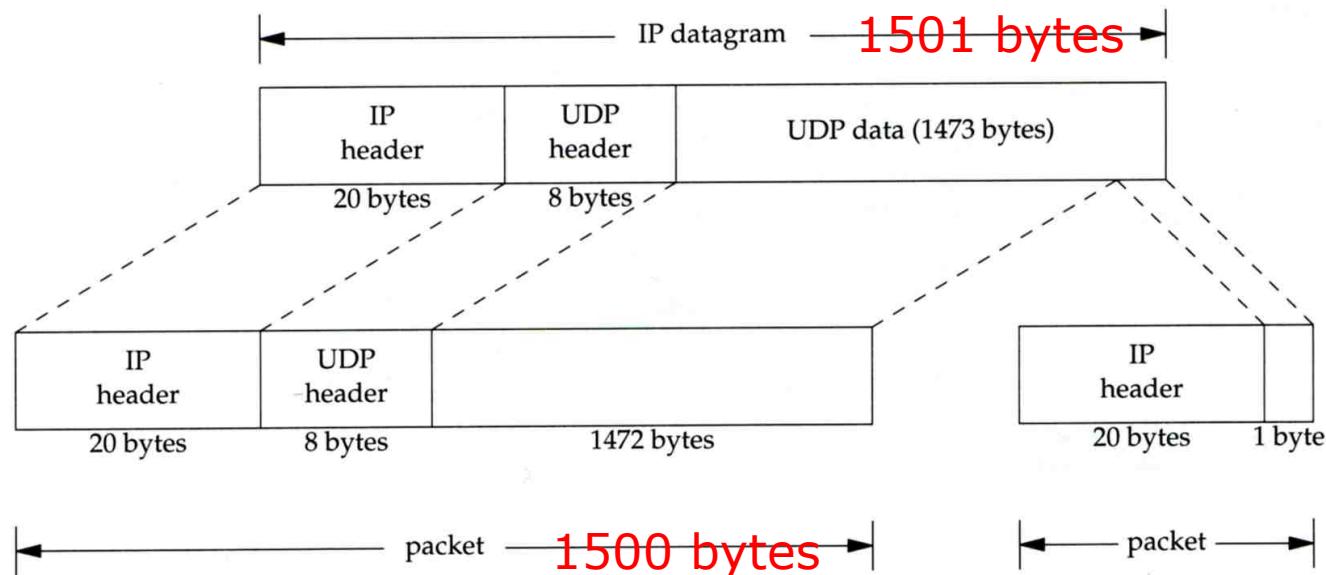
- 8 bytes
 - Source port and destination port
 - Identify sending and receiving process
 - UDP length: ≥ 8



IP Fragmentation (1)

□ MTU limitation

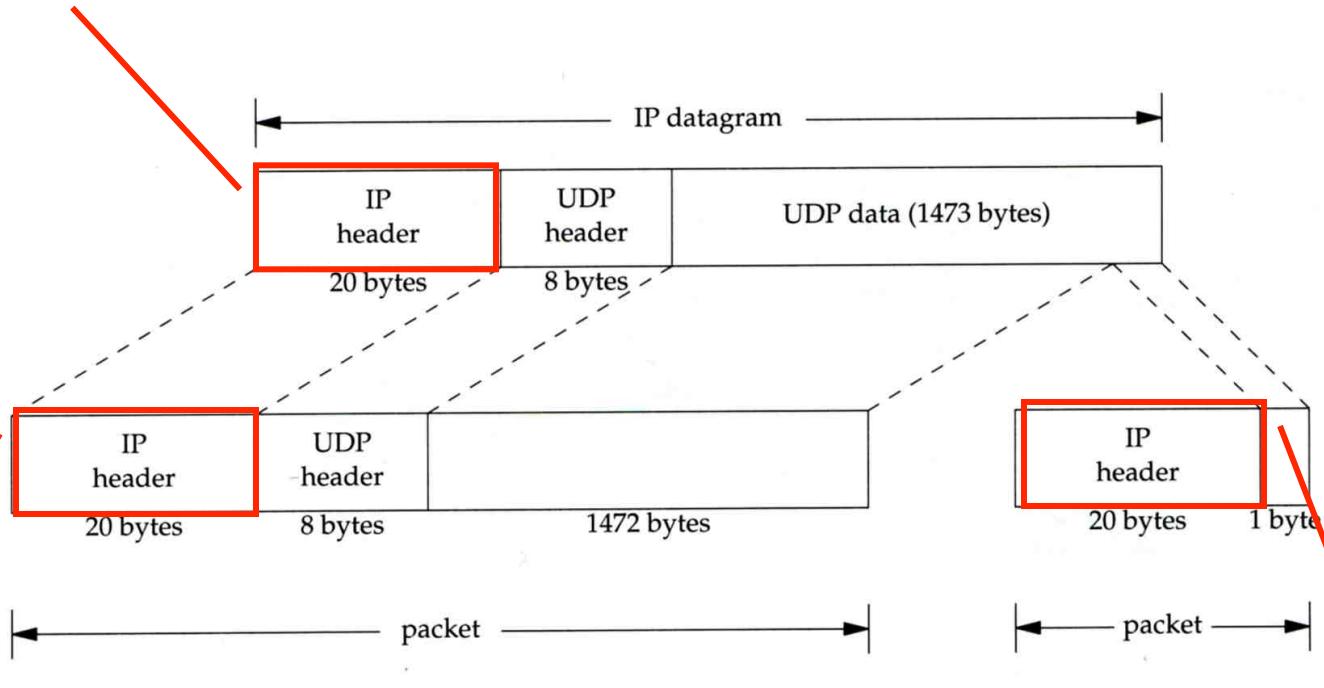
- Before network-layer to link-layer
 - IP will check the size and link-layer MTU
 - Do fragmentation if necessary
- Fragmentation may be done at sending host or routers
- Reassembly is done only in receiving host



IP Fragmentation (2)

identification:
flags:
fragment offset

which unique IP datagram
more fragments?
offset of this datagram from the beginning of original datagram



identification:
flags:
fragment offset

the same
more fragments
0

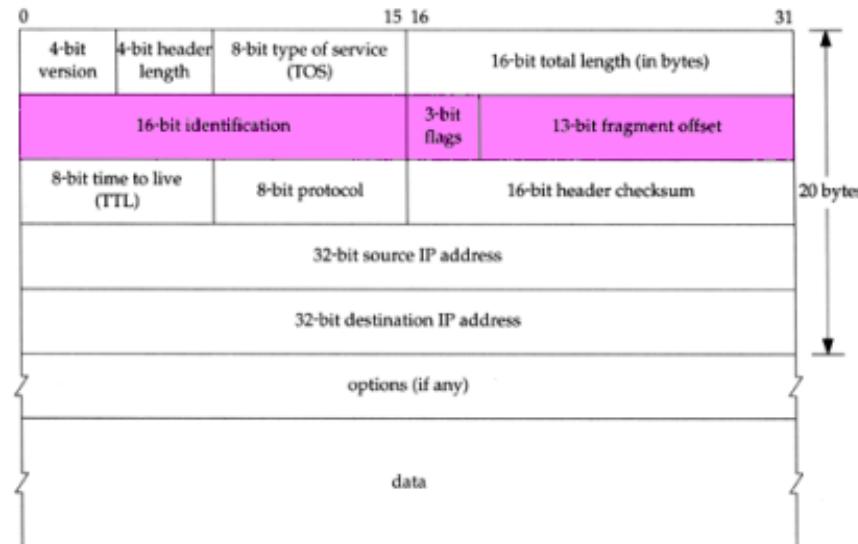
identification:
flags:
fragment offset

the same
end of fragments
1480

IP Fragmentation (3)

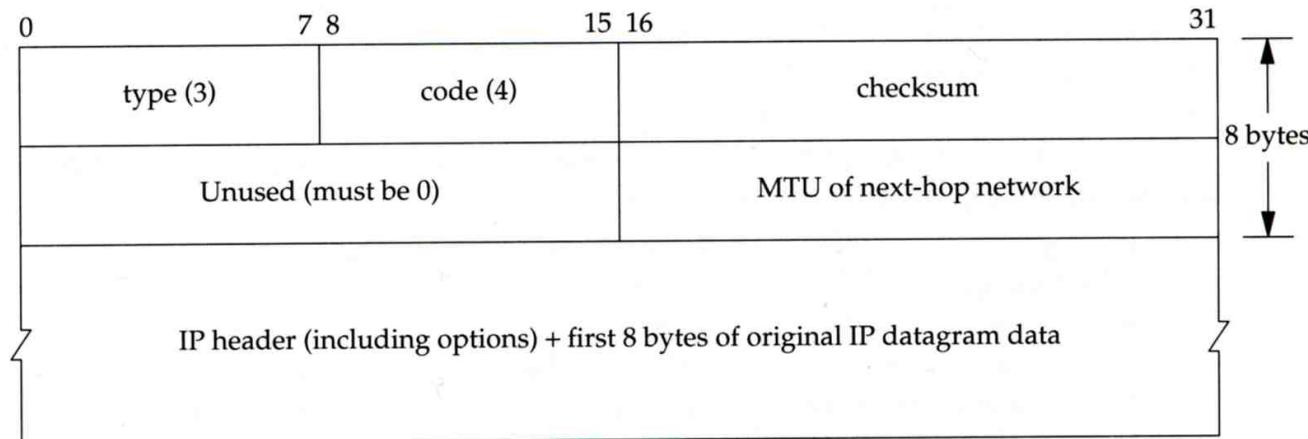
□ Issues of fragmentation

- 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

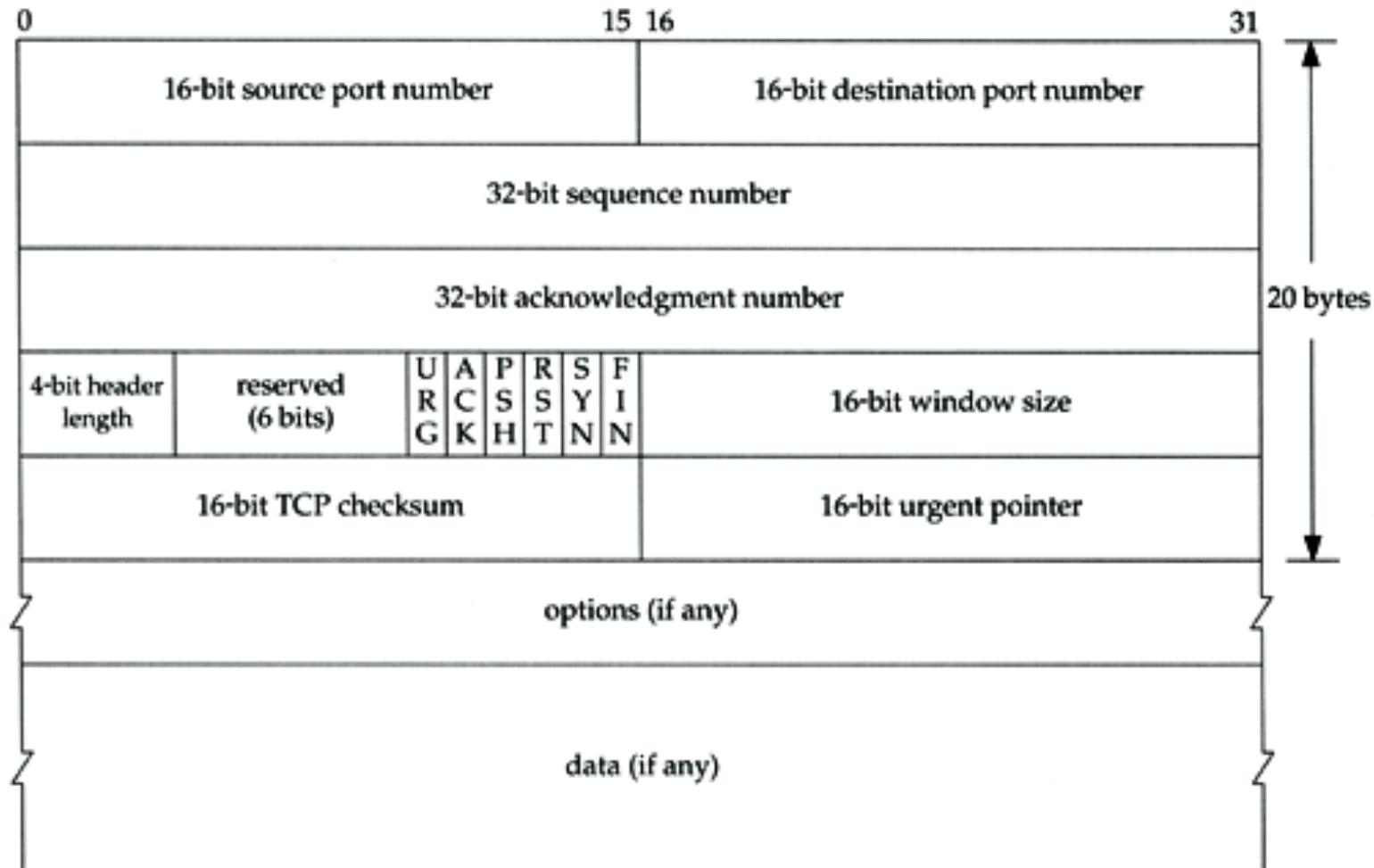
TCP

□ 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)



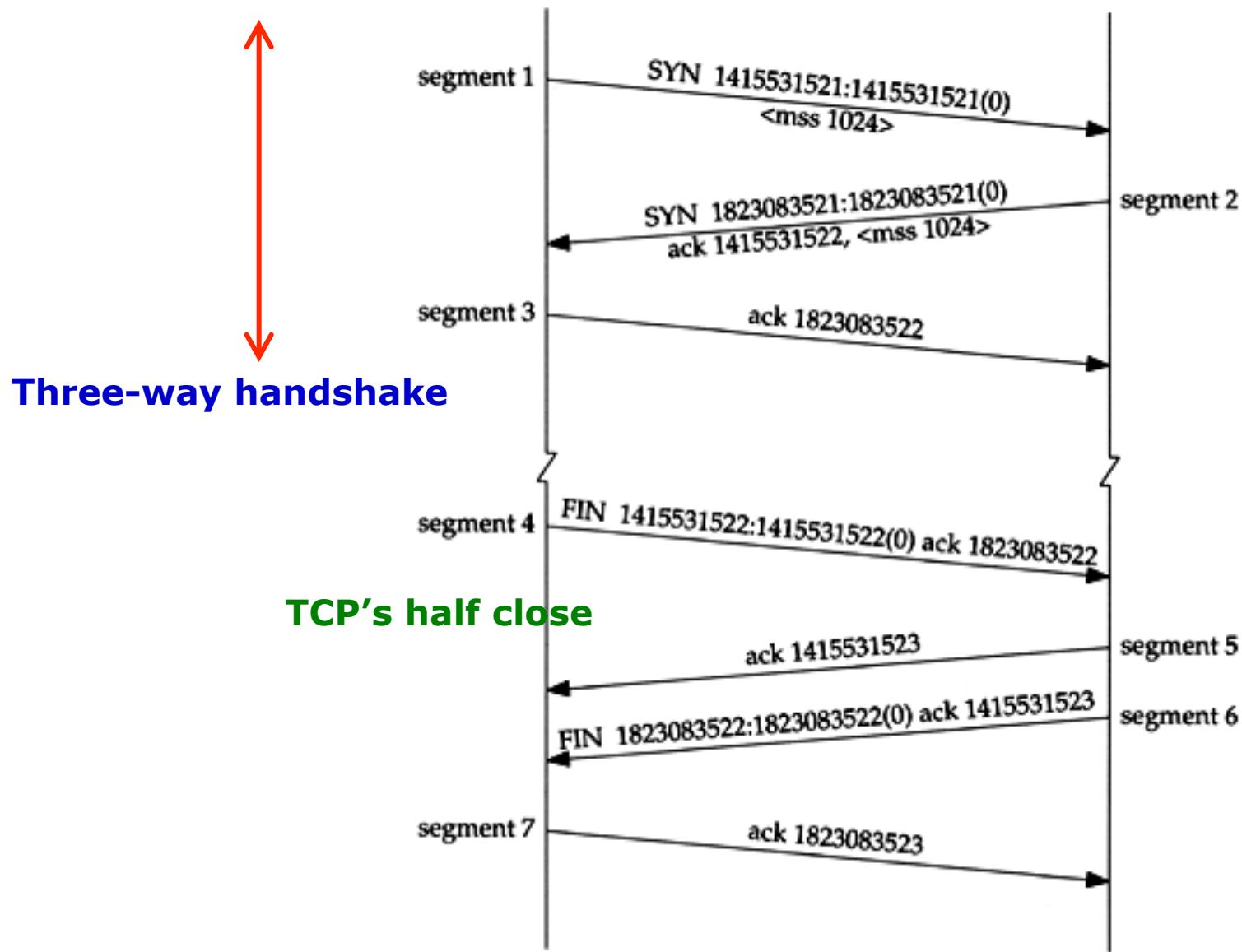
TCP

– 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



Appendix of IP Options: IP Timestamp Option

□ IP Timestamp Option

- Similar to RR option
- Record Timestamp in option field
 - code, len, ptr are the same as IP RR option
 - OF
 - Overflow field
 - Router will increment OF if it can't add a timestamp because of no room left
 - FL
 - Flags
 - 0: only timestamp
 - 1: both timestamp and IP address
 - 3: the sender initiates the options with up to 4 pairs of IP address and timestamp

