Chapter 13
TCP/IP Networking

Overview

❑ Introduction

❑ Network Interface and Hardware

❑ Layers of TCP/IP

- Link Layer

- Network Layer

- Transport Layer

- Application Layer

❑ ARP

❑ Setting up Network

Introduction
– Basic Term

❑ IP

- 32-bits, Unique Internet Address of a host

❑ Port

- 16-bits, Uniquely identify application

❑ MAC Address

- Media Access Control Address
- 48-bits, Network Interface Card (NIC) Hardware address
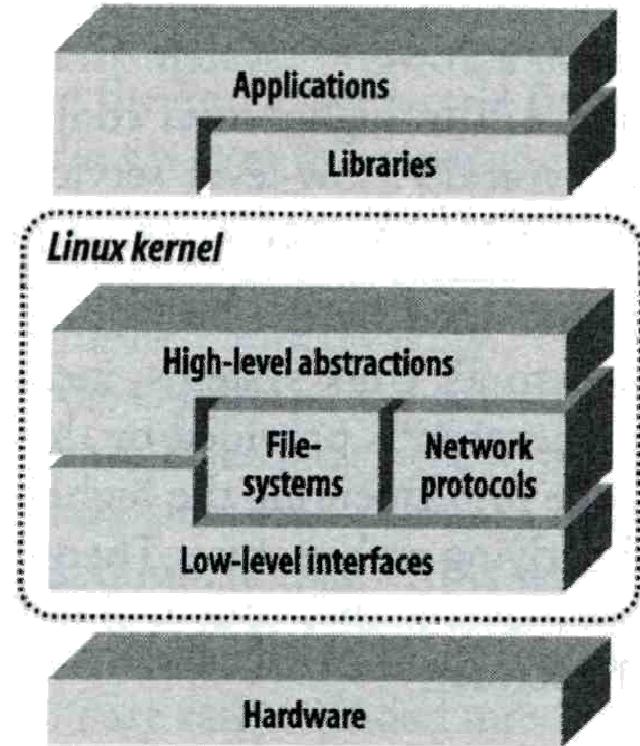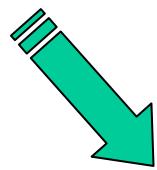
```
sabsd [/home/chwong] -chwong- ifconfig
sk0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
    options=b<RXCSUM,TXCSUM,VLAN_MTU>
    inet 140.113.17.215 netmask 0xffffff00 broadcast 140.113.17.255
    inet 140.113.17.221 netmask 0xffffffff broadcast 140.113.17.221
    ether 00:11:d8:06:1e:81
    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
```

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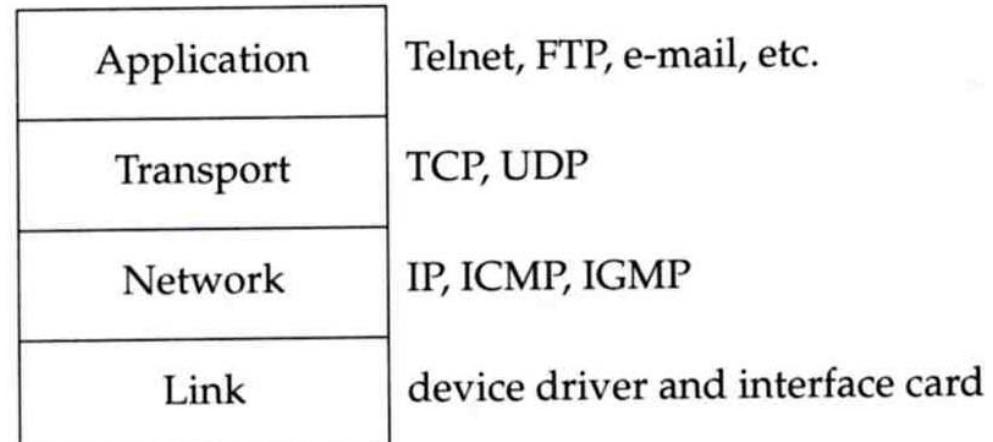
We need something to do the translating work!
TCP/IP it is!!

Introduction
– Layers of TCP/IP (1)

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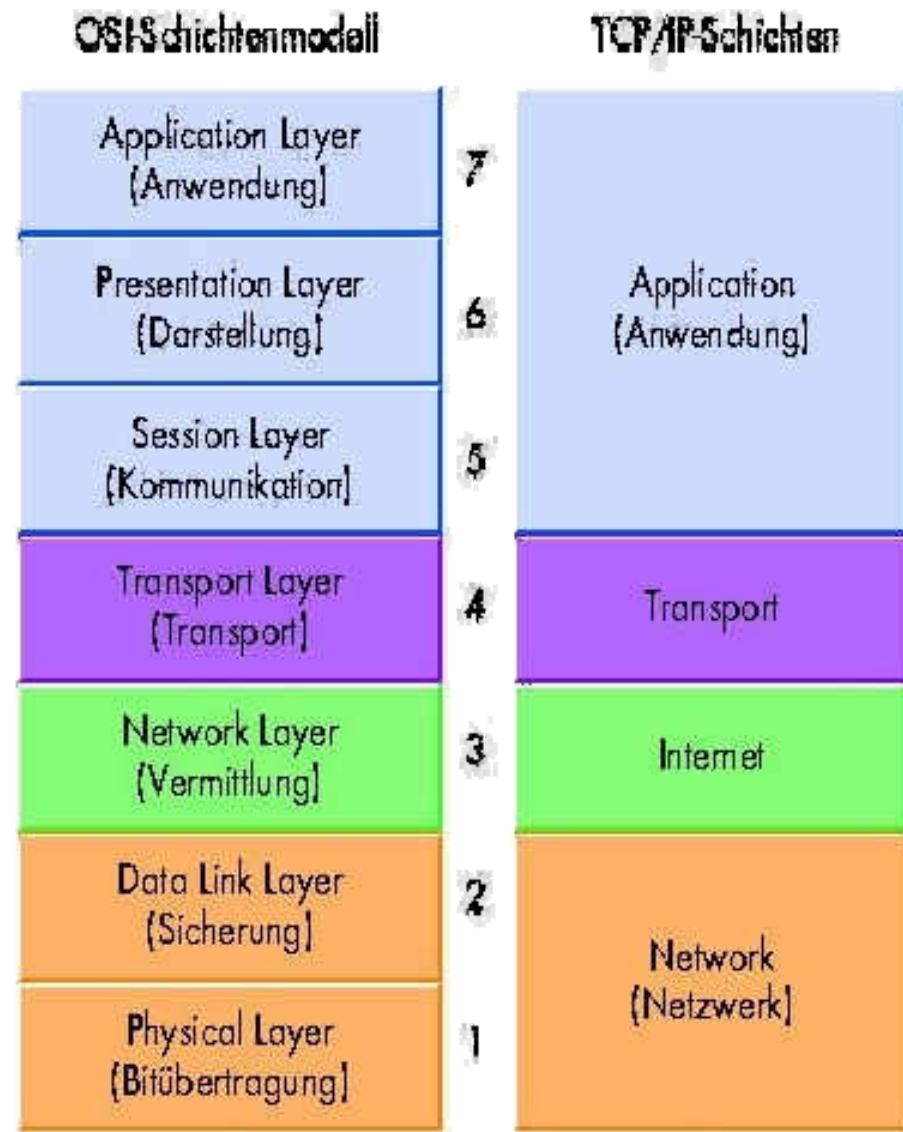
- 4 layers Layering architecture
  - ➢ Link layer (data-link layer)
    - Include device drivers to handle hardware details
  - ➢ Network layer (IP)
    - Handle the movement of packets around the network
  - ➢ Transport layer (Port)
    - Handle flow of data between hosts
  - ➢ Application

Application	Telnet, FTP, e-mail, etc.
Transport	TCP, UDP
Network	IP, ICMP, IGMP
Link	device driver and interface card

Introduction
– Layers of TCP/IP (2)
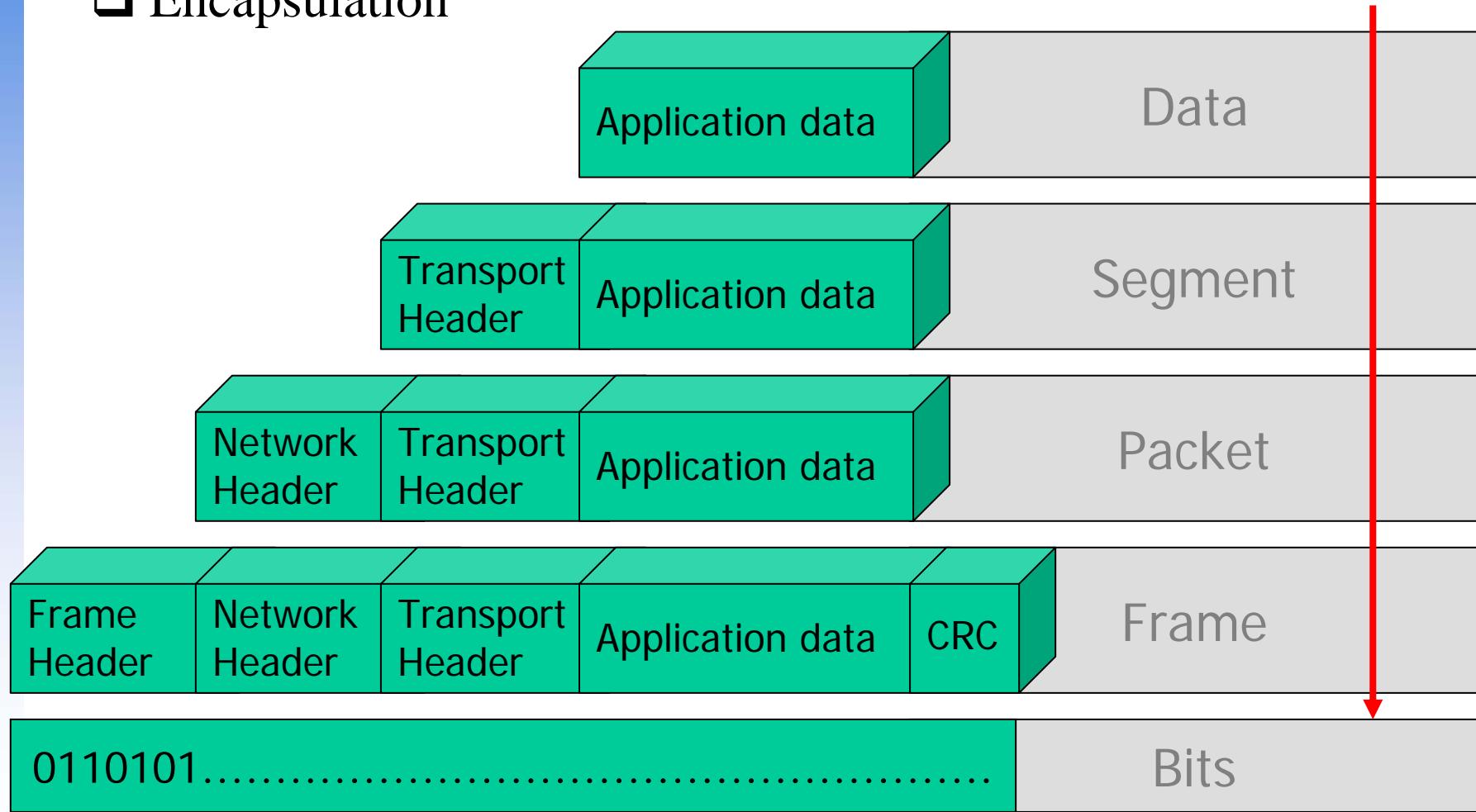
❑ ISO/OSI Model and
   TCP/IP Model

OSISchichtenmodell		TCP/IP-Schichten
Application Layer (Anwendung)	7	Application (Anwendung)
Presentation Layer (Darstellung)	6	
Session Layer (Kommunikation)	5	
Transport Layer (Transport)	4	Transport
Network Layer (Vermittlung)	3	Internet
Data Link Layer (Sicherung)	2	Network (Netzwerk)
Physical Layer (Bitübertragung)	1	

Introduction
– Layers of TCP/IP (3)

❑ Encapsulation

			Application data		Data
		Transport Header	Application data		Segment
	Network Header	Transport Header	Application data		Packet
Frame Header	Network Header	Transport Header	Application data	CRC	Frame
0110101...					Bits

Introduction
## – Layers of TCP/IP (4)

❑ Demultiplexing
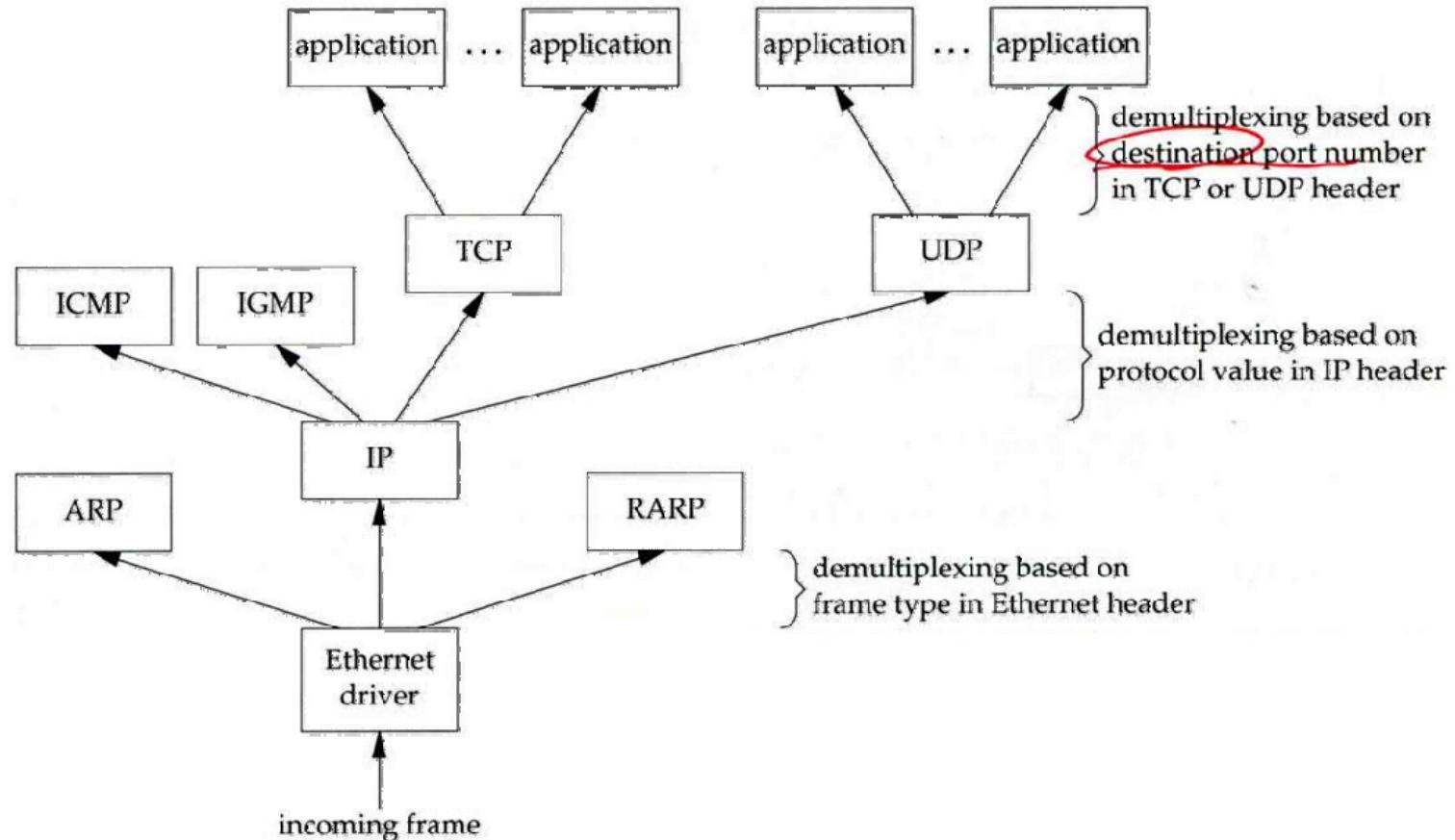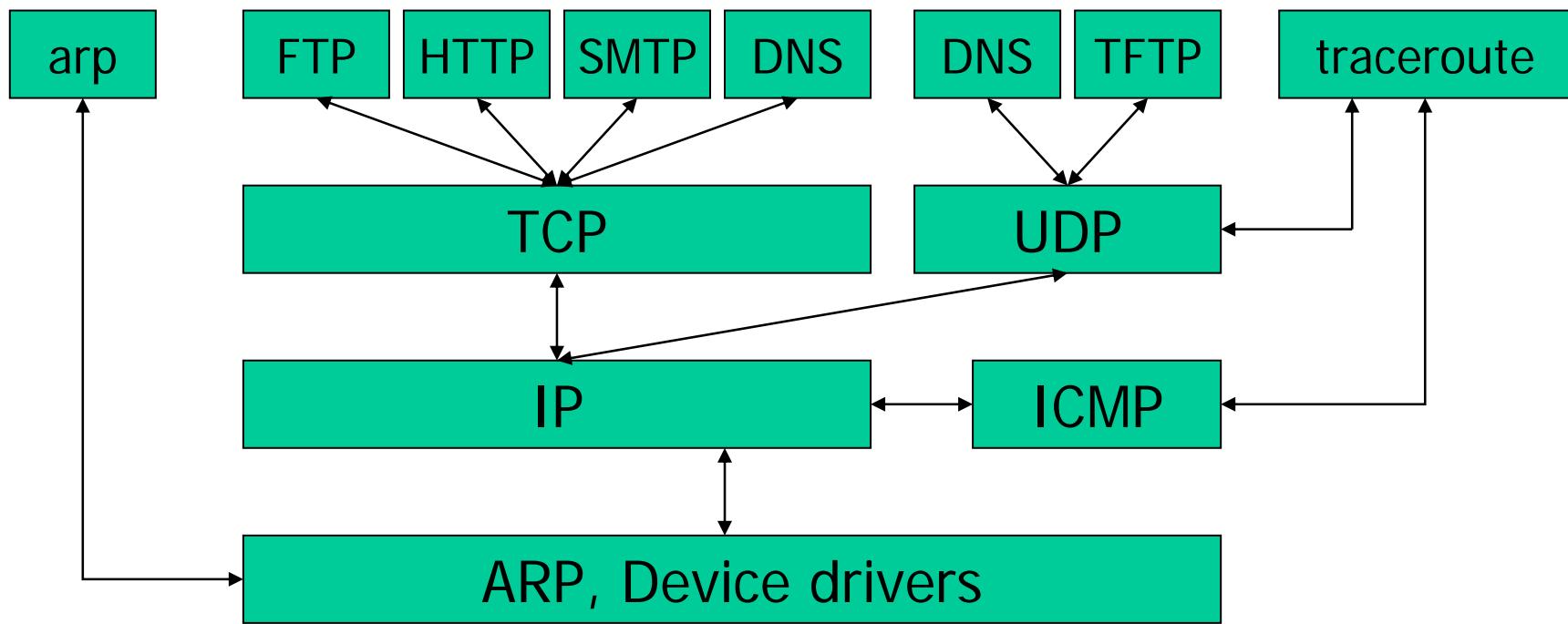
Figure 1.8   The demultiplexing of a received Ethernet frame.

# Introduction
–TCP/IP Family
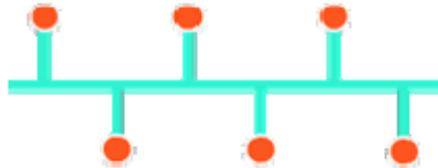
Network Interface and Hardware
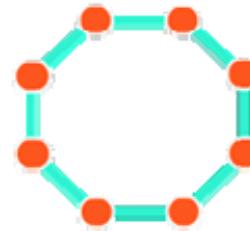
❑ LAN (Local), WAN (Wide), MAN (Metropolitan)

- Ethernet, Token-Ring, FDDI
- PPP, xDSL, ISDN

❑ Physical Topologies (see next slide)

❑ Logical Topologies

- Broadcast, Token-passing

❑ Common LAN Devices

- NIC, Repeater, Hub, Bridge, Switch, Router

❑ Common LAN Media

- UTP, STP, Coaxial Cable, Fiber Optic Cable
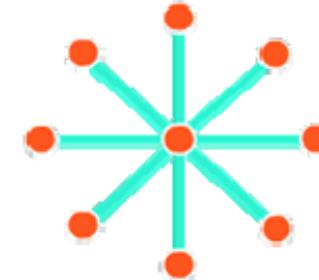
Network Interface and Hardware
## – Physical Topologies
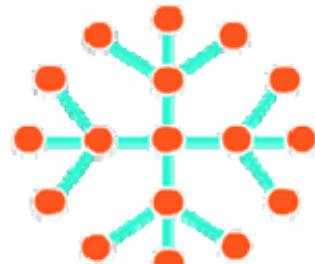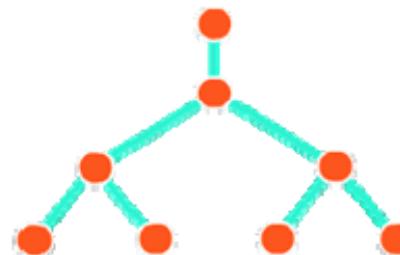
Bus   Ring   Star

Extended Star   Hierarchical   Mesh
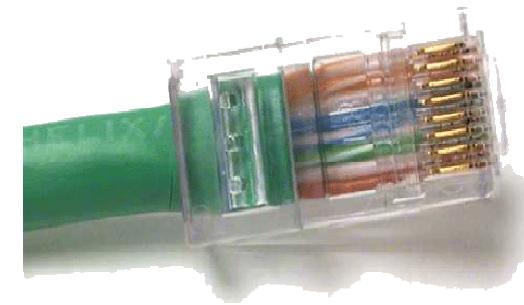
Network Interface and Hardware – Media

❑ Media

- Coaxial Cable
  - ➢ Thicknet v.s. thinnet
  - ➢ BNC connector
- Twisted Pair Standards

Pin#	1	2	3	4	5	6	7	8
T568-A	W/G	Green	W/O	Blue	W/Blue	Orange	W/Br	Brown
T568-B	W/O	Orange	W/G	Blue	W/Blue	Green	W/Br	Brown

  - ➢ Straight-through v.s. Crossover
  - ➢ RJ-45 connector
- Fiber Optic Cable
  - ➢ Multimode v.s. single mode
- Wireless
  - ➢ IrDA, Radio (2.4GHz, 5GHz)

The Link Layer

❑ Ethernet: the common LAN

- 10 Mb/s → 100 Mb/s → 1Gb/s
- 802.3 → 802.3u → 802.3z
- CSMA/CD (Carrier Sense Multiple Access/Collision Detect)

❑ Ethernet Address (48bits)

- 00:80:c8:92:0e:e1

❑ Ethernet Frame

- Ethernet MTU is 1500 bytes.

Preamble 64 bits	D addr 48 bits	S addr 48 bits	Type 16 bits	Data (max 1500 bytes)	CRC 32 bits

The Network Layer

❑ Path Determination

- The Internet Protocol (IP)

  ➢ IP address (32 bits)

❑ Topics

- IP Address

- Subnetting and netmask

- Address types

- Routing

The Network Layer
– IP Address

❑ 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.

The Network Layer
– Subnetting and Netmask (1)

❑ 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

❑ 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

The Network Layer
– Subnetting and Netmask (2)

❑ 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**

The Network Layer
– Subnetting and Netmask (3)

❑ 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

The Network Layer
– Subnetting and Netmask (4)

❑ 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
```

The Network Layer
– Subnetting and Netmask (5)

❑ 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

The Network Layer
– Address Types (1)

❑ Unicast

- Address refer to a single hosts, only the host with that IP will receive the data
- Ex:
  - ➢ ssh 140.113.209.65

❑ Broadcast

- Addresses that include all hosts on the local network
- All hosts on the same network will receive the data
- Ex:
  - ➢ arp packet

❑ Multicast

- Addresses that identify a group of hosts
- Only hosts on the same group will receive the data
- Ex:
  - ➢ Video conference

The Network Layer
– Address Types (2)

❑ Private Address
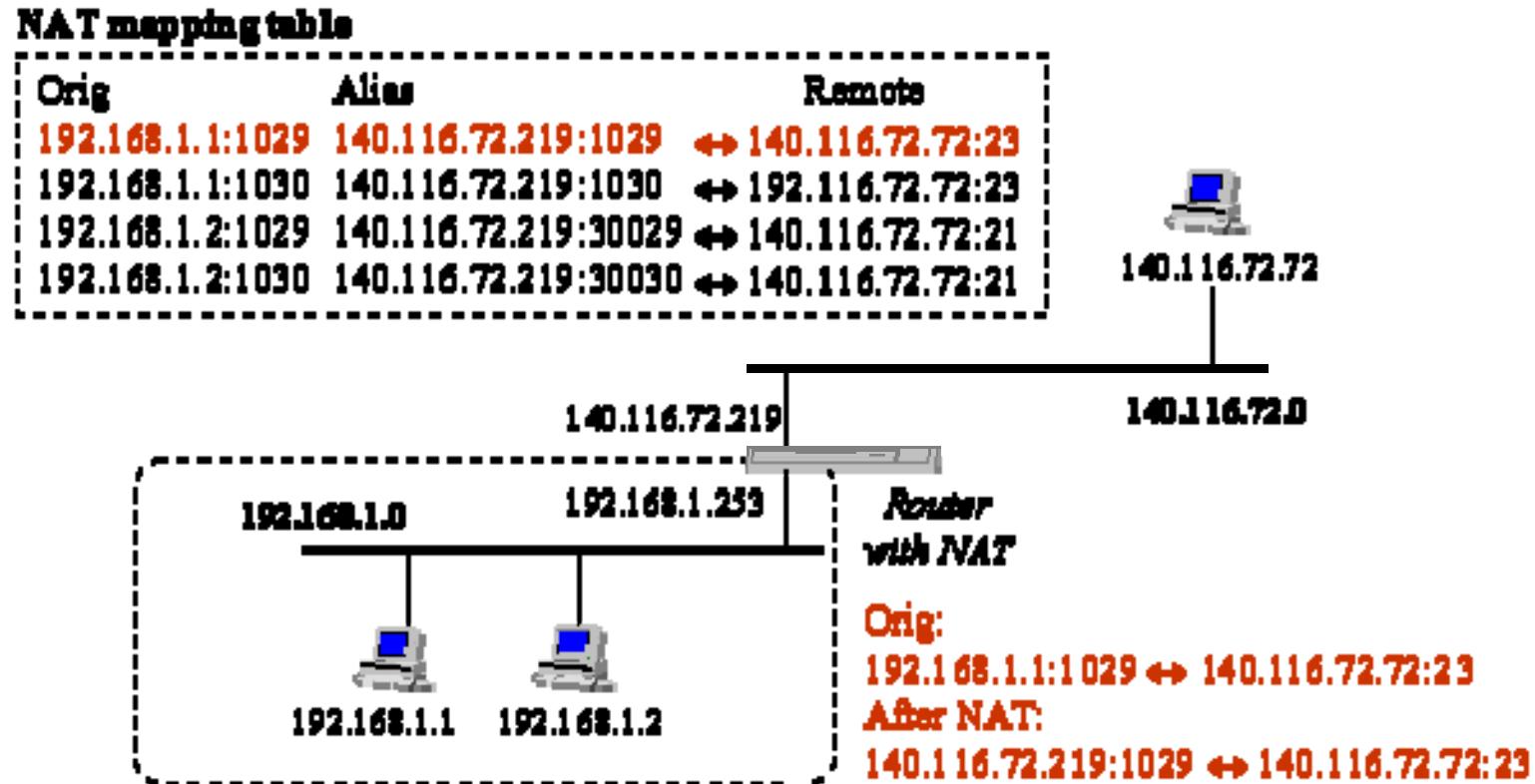
- Packets that bearing private address will not go out to the Internet
- 3 private addresses range
  - ➤ Depend on the size of your organization

| IP class	From	To	CIDR range
Class A	10.0.0.0	10.255.255.255	10.0.0.0/8
Class B	172.16.0.0	172.31.255.255	172.16.0.0/12
Class C	192.168.0.0	192.168.255.255	192.168.0.0/16

The Network Layer
– Address Types (3)

- NAT
  - ➢ Network Address Translation
  - ➢ Allow hosts using private address to talk with outside

NAT mapping table

Orig	Alias		Remote
192.168.1.1:1029	140.116.72.219:1029	↔	140.116.72.72:23
192.168.1.1:1030	140.116.72.219:1030	↔	192.116.72.72:23
192.168.1.2:1029	140.116.72.219:30029	↔	140.116.72.72:21
192.168.1.2:1030	140.116.72.219:30030	↔	140.116.72.72:21

140.116.72.72

140.116.72.0

140.116.72.219

192.168.1.253

Router with NAT

192.168.1.0

192.168.1.1   192.168.1.2

Orig:
192.168.1.1:1029 ↔ 140.116.72.72:23
After NAT:
140.116.72.219:1029 ↔ 140.116.72.72:23

The Network Layer
– Routing (1)

- ❑ Goal: Direct a packet closer to the destination
- ❑ Flat v.s. Hierarchical
- ❑ Routing table
  - Routing information (which kind of packets to which way)
  - Rule-based information
  - Kernel will pick the most suitable way to route the packets

```
chbsd [/home/chwong] -chwong- netstat -rn
Routing tables

Internet:
Destination          Gateway              Flags     Refs        Use  Netif Expire
default              140.113.17.254       UGS          0    4439610    dc0
127.0.0.1            127.0.0.1            UH           0       3887    lo0
140.113.17/24        link#1               UC           0          0    dc0
140.113.17.209       00:0d:61:21:02:54    UHLW         1         38    dc0      477
140.113.17.212       00:90:96:23:8f:7d    UHLW         1      22558    lo0
140.113.17.215       00:11:d8:06:1e:81    UHLW         1         17    dc0     1188
140.113.17.248       00:0b:ac:d7:93:40    UHLW         1          0    dc0     1170
140.113.17.254       00:90:69:64:ec:00    UHLW         2          0    dc0     1200
```

The Network Layer
– Routing (2)

❑ Static route

- Statically configured by "route" command

- Ex:

  ➢ % route add default 140.113.235.254

  ➢ % route add 192.168.1.0/24 192.168.1.254

❑ Dynamic route

- gated

The Network Layer
– Routing (3)

❑ "ping -R" and "traceroute"

```
chbsd [/home/chwong] -chwong- ping -c 1 -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=2.249 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)

--- www.nctu.edu.tw ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 2.249/2.249/2.249/0.000 ms

chbsd [/home/chwong] -chwong- traceroute www.nctu.edu.tw
traceroute to www.nctu.edu.tw (140.113.250.5), 64 hops max, 40 byte packets
 1  e3rtn (140.113.17.254)  0.524 ms  0.406 ms  0.512 ms
 2  ProjE27-254.NCTU.edu.tw (140.113.27.254)  0.574 ms  0.501 ms  0.422 ms
 3  140.113.0.58 (140.113.0.58)  0.487 ms  0.583 ms  0.541 ms
 4  www.NCTU.edu.tw (140.113.250.5)  0.673 ms  0.611 ms  0.621 ms
```

The Transport Layer

❑ UDP v.s. TCP

Function	UDP	TCP
Connection-oriented	No	Yes
Message boundaries	Yes	No
Data checksum	Optional	Yes
Positive acknowledgement	No	Yes
Time-out and retransmit	No	Yes
Duplicate detection	No	Yes
Sequencing	No	Yes
Flow control	No	Yes

The Transport Layer
– ports

❑ 16-bits number

❑ Preserve ports

- 1 ~ 1024 (root access only)

❑ Well-known port

➢ /etc/services

```
...
chargen          19/tcp    ttytst source        #Character Generator
chargen          19/udp    ttytst source        #Character Generator
ftp-data         20/tcp    #File Transfer [Default Data]
ftp-data         20/udp    #File Transfer [Default Data]
ftp              21/tcp    #File Transfer [Control]
ftp              21/udp    #File Transfer [Control]
ssh              22/tcp    #Secure Shell Login
ssh              22/udp    #Secure Shell Login
telnet           23/tcp
telnet           23/udp
...
```

The Transport Layer
– useful commands

❑ tcpdump, sniffit, trafshow, netstat -s

```
chbsd [/home/chwong] -chwong- sudo tcpdump -n host 140.113.235.131
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on dc0, link-type EN10MB (Ethernet), capture size 96 bytes
11:25:50.996542 IP 140.113.17.212.61233 > 140.113.235.131.22: P 266166194:266166226(32)
ack 938637316 win 33304 <nop,nop,timestamp 3368918203 130908112>
11:25:50.998247 IP 140.113.235.131.22 > 140.113.17.212.61233: P 1:33(32) ack 32 win 33304
<nop,nop,timestamp 134993614 3368918203>
11:25:50.998396 IP 140.113.235.131.22 > 140.113.17.212.61233: P 33:65(32) ack 32 win
33304 <nop,nop,timestamp 134993614 3368918203>
11:25:50.998438 IP 140.113.17.212.61233 > 140.113.235.131.22: . ack 65 win 33288
<nop,nop,timestamp 3368918205 134993614>
11:26:36.935422 IP 140.113.17.212 > 140.113.235.131: ICMP echo request, id 28124, seq 0,
length 64
11:26:36.935761 IP 140.113.235.131 > 140.113.17.212: ICMP echo reply, id 28124, seq 0,
length 64
^C
6 packets captured
697 packets received by filter
0 packets dropped by kernel
```

The Application Layer

❑ The Client-Server Model

- Port Numbers:
  - ➢ /etc/services
  - ➢ The first 1024 ports are reserved ports
- Internet Services
  - ➢ inetd and /etc/inetd.conf
- RPC Services
  - ➢ portmap, /etc/rpc

The Application Layer
– inetd

❑ inetd – internet ``super-server''

- add inetd_enable="YES" into /etc/rc.conf
- /etc/inetd.conf

```
daytime      stream  tcp  nowait  root   internal
ftp          stream  tcp  nowait  root   /usr/libexec/ftpd       ftpd -l
ssh          stream  tcp  nowait  root   /usr/sbin/sshd          sshd -i -4
telnet       stream  tcp  nowait  root   /usr/libexec/telnetd    telnetd
pop3         stream  tcp  nowait  root   /usr/local/libexec/popper    popper
```

- /etc/services
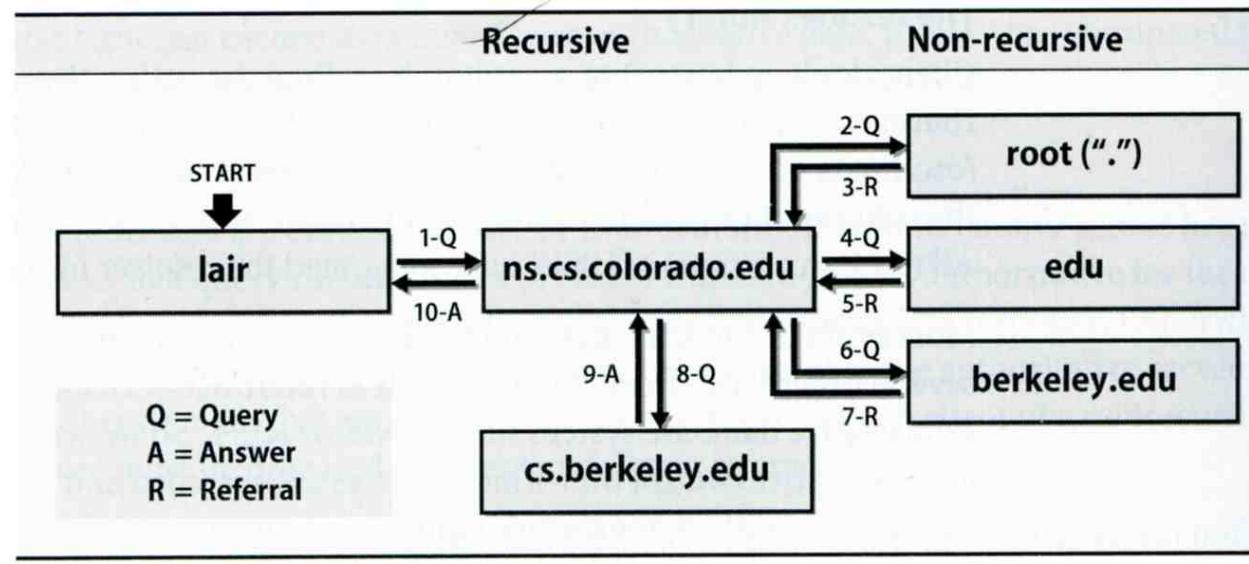
```
daytime      13/tcp
ftp-data     20/tcp    #File Transfer [Default Data]
ftp          21/tcp    #File Transfer [Control]
ssh          22/tcp    #Secure Shell Login
telnet       23/tcp
pop3         110/tcp   #Post Office Protocol - Version 3
```

The Application Layer
– DNS

❑ **Domain Name System**

- Record IP-hostname mapping
- DNS query
  - ➢ "what is the IP of vangogh.cs.berkeley.edu" from lair.cs.colorado.edu
- Hierarchical architecture
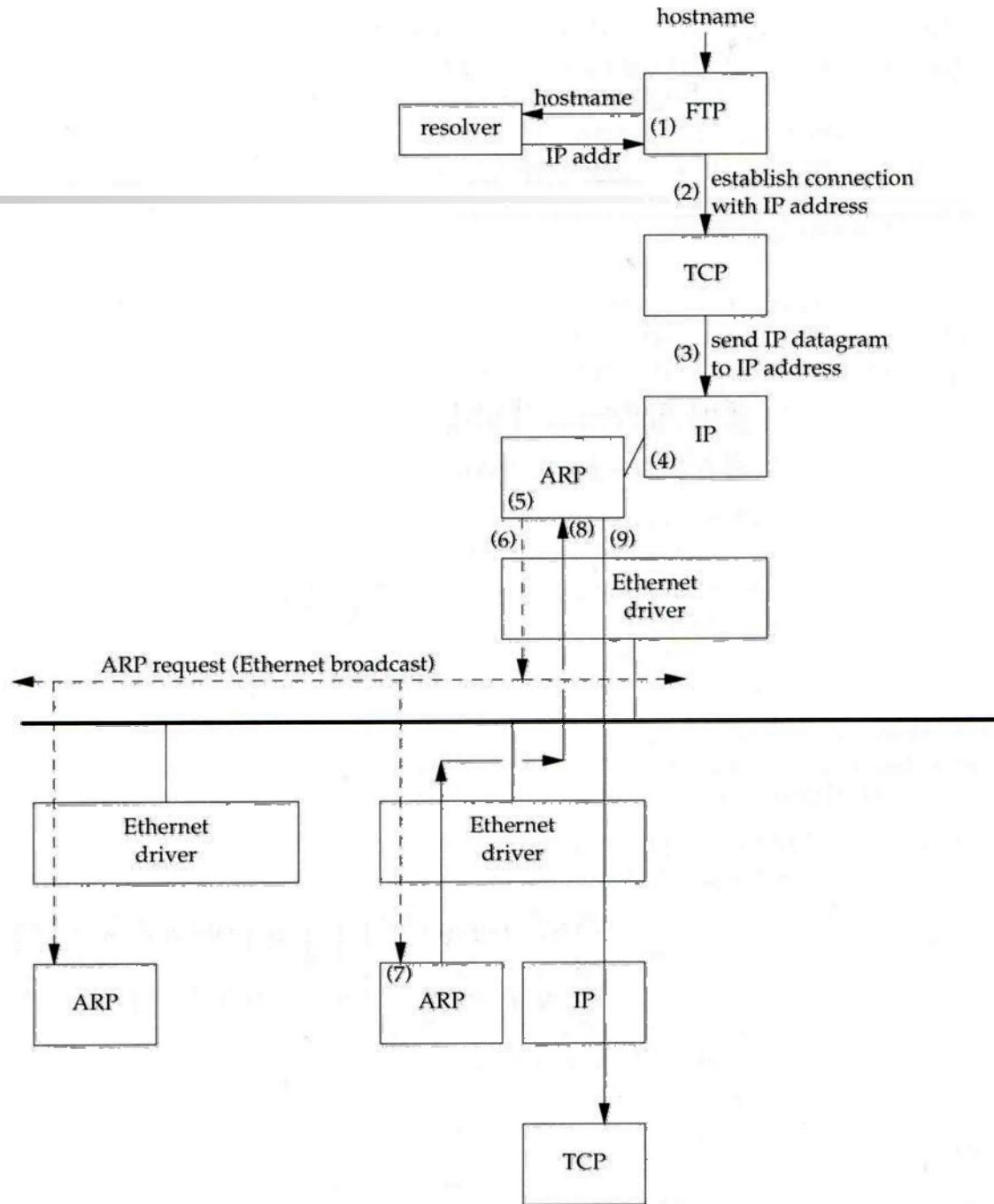
ARP (1)

❑ **Address Resolution Protocol**

- Ask MAC address of certain IP

- Broadcast

- Any one receiving ARP packet and having this IP will reply to the sender

- When the host owing this IP is not on the same network, sender will use the MAC address of next-hop router to send the packet

ARP (2)

ARP (3)

❑ 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

```
[chwong@mg-215]~> arp -a
crypto23.csie.nctu.edu.tw  (140.113.208.143) at 00:16:e6:5b:fa:e9 on fxp1 [ethernet]
e3rtn-208.csie.nctu.edu.tw (140.113.208.254) at 00:0e:38:a4:c2:00 on fxp1 [ethernet]
e3rtn-210.csie.nctu.edu.tw (140.113.210.254) at 00:0e:38:a4:c2:00 on fxp2 [ethernet]
winpc7.csie.nctu.edu.tw    (140.113.215.187) at 00:17:31:84:6c:0f on fxp3 [ethernet]
e3rtn-215.csie.nctu.edu.tw (140.113.215.254) at 00:0e:38:a4:c2:00 on fxp3 [ethernet]
e3rtn-216.csie.nctu.edu.tw (140.113.216.254) at 00:0e:38:a4:c2:00 on fxp0 [ethernet]
```

Setup network connection

❑ Steps

- Assign an IP address and hostname
- Default route
- DNS
- Utility to test whether you connect to the Internet

Setup network connection
– assign IP, hostname and default route (1)

❑ FreeBSD

- In /etc/rc.conf

```
defaultrouter="140.113.17.254"
hostname="chbsd.csie.nctu.edu.tw"
ifconfig_fxp0="inet 140.113.17.212  netmask 255.255.255.0 media autoselect"
ifconfig_fxp1="inet 192.168.1.254  netmask 255.255.255.0 media autoselect"
```

❑ Linux

- /etc/sysconfig/network

- /etc/sysconfig/network-scripts/ifcfg-eth0

```
NETWORKING=yes
HOSTNAME=linux3
GATEWAY=140.113.209.254
```

```
DEVICE=eth0
BOOTPROTO=static
BROADCAST=140.113.209.255
IPADDR=140.113.209.143
NETMASK=255.255.255.0
NETWORK=140.113.209.0
ONBOOT=yes
```

Setup network connection
– assign IP, hostname and default route (2)

❑ /etc/hosts

- Host name database

- Each line is a host
  - ➢ Internet address
  - ➢ Official host name
  - ➢ aliases

```
chwong@qkmj:~> less /etc/hosts
127.0.0.1          localhost
140.113.209.72     ccbsd12 ccbsd12.csie.nctu.edu.tw
140.113.209.2      ccserv
140.113.209.6      ccduty
140.113.209.7      mailgate
140.113.209.32     qkmj
```

Setup network connection
– assign IP, hostname and default route (3)

❑ Solaris

- /etc/inet/netmasks (network and netmask)
- /etc/inet/hosts (hosts)
- /etc/defaultrouter (default router)
- /etc/nodename (host name)
- /etc/resolv.conf (domain, nameserver, search)
- /etc/hostname.*interface* (IP, either hostname in hosts or IP)

```
chwong@ccsun3:/etc> cat hostname.hme0 nodename defaultrouter resolv.conf
140.113.209.3
ccsun3
140.113.209.254
domain csie.nctu.edu.tw
nameserver 140.113.209.1
nameserver 140.113.1.1
search csie.nctu.edu.tw nctu.edu.tw edu.tw tw
tytsai@ccsun3:/etc> cat /etc/inet/netmasks /etc/inet/hosts
140.113.209.0   255.255.255.0
140.113.209.103 ccsun3
140.113.209.110 ccsun10
```

Setup network connection
– assign IP, hostname and default route (4)

❑ Change IP manually

- Ex:

  ➢ **% ifconfig fxp0 inet 140.113.235.4 netmask 255.255.255.0**

  ➢ **% ifconfig fxp0 up**

  ➢ **% ifconfig fxp0 down**

❑ Specify default route manually

- Ex:

  ➢ % route add default 140.113.235.254

Setup network connection
– configuring DNS

❑ FreeBSD, Linux

- /etc/resolv.conf

```
chbsd [/etc] -chwong- cat resolv.conf
domain  csie.nctu.edu.tw
nameserver      140.113.17.5
nameserver      140.113.6.2
```

❑ Host lookup order

- FreeBSD
  - ➢ /etc/host.conf

```
chbsd [/etc] -chwong- cat host.conf
# Auto-generated from nsswitch.conf, do not edit
hosts
bind
```

- Linux
  - ➢ /etc/nsswitch.conf

```
hosts:      files nisplus nis dns
```

Utilities for network connection

❑ ping

- Send ICMP ECHO_REQUEST o a host

```
chbsd [/etc] -chwong- ping -c 1 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=60 time=3.022 ms

--- www.nctu.edu.tw ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 3.022/3.022/3.022/0.000 ms
```

❑ traceroute

- Print the route packets take to network host

```
chbsd [/etc] -chwong- traceroute www.nctu.edu.tw
traceroute to www.nctu.edu.tw (140.113.250.5), 64 hops max, 40 byte packets
 1  e3rtn-235 (140.113.235.254)  0.640 ms  0.449 ms  0.474 ms
 2  140.113.0.210 (140.113.0.210)  0.465 ms  0.310 ms  0.361 ms
 3  140.113.0.166 (140.113.0.166)  0.415 ms  0.379 ms  0.403 ms
 4  140.113.0.149 (140.113.0.149)  0.678 ms  0.536 ms  0.574 ms
 5  www.NCTU.edu.tw (140.113.250.5)  0.533 ms  0.415 ms  0.438 ms
```

Other issues

❑ The following issues will be given in NA (Network Administration)

- DHCP
- PPP
- NAT
- DNS
- Mail
- ...