

A decorative graphic on the left side of the slide, consisting of several overlapping blue rectangular shapes of varying shades and sizes, creating a layered effect.

# TCP/IP Networking

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# Overview

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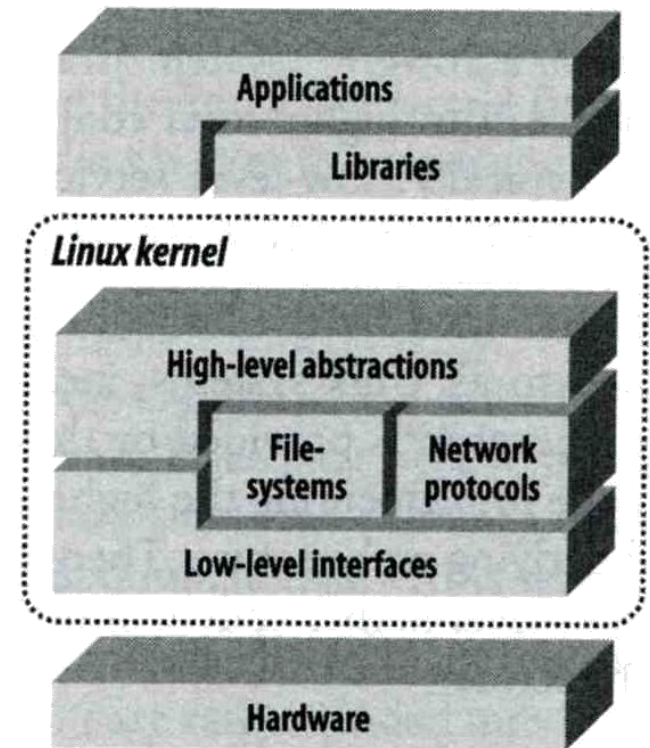
- Introduction
- Layers of TCP/IP
  - Link Layer
  - Network Layer
  - Transport Layer
  - Application Layer
- Network Interface and Hardware
- Networking
- ARP
- Setting up Network

# 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



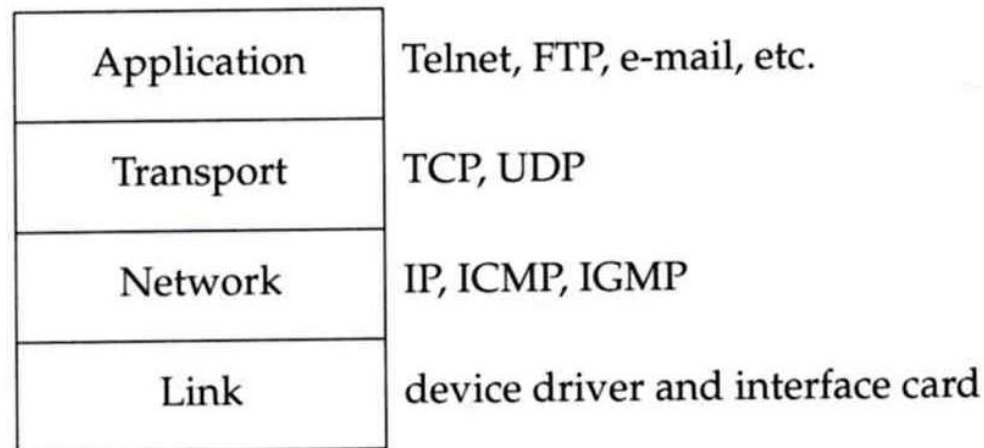
**We need something to do the translating work!**  
**TCP/IP it is!!**

# Introduction

## – Layers of TCP/IP (1)

### □ TCP/IP is a suite of networking protocols

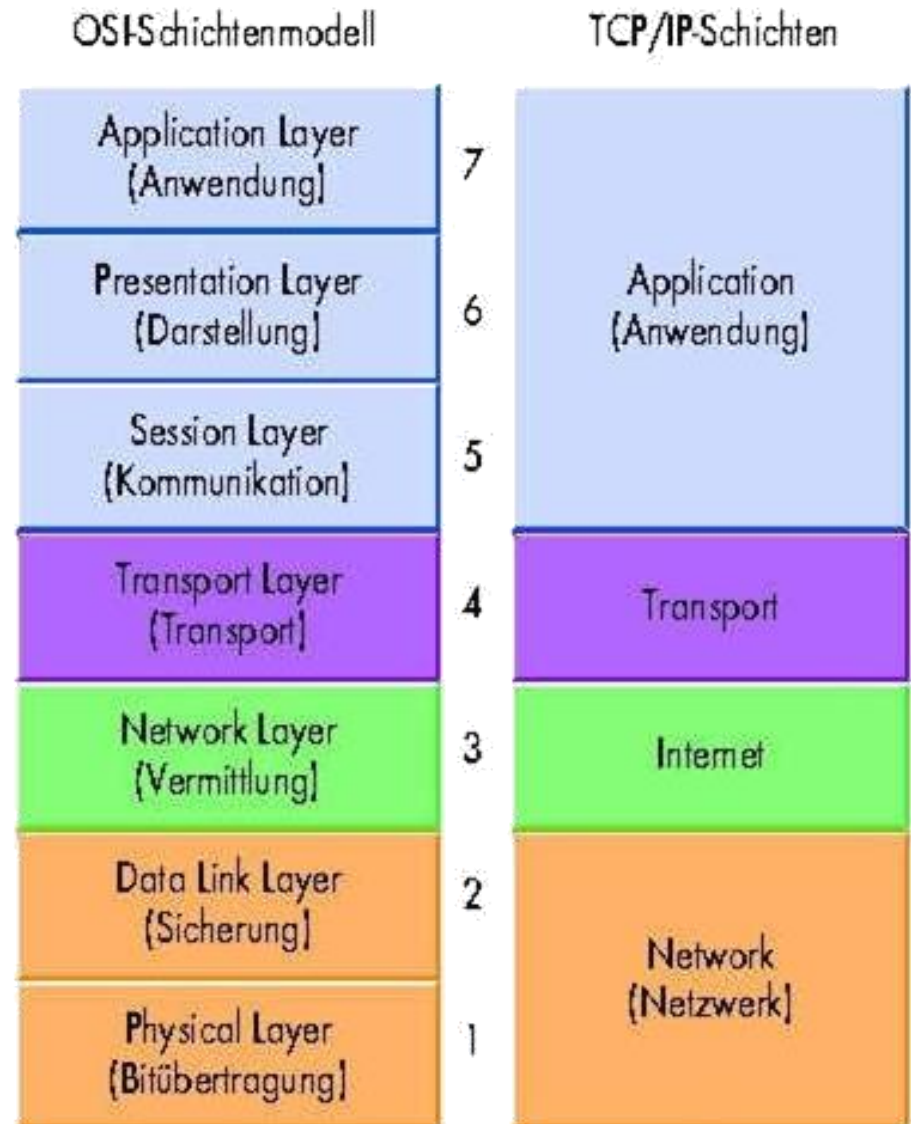
- 4 layers Layering architecture
  - Link layer (data-link layer)
    - Include device drivers to handle hardware details
  - Network layer (IP)
    - Handle the movement of packets around the network
  - Transport layer (Port)
    - Handle flow of data between hosts
  - Application



# Introduction

## – Layers of TCP/IP (2)

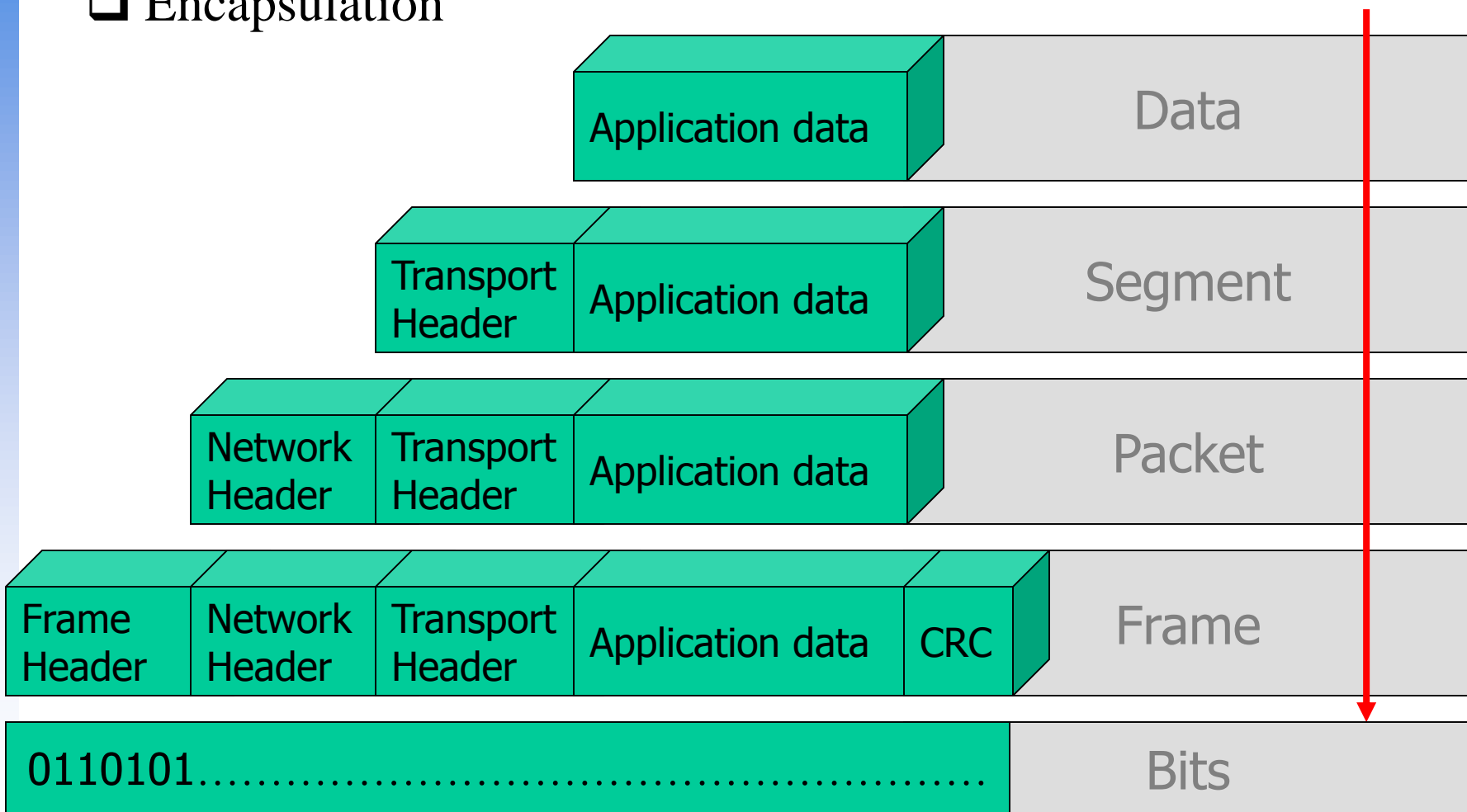
### □ ISO/OSI Model and TCP/IP Model



# Introduction

## - Layers of TCP/IP (3)

### ❑ Encapsulation



# Introduction

## – Layers of TCP/IP (4)

### □ Demultiplexing

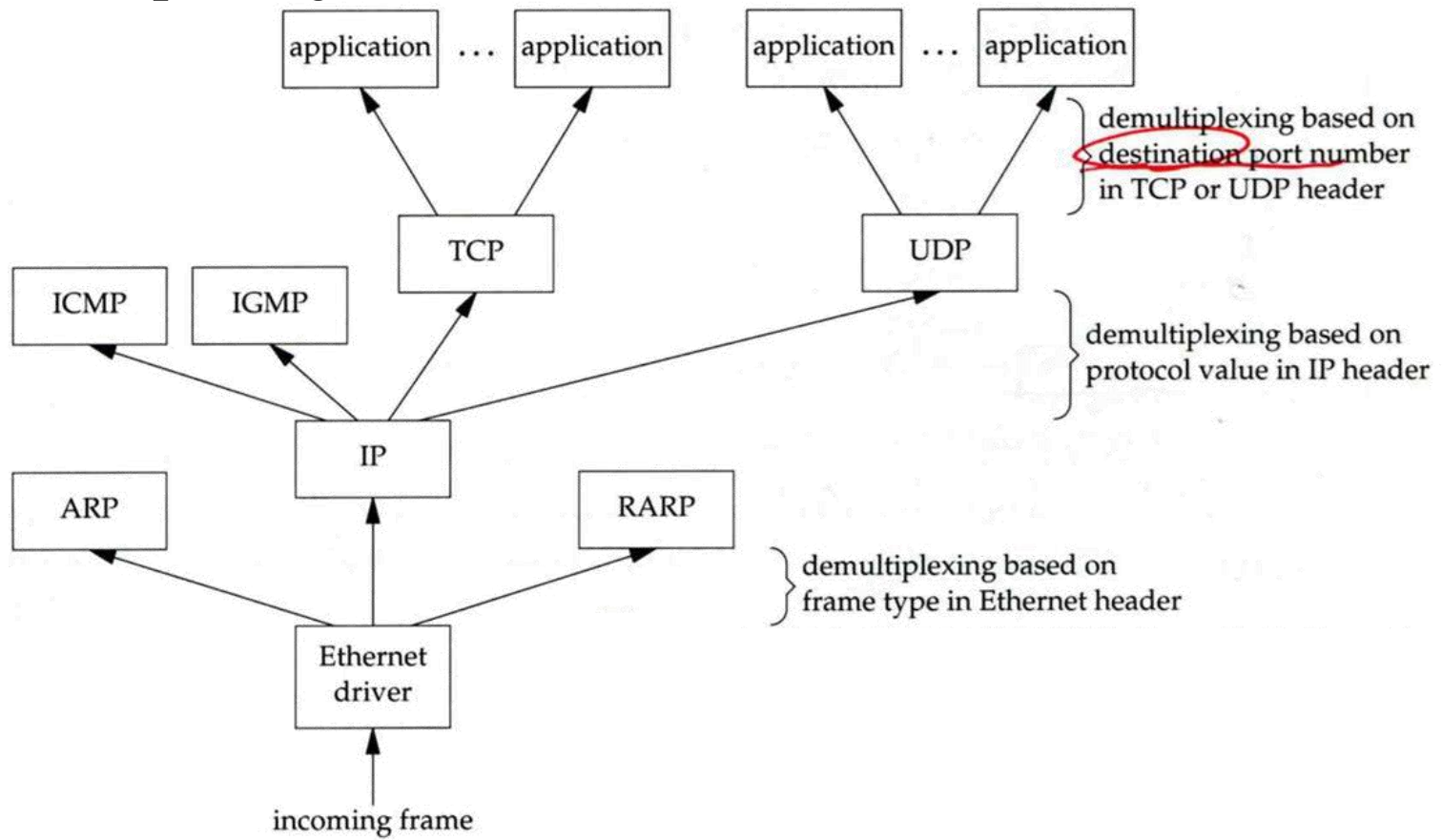
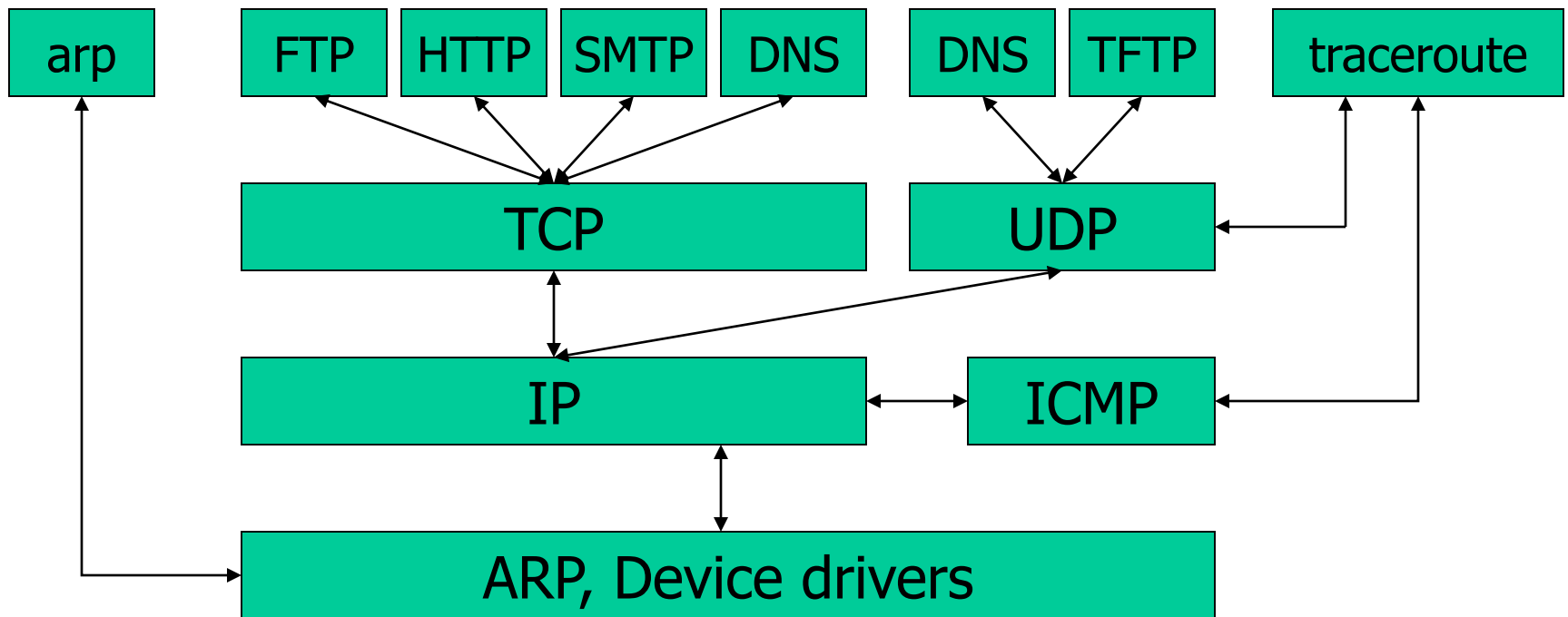


Figure 1.8 The demultiplexing of a received Ethernet frame.

# Introduction

## -TCP/IP Family



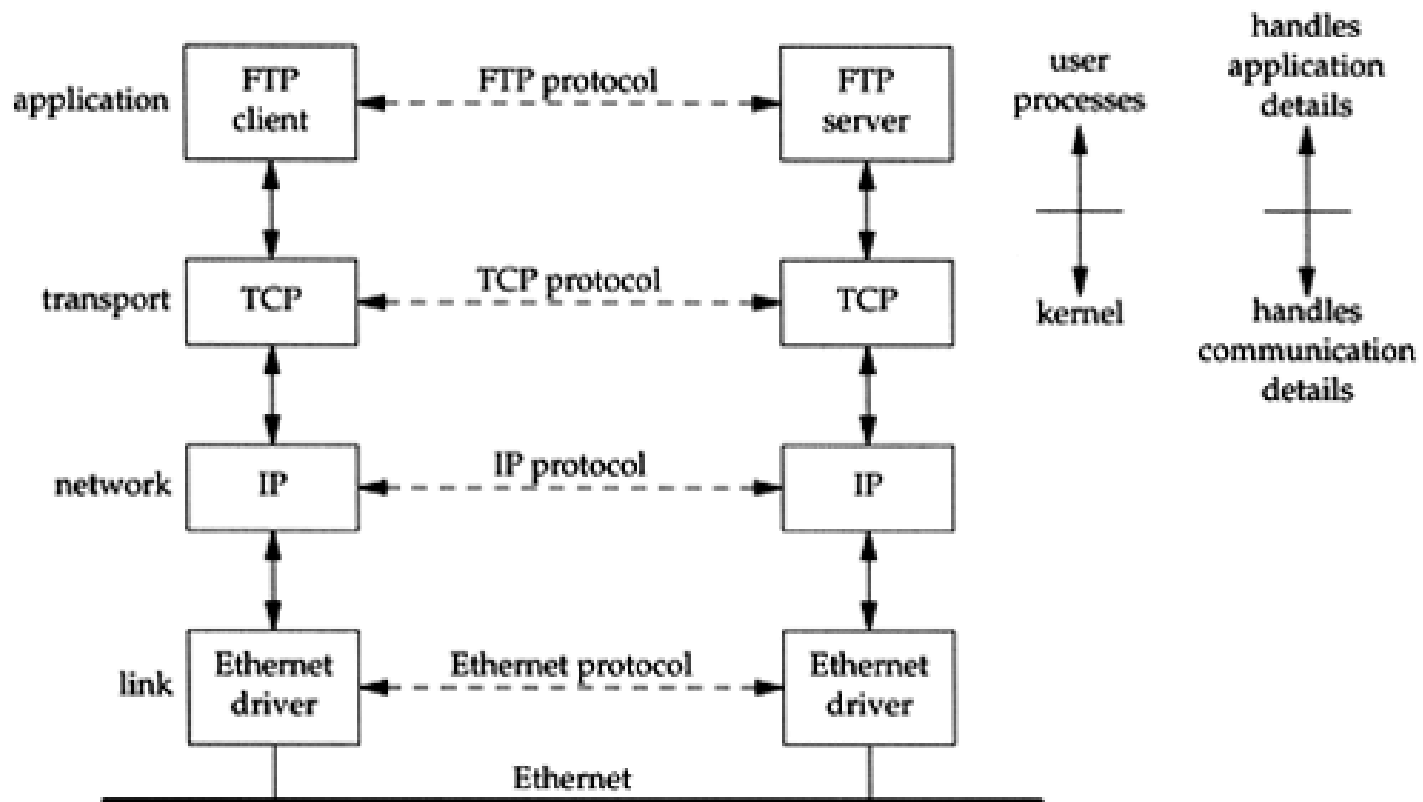


# Introduction

## – Addressing

### □ Addressing

- Nearby (same network)

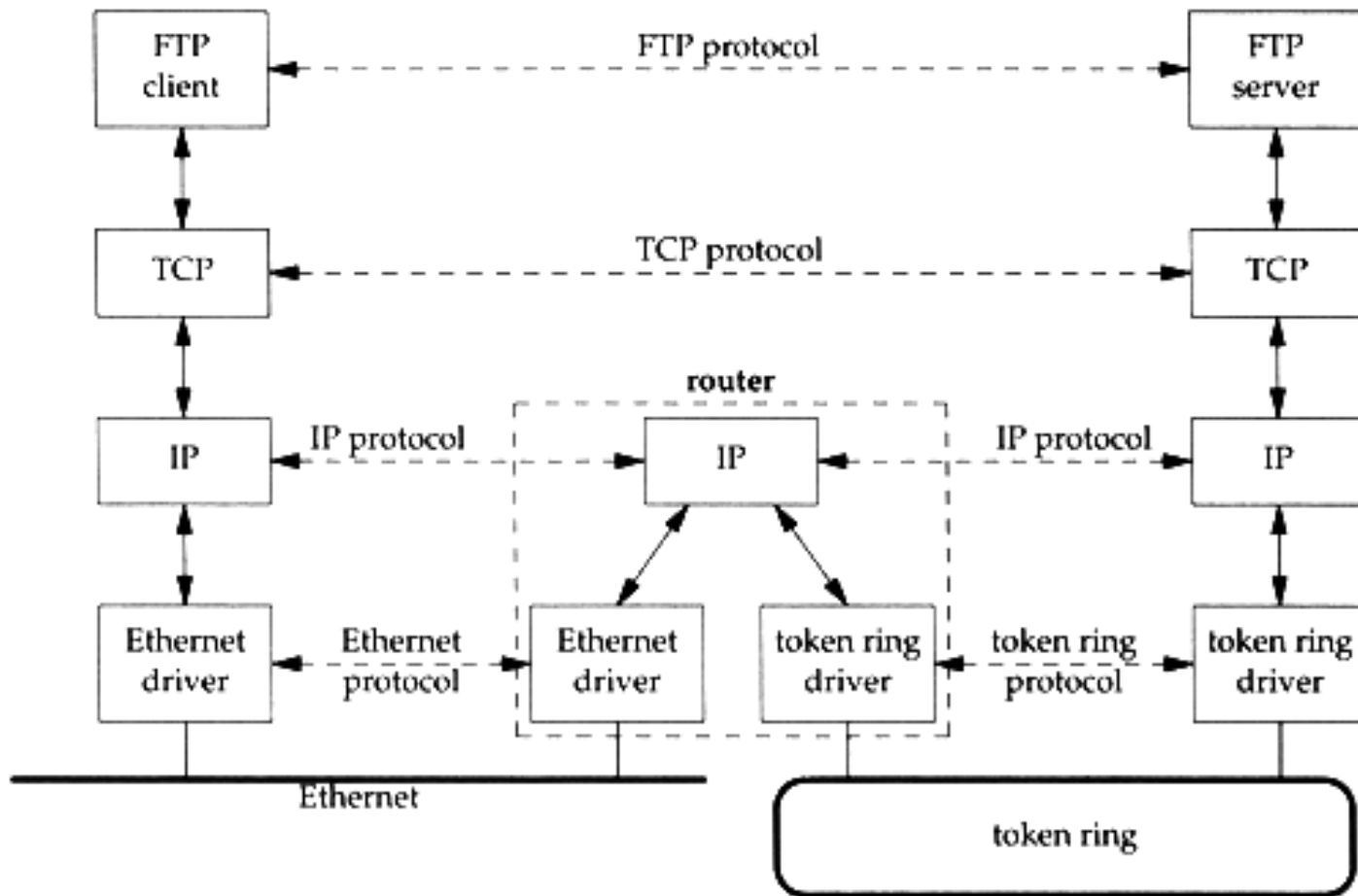


# Introduction

## – Addressing

### □ Addressing

- Faraway (across network)



# Introduction

## – Addressing

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- ❑ 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 0xfffff00 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

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# Network Interface and Hardware

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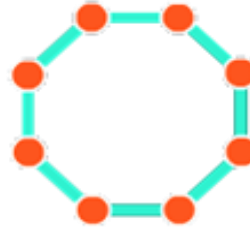
- ❑ LAN (Local), WAN (Wide), MAN (Metropolitan)
  - Ethernet, Token-Ring, FDDI
  - PPP, xDSL, ISDN
- ❑ Physical Topologies (see next slide)
- ❑ Logical Topologies
  - Broadcast, Token-passing
- ❑ Common LAN Devices
  - NIC, Repeater, Hub, Bridge, Switch, Router
- ❑ Common LAN Media
  - UTP, STP, Coaxial Cable, Fiber Optic Cable

# Network Interface and Hardware

## – Physical Topologies



Bus



Ring



Star



Extended  
Star



Hierarchical



Mesh

# Network Interface and Hardware

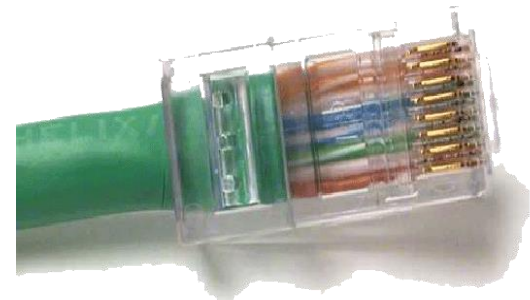
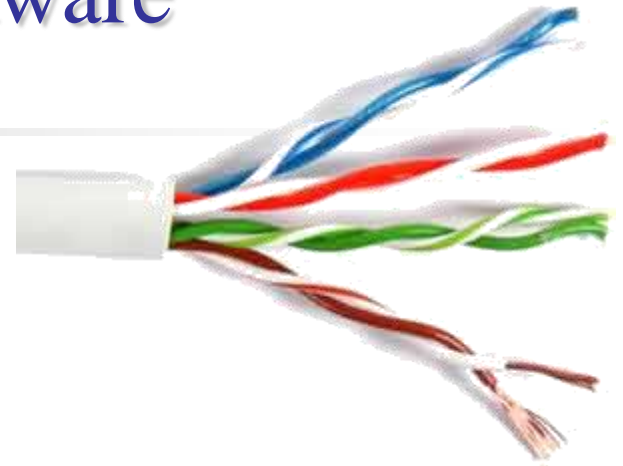
## – Media

### □ 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

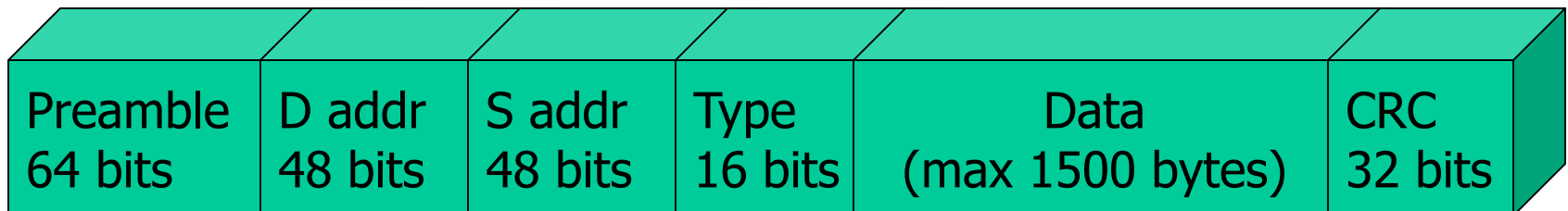
- 10 Mb/s → 100 Mb/s → 1Gb/s
- 802.3 → 802.3u → 802.3z
- CSMA/CD (Carrier Sense Multiple Access/Collision Detect)

## ❑ Ethernet Address (48bits)

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

## ❑ Ethernet Frame

- Ethernet MTU (Maximum Transmission Unit) is 1500 bytes
- IP fragmentation
- Path MTU
  - MTU of various physical device







# Network Layer

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# The Network Layer

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## ❑ 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:  $256 * 256 = 65535$

### ❑ IP address category

Class	1 <sup>st</sup> byte <sup>a</sup>	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)

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### ❑ 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 <sup>a</sup>	Host bits	Hosts/net <sup>b</sup>	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	0xFFFFF000
/25	7	126	255.255.255.128	0xFFFFF800
/26	6	62	255.255.255.192	0xFFFFFC00
/27	5	30	255.255.255.224	0xFFFFFE00
/28	4	14	255.255.255.240	0xFFFFF000
/29	3	6	255.255.255.248	0xFFFFF008
/30	2	2	255.255.255.252	0xFFFFF00C



# The Network Layer

## — IP address crisis

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### ❑ IP address crisis

- Run out of class B address
  - The most desirable ones for moderately large organizations
- IP address were being allocated on a FCFS
  - With no locality of reference

### ❑ Solutions

- Short term
  - Subnetting and CIDR (classless inter-domain routing)
  - NAT (network address translation)
- Long term
  - IPv6

# The Network Layer

## – NAT (1)

### ❑ 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

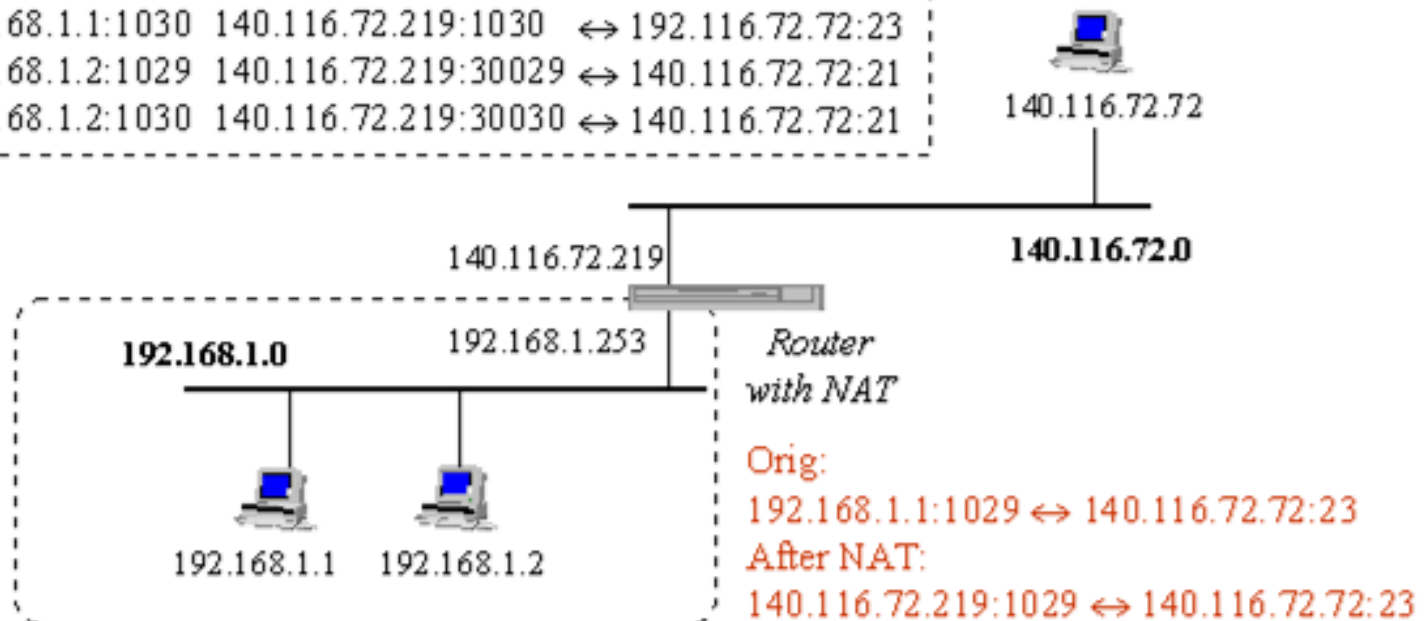
# The Network Layer

## – NAT (2)

- 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	↔ 140.116.72.72:23
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



# 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
<b>default</b>	<b>140.113.17.254</b>	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
```



# Transport Layer

---

# The Transport Layer

## – ports

- ❑ 16-bits number
- ❑ Preserve ports
  - 1 ~ 1024 (root access only)
- ❑ Well-known port
  - /etc/services

```
...
chargen      19/tcp      ttypst source      #Character Generator
chargen      19/udp      ttypst 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

## ❑ 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

## – 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

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## ❑ The Client-Server Model

- Port Numbers:
  - /etc/services
  - The first 1024 ports are reserved ports
- Internet Services
  - inetd and /etc/inetd.conf
- DNS

# 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

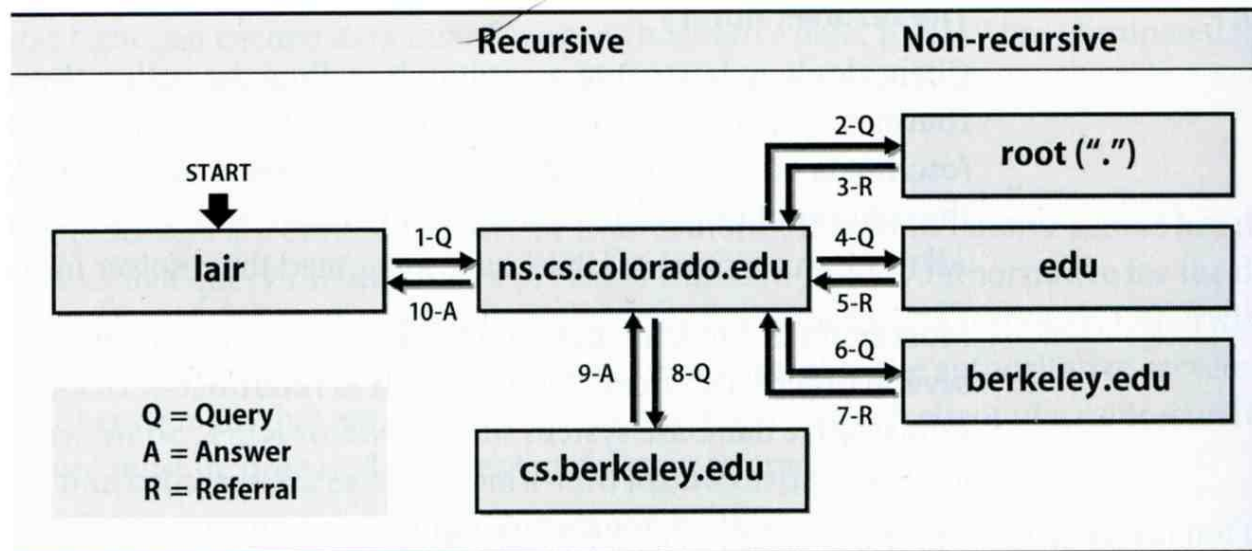
```

# 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



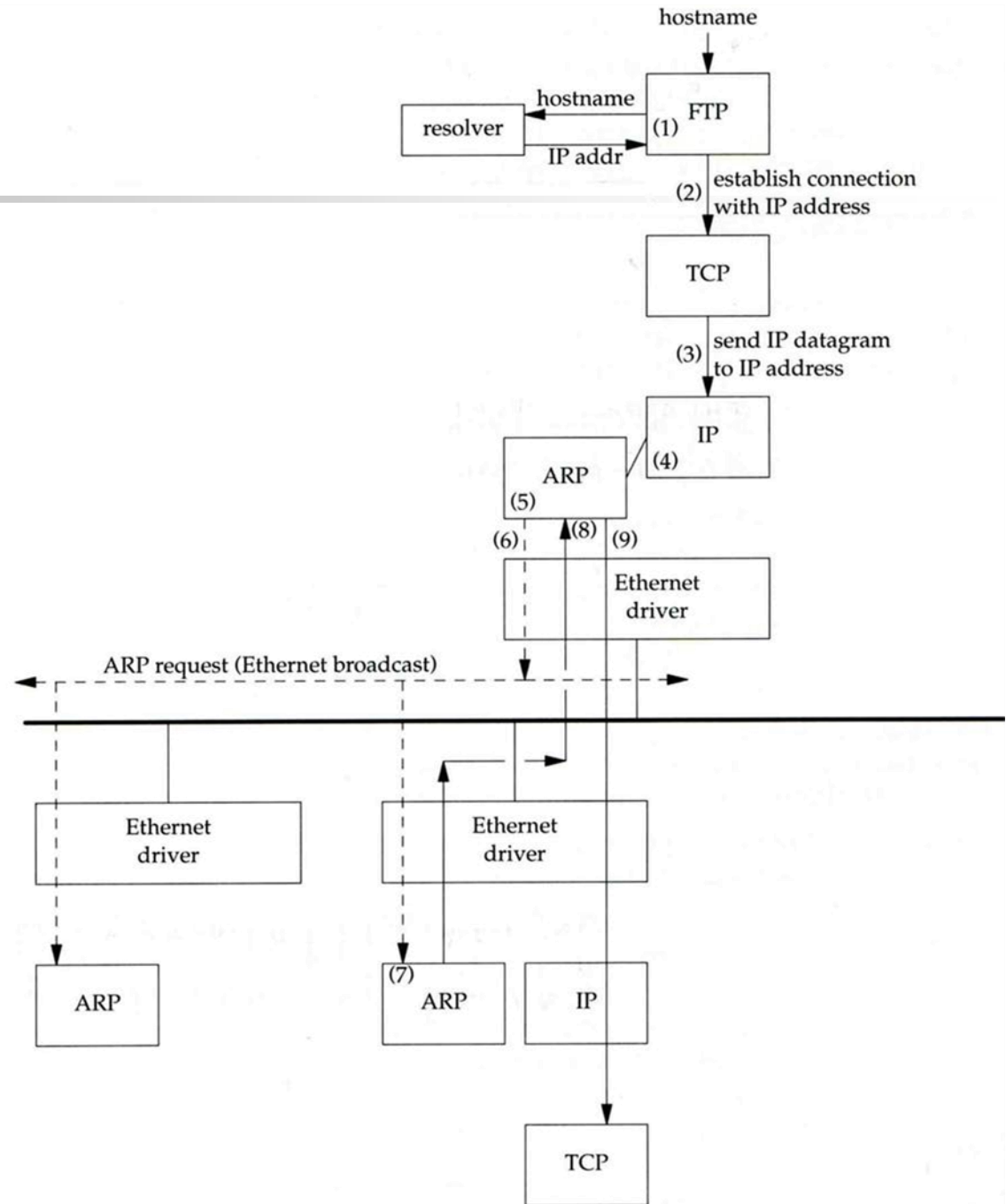
# ARP (1)

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## □ 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"  
ifconfig_fxp0_alias0="inet 140.113.17.214 netmask 255.255.255.255"  
ifconfig_fxp1="inet 192.168.1.254 netmask 255.255.255.0"
```

### ❑ 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 cbsd12 cbsd12.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)

```
sun1 [/etc] -chwong- cat hostname.rtl0 nodename defaultrouter resolv.conf
sun1
sun1.cs.nctu.edu.tw
140.113.235.254
domain cs.nctu.edu.tw
nameserver 140.113.235.107
nameserver 140.113.6.2
sun1 [/etc] -chwong- cat /etc/inet/netmasks /etc/inet/hosts
140.113.235.0    255.255.255.0
127.0.0.1      localhost
140.113.235.102 csduty
140.113.235.171 sun1
140.113.235.101 cshome
```

# 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 cs.nctu.edu.tw
nameserver 140.113.235.107
search cs.nctu.edu.tw csie.nctu.edu.tw nctu.edu.tw
```

### ❑ Host lookup order

- FreeBSD, Linux
  - /etc/nsswitch.conf

```
chbsd [/etc] -chwong- cat nsswitch.conf
group: compat
group_compat: nis
hosts: files dns
networks: files
passwd: compat
passwd_compat: nis
shells: files
services: compat
services_compat: nis
protocols: files
rpc: files
```

# Utilities for network connection

## ❑ ping

- Send ICMP ECHO\_REQUEST to 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
```

# Useful Utilities in ports

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- ❑ net/mtr
  - Traceroute and ping in a single graphical network diagnostic tool
- ❑ net/nload
  - Console application which monitors network traffic in real time
- ❑ net/wireshark
- ❑ net/tshark
  - A powerful network analyzer/capture tool



# Other issues

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- ❑ The following issues will be given in NA (Network Administration)
  - DHCP
  - PPP
  - NAT
  - DNS
  - Mail
  - ...