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

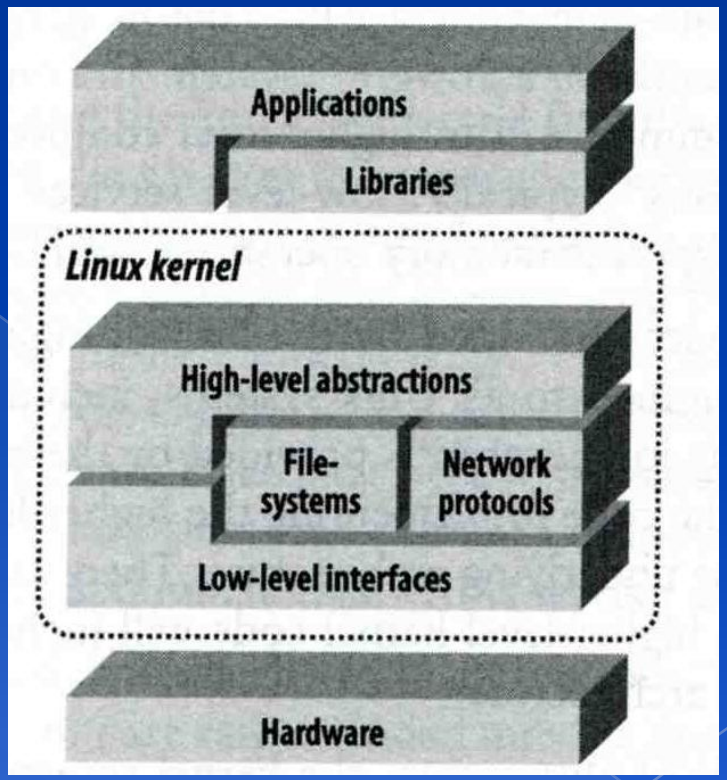
Introduction
– Basic Term

- 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

```
em0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 9000
        options=9b<RXCSUM,TXCSUM,VLAN_MTU,VLAN_HWTAGGING,VLAN_HWCSUM>
        ether 00:0e:0c:01:da:bc
        inet 192.168.7.2 netmask 0xffffff00 broadcast 192.168.7.255
        media: Ethernet autoselect (1000baseTX <full-duplex>)
        status: active
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> metric 0 mtu 16384
        inet6 fe80::1%lo0 prefixlen 64 scopeid 0x3
        inet6 ::1 prefixlen 128
        inet 127.0.0.1 netmask 0xff000000
```

Introduction
– Why TCP/IP ?

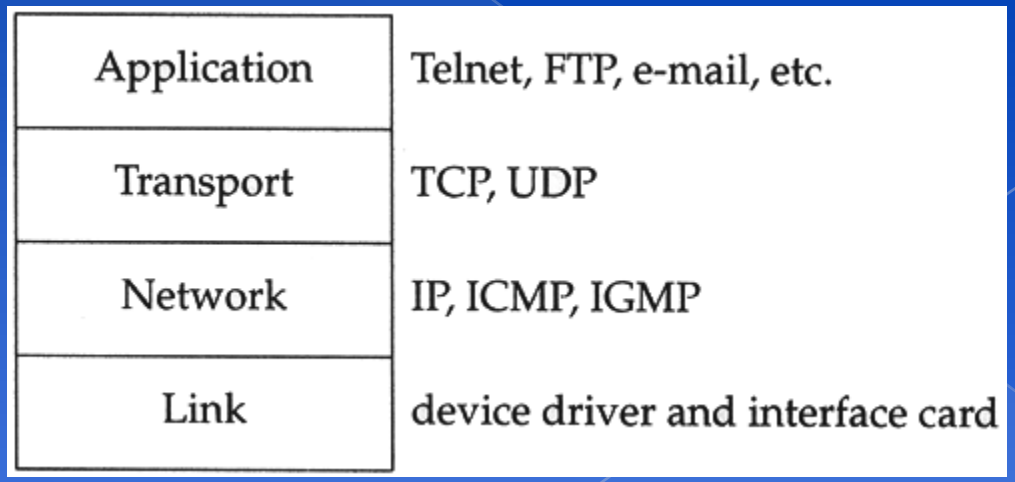
- The gap between applications and Network
  - Network
    - 802.3 Ethernet
    - 802.4 Token bus
    - 802.5 Token Ring
    - 802.11 Wireless
  - Application
    - Reliable
    - Performance



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

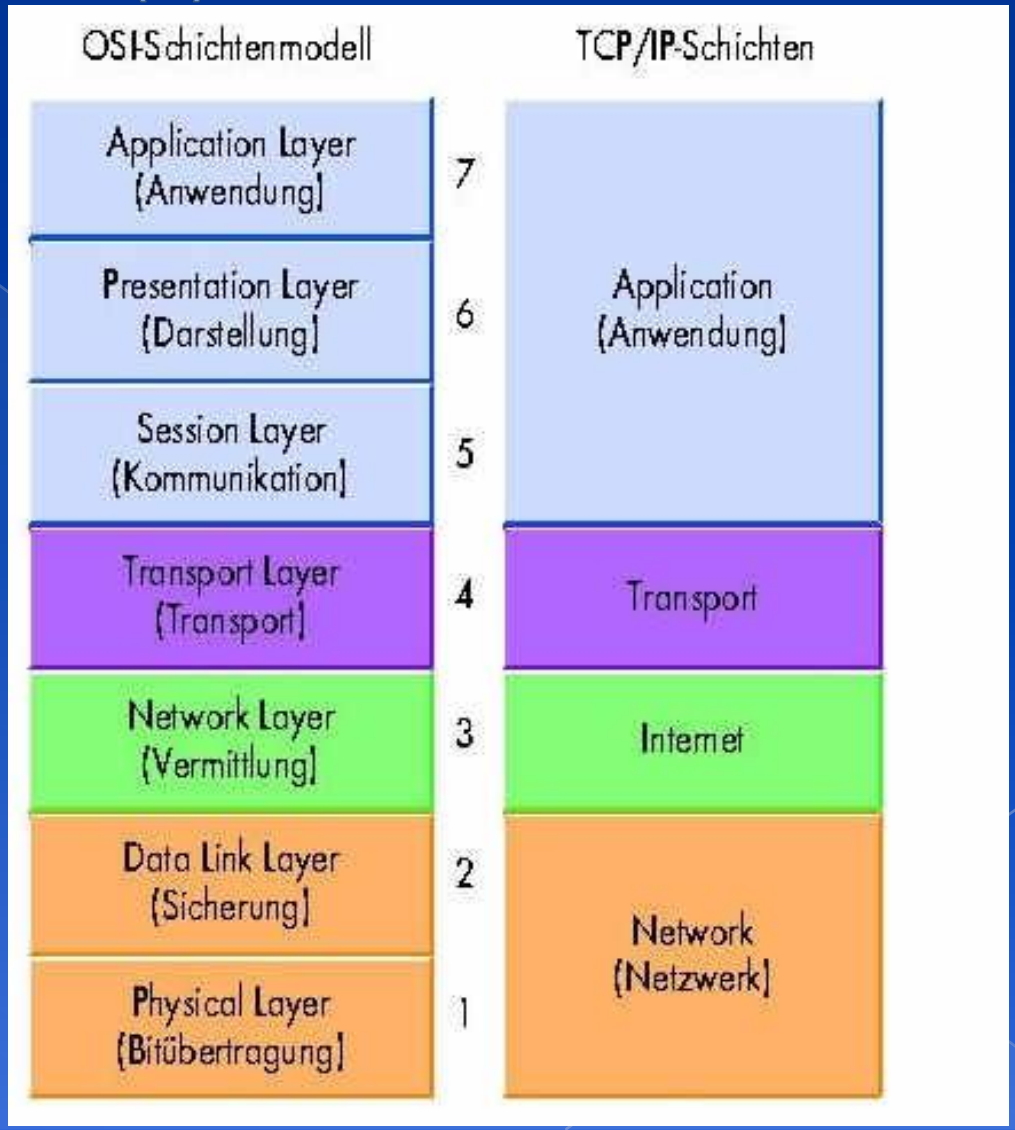
Introduction
– Layers of TCP/IP (1)

- 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



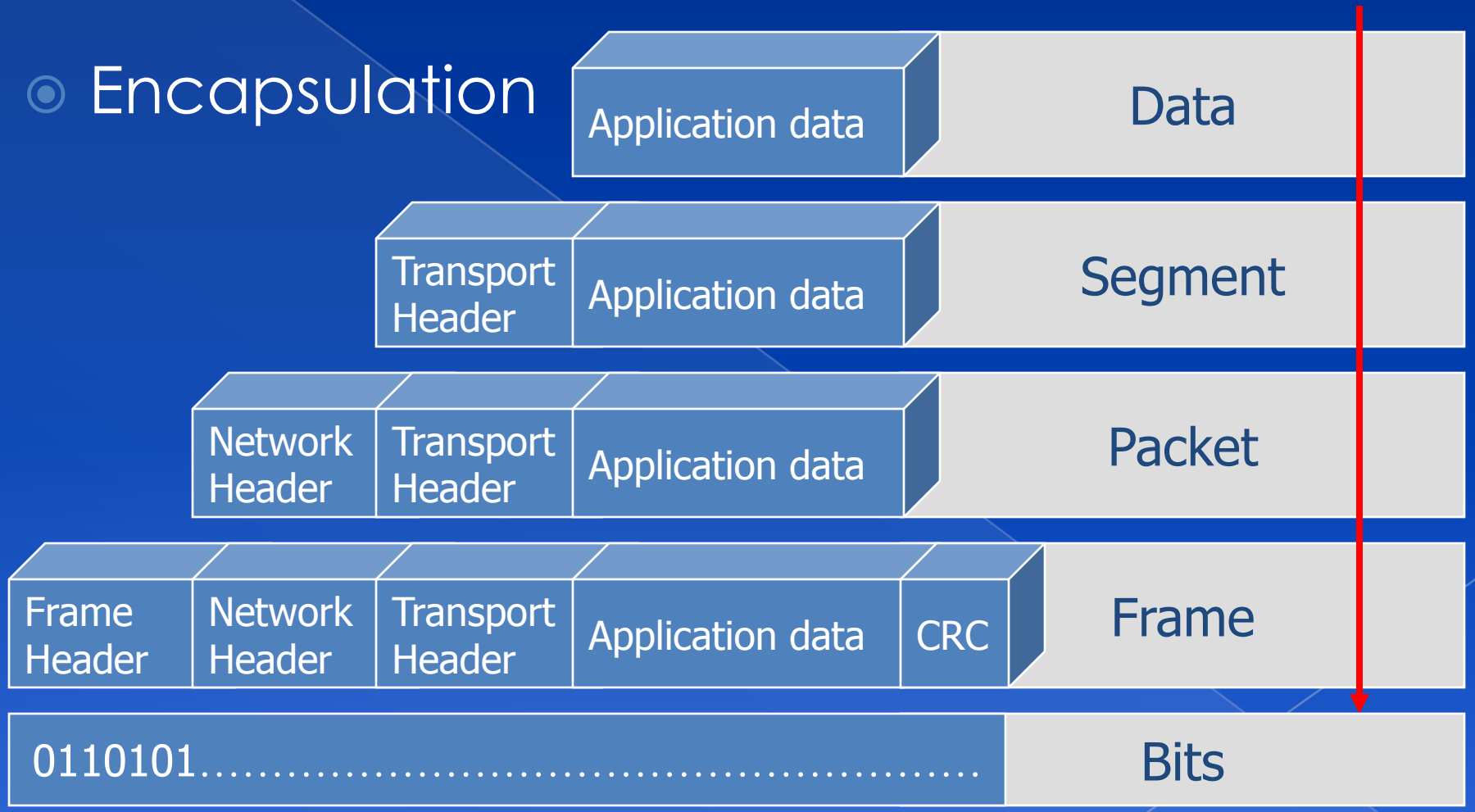
Introduction
– Layers of TCP/IP (2)

- ISO/OSI Model
- TCP/IP Model



Introduction
– Layers of TCP/IP (3)

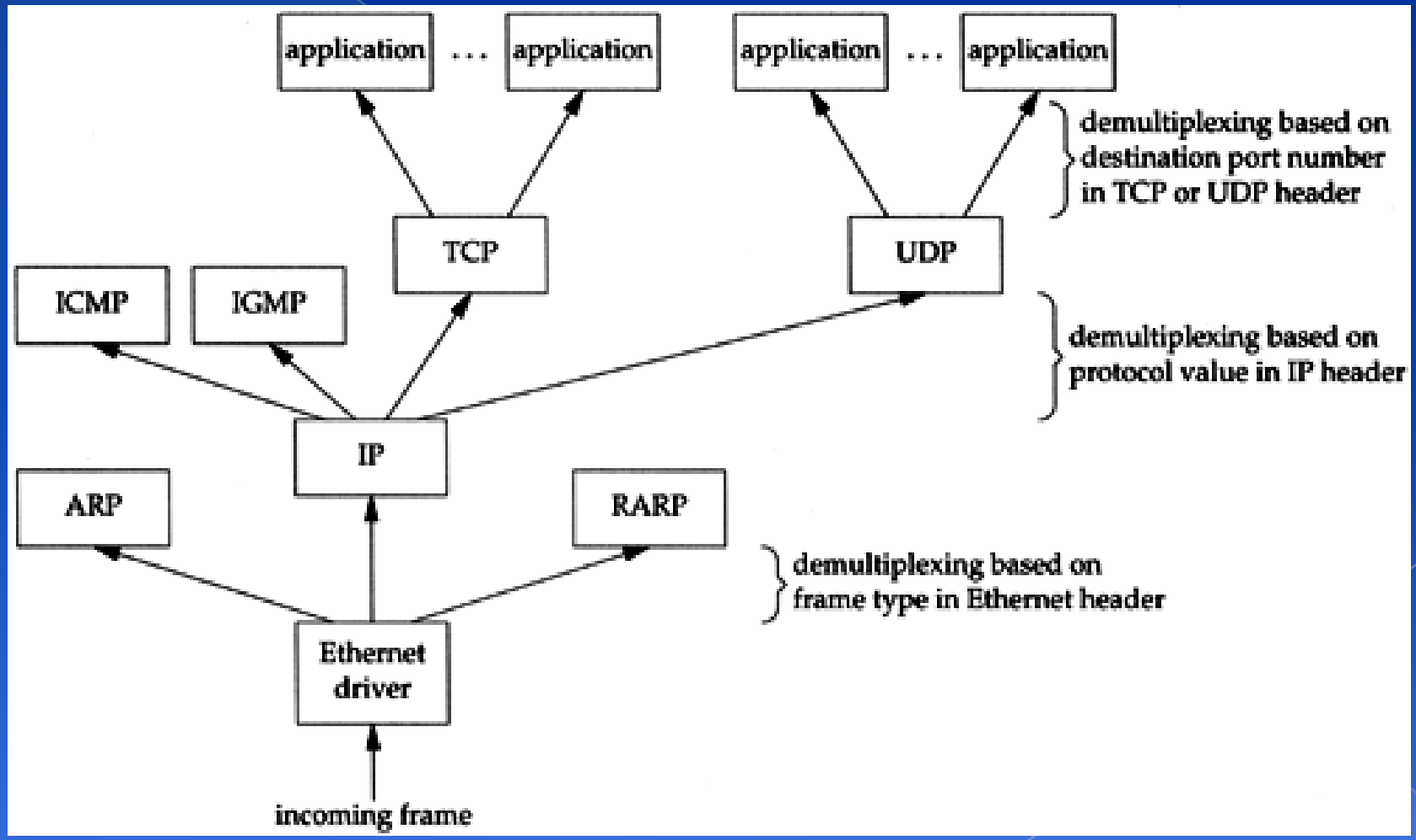
- Encapsulation



Introduction

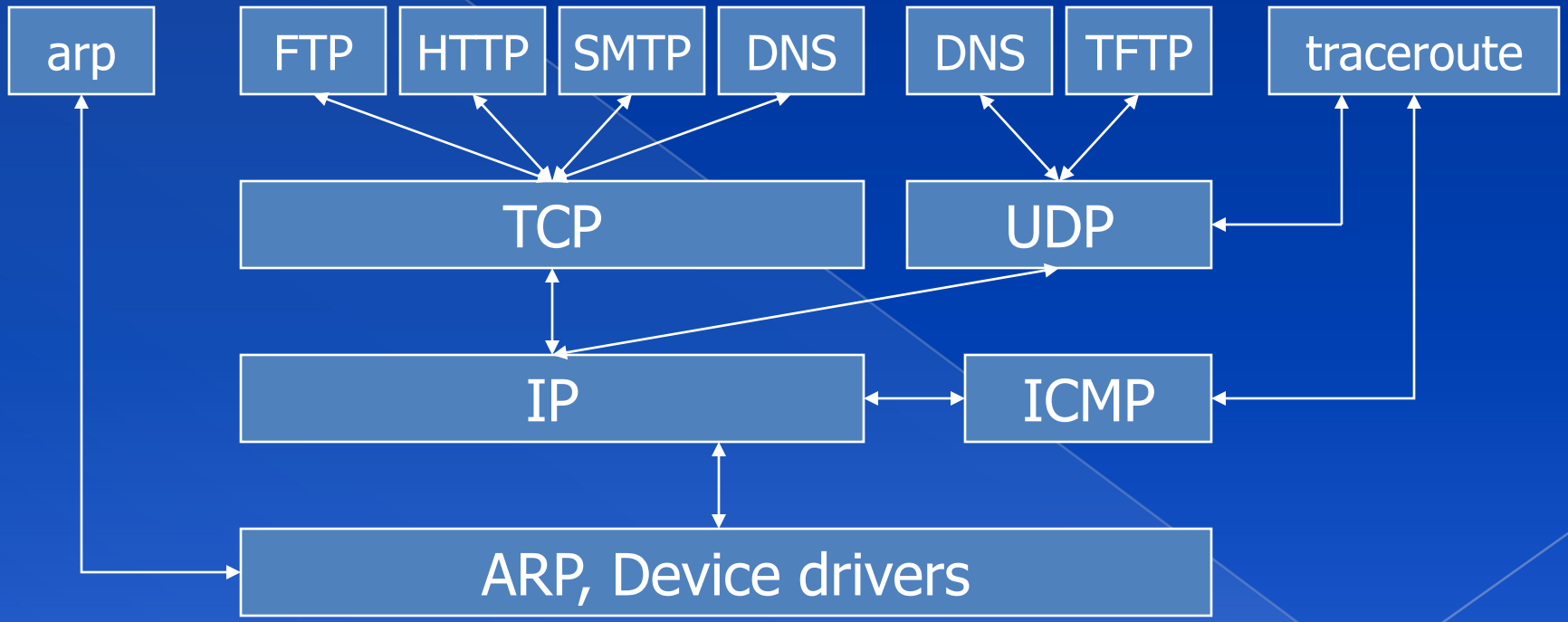
– Layers of TCP/IP (4)

- Demultiplexing



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

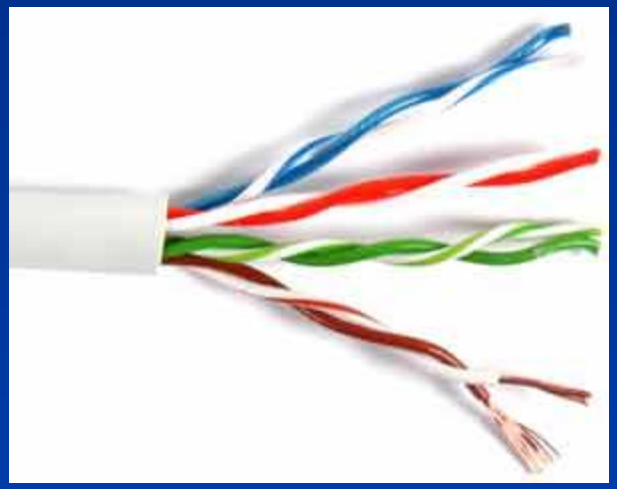
Extended Star

Hierarchical

Mesh

Network Interface and Hardware

– Media



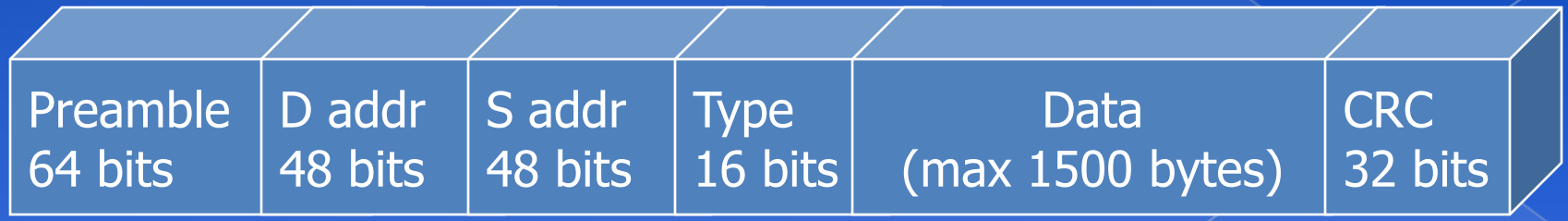
- Media
  - Coaxial Cable
    - Thicknet v.s. thinnet
    - BNC connector
  - Twisted Pair Standards

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 (B-B) v.s. Crossover (A-B)
    - 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.



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
- 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.

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

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	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

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

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

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 140.113.17.209
- 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

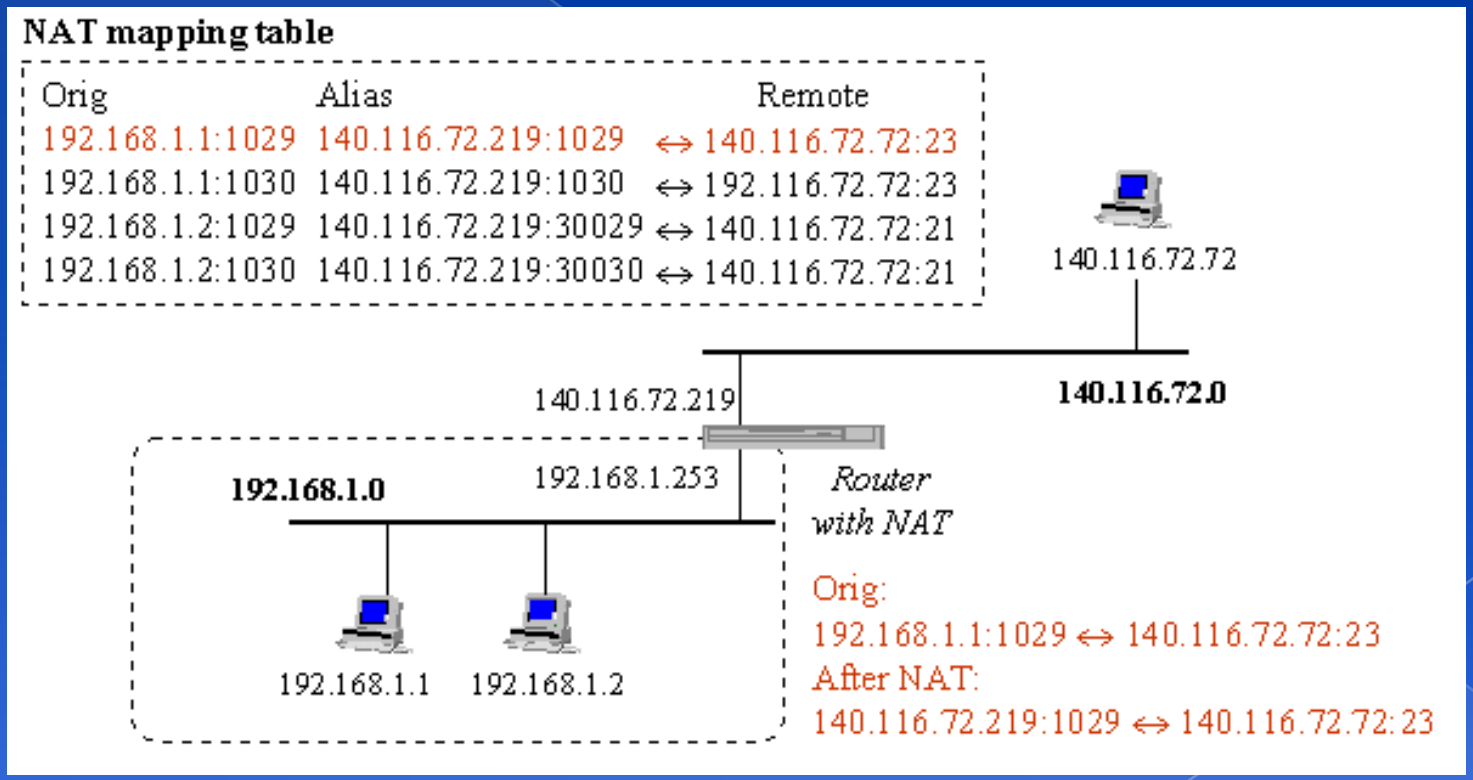
The Network Layer
– Address Types (2)

- 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



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

```
lucky7:~ -lwhsu- netstat -nr
Routing tables

Internet:
Destination        Gateway            Flags    Refs      Use  Netif Expire
default            140.113.17.254     UGS         0  6207156    em0
127.0.0.1          127.0.0.1          UH          0    66656    lo0
140.113.17.0/24    link#2             UC          0        0    em0
140.113.17.24      00:02:b3:99:3e:71  UHLW        1     2178    em0   1145
140.113.17.237     00:0e:0c:a9:fc:30  UHLW        1       80    lo0
140.113.17.248     00:0b:ac:d7:93:40  UHLW        1        0    em0   1191
140.113.17.254     00:90:69:64:ec:00  UHLW        2        0    em0   1200
140.113.17.255     ff:ff:ff:ff:ff:ff  UHLWb       1      629    em0
```

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"

```
knight:~ -lwhsu- ping -c 1 -R www.nctu.edu.tw
PING www.nctu.edu.tw (140.113.4.82): 56 data bytes
64 bytes from 140.113.4.82: icmp_seq=0 ttl=62 time=1.247 ms
RR:     140.113.0.165
        not-a-legal-address (140.113.4.254)
        www.NCTU.edu.tw (140.113.4.82)
        www.NCTU.edu.tw (140.113.4.82)
        140.113.0.166
        e3rtn-24.cs.nctu.edu.tw (140.113.24.254)
        lwhsusvr.cs.nctu.edu.tw (140.113.24.67)

--- www.nctu.edu.tw ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 1.247/1.247/1.247/0.000 ms
knight:~ -lwhsu- traceroute www.nctu.edu.tw
traceroute: Warning: www.nctu.edu.tw has multiple addresses; using 140.114.60.211
traceroute to www.nctu.edu.tw (140.114.60.211), 64 hops max, 40 byte packets
 1  e3rtn-24.cs.nctu.edu.tw (140.113.24.254)  0.508 ms  0.335 ms  0.225 ms
 2  140.113.0.166 (140.113.0.166)  3.586 ms  0.482 ms  0.432 ms
 3  140.113.0.153 (140.113.0.153)  0.577 ms  0.328 ms  0.283 ms
 4  c7609-1-c7609C.nthu.edu.tw (140.114.1.182)  0.467 ms  0.335 ms  0.343 ms
 5  www-nctu.et.nthu.edu.tw (140.114.60.211)  0.374 ms !Z  0.366 ms !Z  0.407 ms !Z
knight:~ -lwhsu-
```

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

```
lucky7:~ -lwhsu- 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“
  - /etc/inetd.conf
    - inetd_enable="YES"

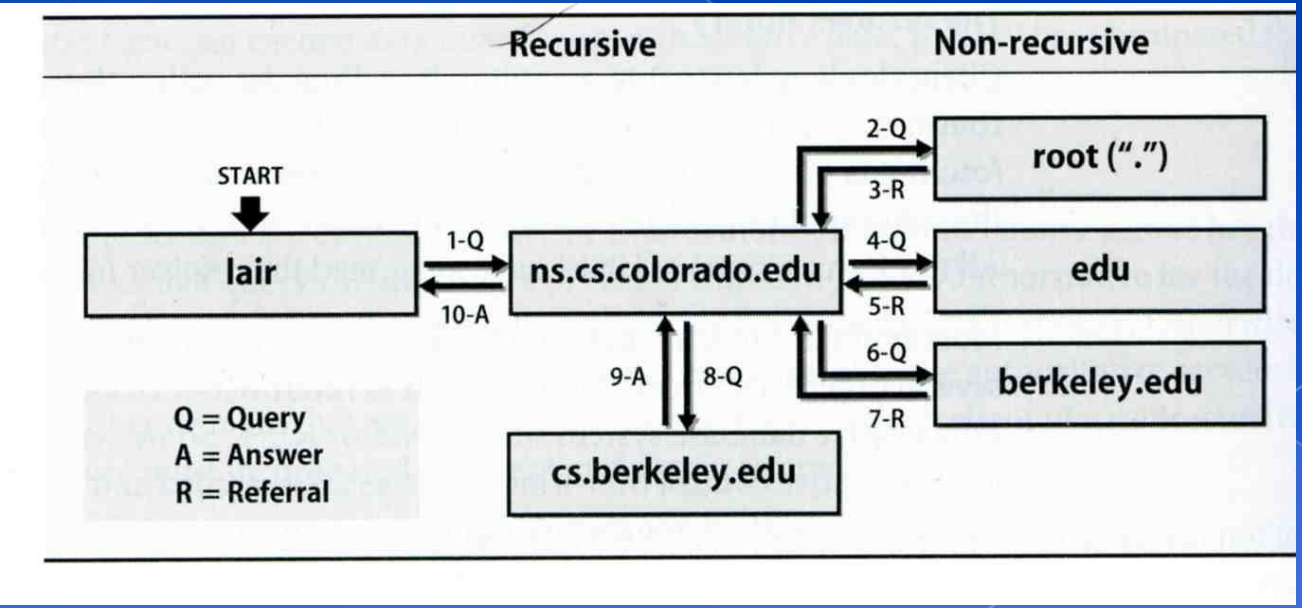
```
daytime  stream  tcp   nowait  root    internal
ftp      stream  tcp   nowait  root    /usr/libexec/ftpd              ftpd -l
ssh      stream  tcp   nowait  root    /usr/sbin/sshd                 sshd -i -4
telnet   stream  tcp   nowait  root    /usr/libexec/telnetd           telnetd
pop3     stream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

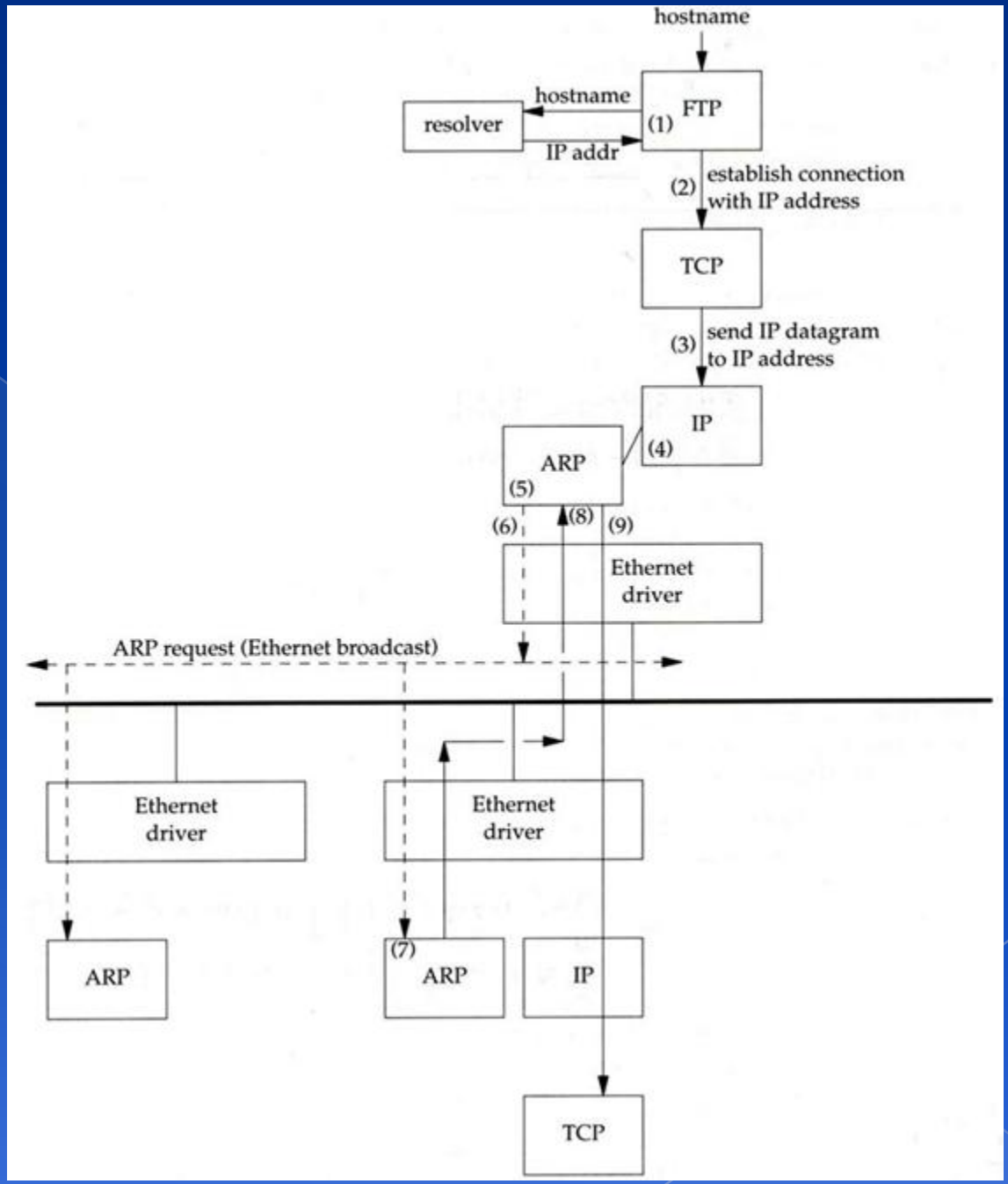
- Domain Name System
  - Record IP-hostname mapping
  - DNS query
    - "what is the IP of vangogh.cs.berkeley.edu" from lair.cs.colorado.edu
  - Hierarchical architecture



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)


hostname
FTP
(1)
hostname
resolver
IP addr
(2)
establish connection
with IP address
TCP
(3)
send IP datagram
to IP address
IP
(4)
ARP
(5)
(6)
(8)
(9)
Ethernet
driver
ARP request (Ethernet broadcast)
Ethernet
driver
Ethernet
driver
ARP
(7)
ARP
IP
TCP

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

```
mg-215:~ -lwhsu- arp –a
? (140.113.208.0) at ff:ff:ff:ff:ff:ff on fxp1 permanent [ethernet]
? (140.113.208.255) at ff:ff:ff:ff:ff:ff on fxp1 permanent [ethernet]
? (140.113.210.0) at ff:ff:ff:ff:ff:ff on fxp2 permanent [ethernet]
e3rtn-208.cs.nctu.edu.tw (140.113.208.254) at 00:0e:38:a4:c2:00 on fxp1 [ethernet]
e3rtn-210.cs.nctu.edu.tw (140.113.210.254) at 00:0e:38:a4:c2:00 on fxp2 [ethernet]
e3rtn-215.cs.nctu.edu.tw (140.113.215.254) at 00:0e:38:a4:c2:00 on fxp3 [ethernet]
e3rtn-216.cs.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="lucky7.cs.nctu.edu.tw"
ifconfig_fxp0="inet 140.113.17.237  netmask 255.255.255.0"
ifconfig_fxp0_alias="inet 192.168.17.240  netmask 255.255.255.0"
ifconfig_fxp1="inet 140.113.209.200  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

```
magpie:~ -lwhsu- cat /etc/hosts
#
127.0.0.1       localhost
140.113.209.1   operator
140.113.209.2   ccserv
140.113.209.6   ccduty
140.113.209.7   mailgate
140.113.209.10  cchome
```

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] -lwhsu- cat hostname.rtls0 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] -lwhsu- 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

```
lucky7:/etc -lwhsu- cat resolv.conf
domain          cs.nctu.edu.tw
nameserver      140.113.17.24
search  cs.nctu.edu.tw csie.nctu.edu.tw nctu.edu.tw
```

- Host lookup order
  - FreeBSD, Linux
    - /etc/nsswitch.conf

```
lucky7:/etc -lwhsu- 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 o a host

```
lucky7:~ -lwhsu- ping -c 1 www.nctu.edu.tw
PING www.nctu.edu.tw (140.113.4.82): 56 data bytes
64 bytes from 140.113.4.82: icmp_seq=0 ttl=61 time=0.399 ms

--- www.nctu.edu.tw ping statistics ---
1 packets transmitted, 1 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 0.399/0.399/0.399/0.000 ms
```

- traceroute

```
lucky7:~ -lwhsu- traceroute www.nctu.edu.tw
traceroute: Warning: www.nctu.edu.tw has multiple addresses; using 140.114.60.211
traceroute to www.nctu.edu.tw (140.114.60.211), 64 hops max, 52 byte packets
 1  e3rtn (140.113.17.254)  0.410 ms  0.230 ms  0.357 ms
 2  ProjE27-254.NCTU.edu.tw (140.113.27.254)  0.356 ms  0.351 ms  0.370 ms
 3  140.113.0.58 (140.113.0.58)  0.360 ms  0.354 ms  0.367 ms
 4  140.113.0.153 (140.113.0.153)  0.362 ms  0.357 ms  0.374 ms
 5  c7609-1-c7609C.nthu.edu.tw (140.114.1.182)  0.491 ms  0.359 ms  0.360 ms
 6  www-nctu.et.nthu.edu.tw (140.114.60.211)  0.486 ms !Z  0.353 ms !Z  0.364 ms !Z
```

Useful utilities in ports

- 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

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