TCP/IP Networking

wangth (2017-2020, CC BY-SA)
? (1996-2016)

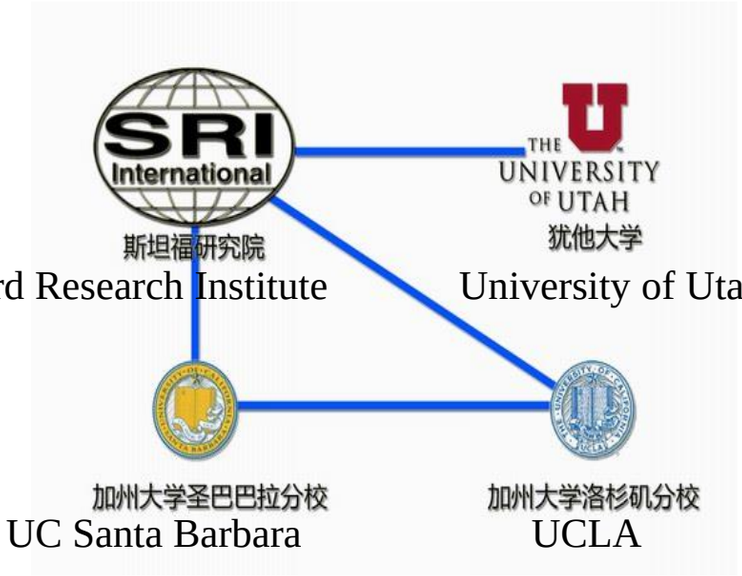
交大資工系資訊中心
Computer Center of Department of Computer Science, NCTU

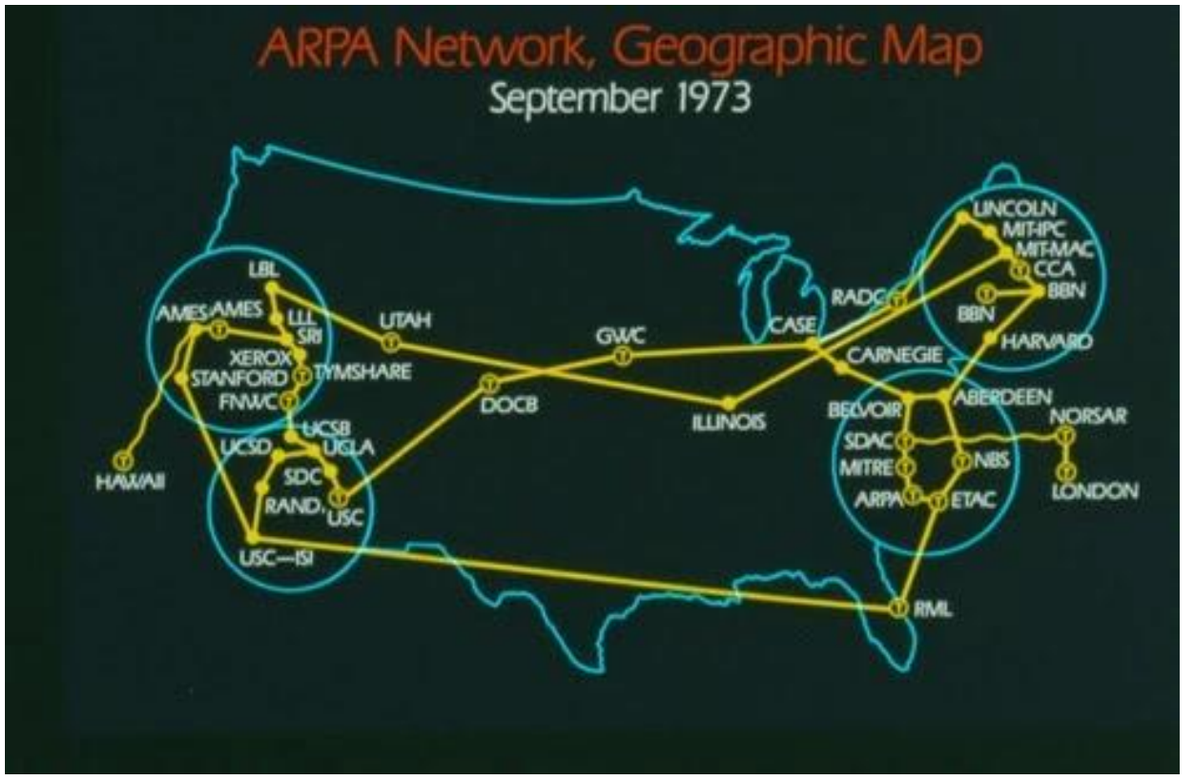
Overview

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

Introduction – ARPANET

- Advanced Research Projects Agency Network
  - NCP (Network Control Protocol)
    - Allow an exchange of information between separated computers

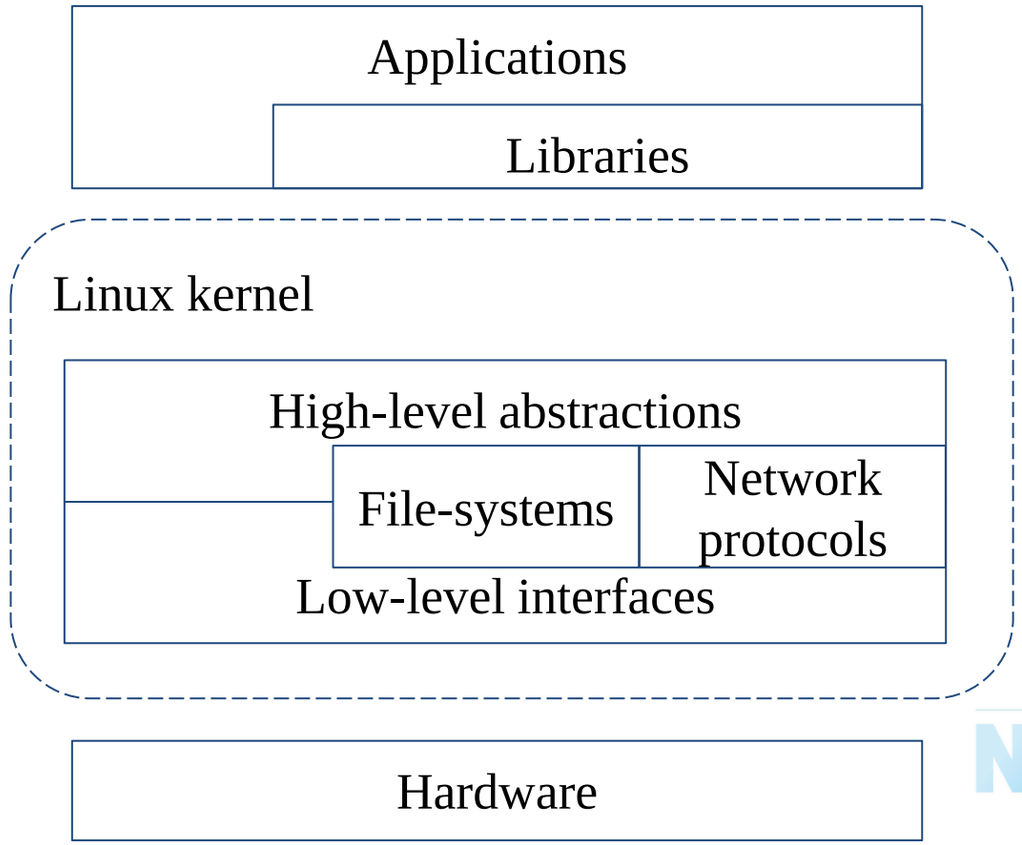




https://inventiontourblog.wordpress.com/2015/03/31/internet-advanced-research-project-agency-arpa-develops-the-first-computer-network/

Introduction – Why TCP/IP ?

- Transmission Control Protocol / Internet Protocol
- The gap between applications and Network
  - Network
    - 802.3 Ethernet
    - 802.4 Token bus
    - 802.5 Token Ring
    - 802.11 Wireless
    - 802.16 WiMAX
  - Application
    - Reliable
    - Performance



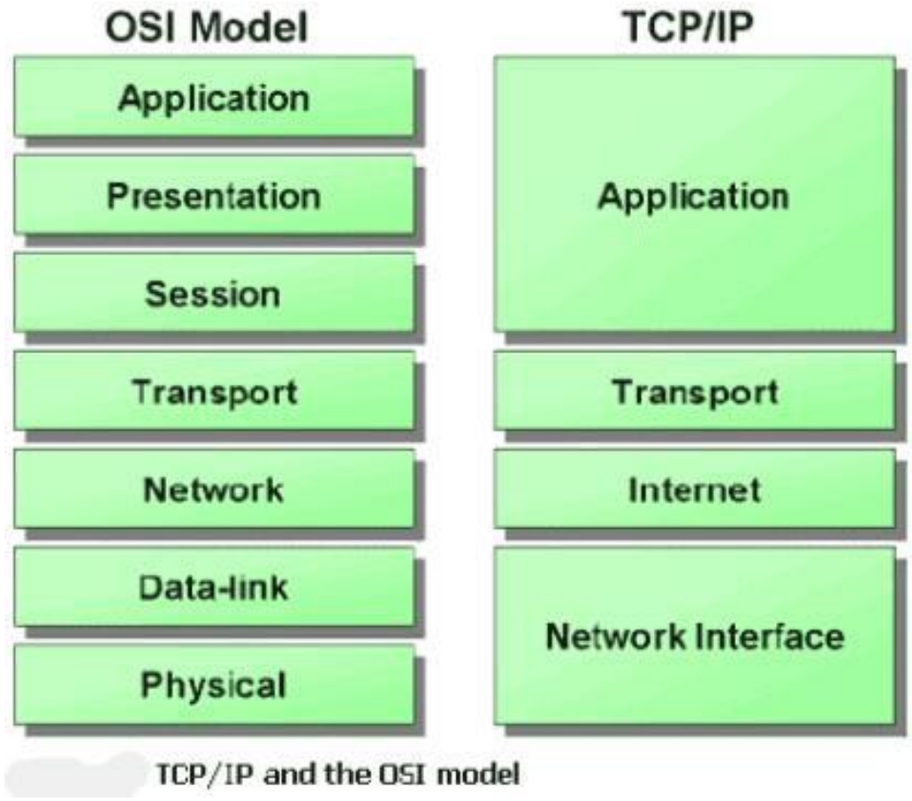
Introduction – Layers of TCP/IP (1)

- TCP/IP is a suite of networking protocols
  - 4-layer 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
Transport	TCP, UDP
Network	IP, ICMP, IGMP
Link	Device driver and interface card

Introduction – Layers of TCP/IP (2)

- ISO/OSI Model (International Organization for Standardization / Open System Interconnection Reference Model)
- TCP/IP Model

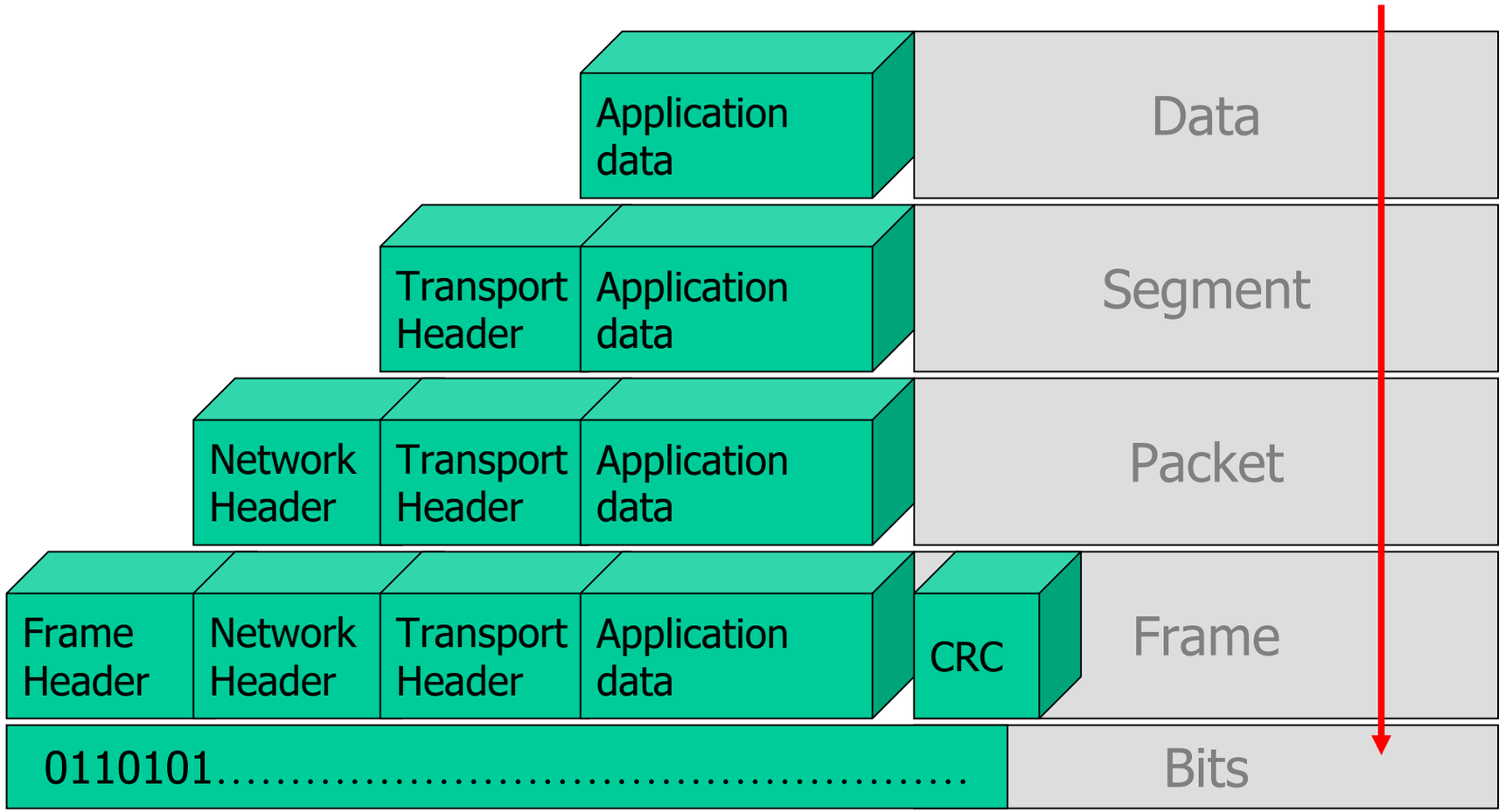


TCP/IP and the OSI model

http://wiki.cas.mcmaster.ca/index.php/TCP/IP_Application_Development

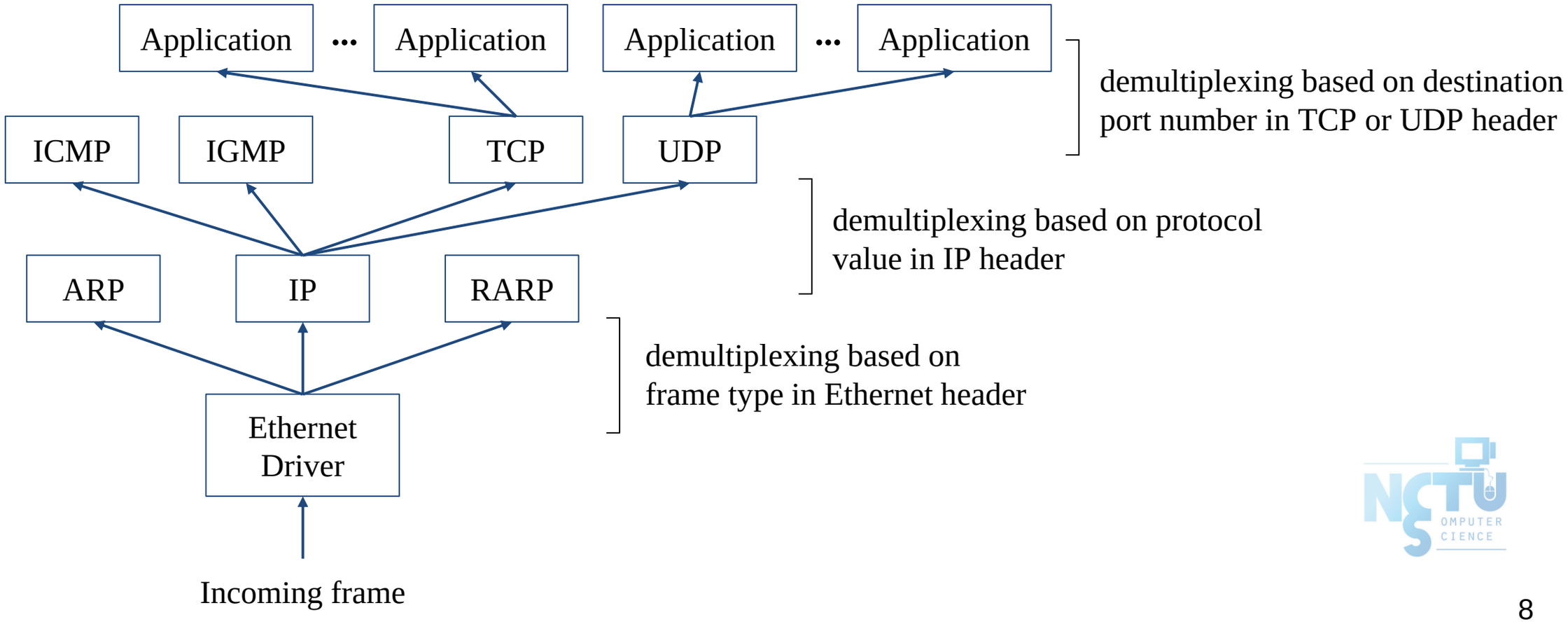
Introduction – Layers of TCP/IP (3)

- Encapsulation (Multiplexing)
  - Gathering data from multiple sockets, enveloping data with header

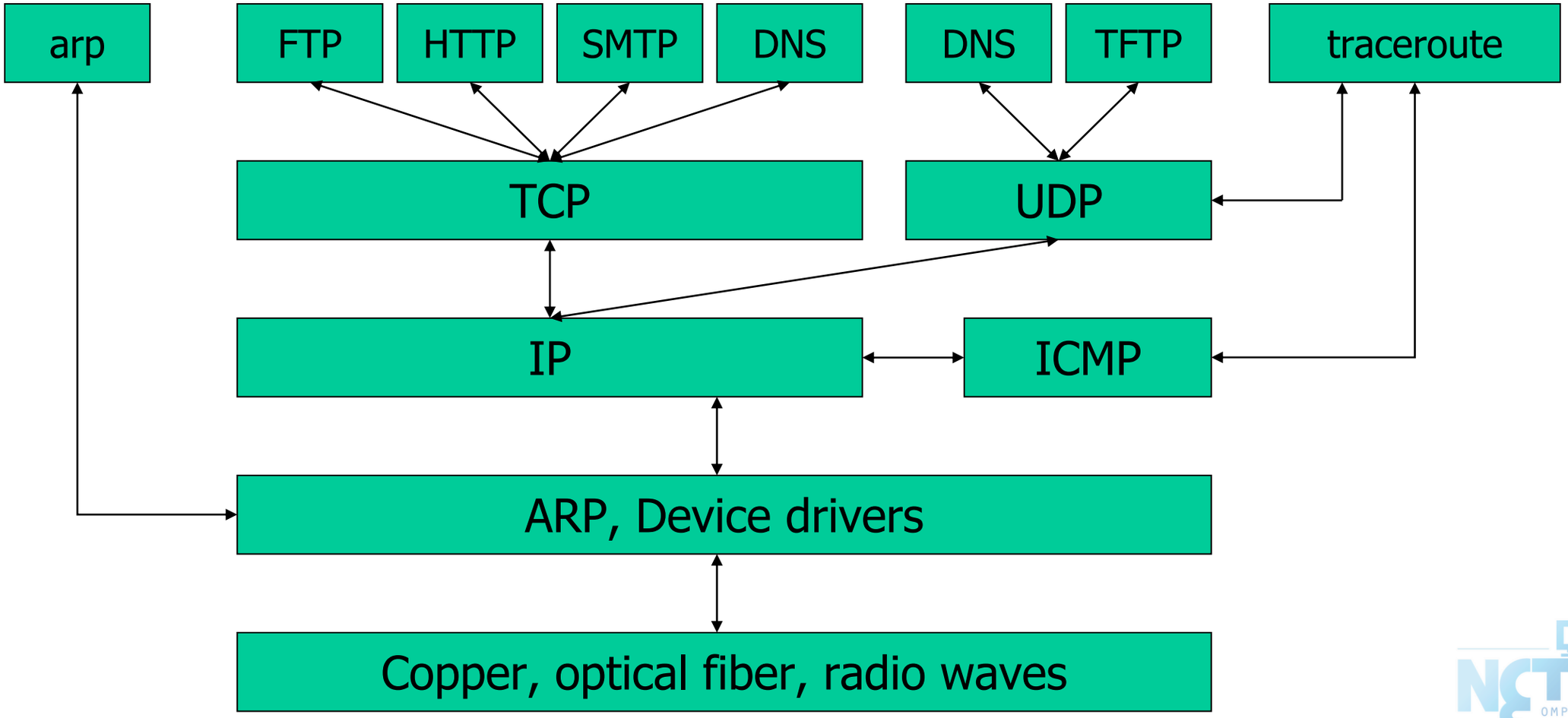


Introduction – Layers of TCP/IP (4)

- Decapsulation (Demultiplexing)
  - Delivering received segments to correct socket

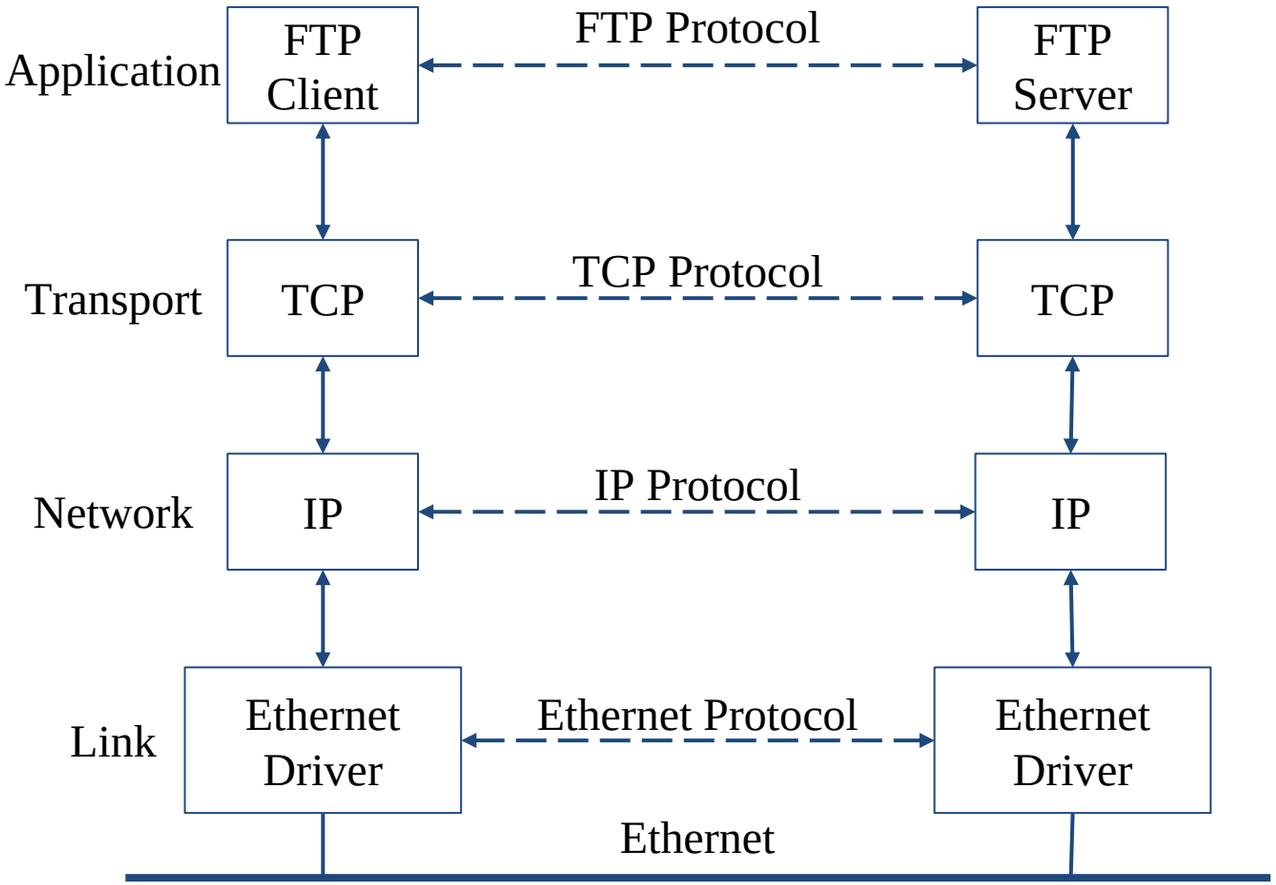


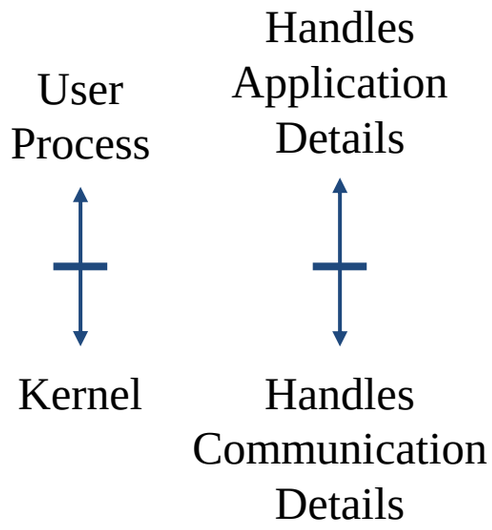
Introduction – TCP/IP Family



Introduction – Addressing

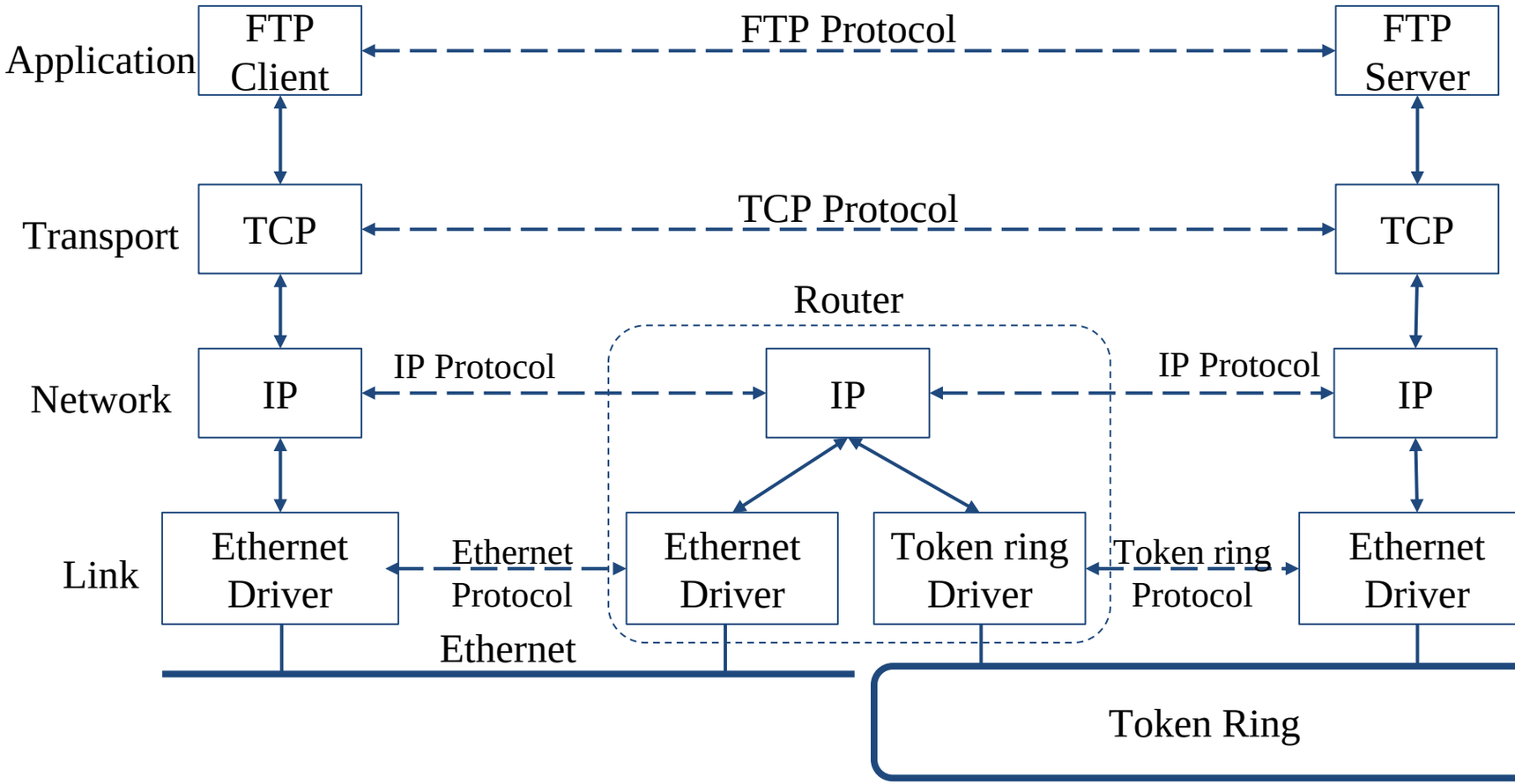
- Addressing
  - Nearby (same network)





Introduction – Addressing

- Addressing
  - Faraway (across network)



Introduction – Addressing

- IP
  - 32-bits, Unique Internet Address of a host
- Port
  - 16-bits, Uniquely identify application
- MAC Address
  - Media Access Control Address

```
$ 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
```

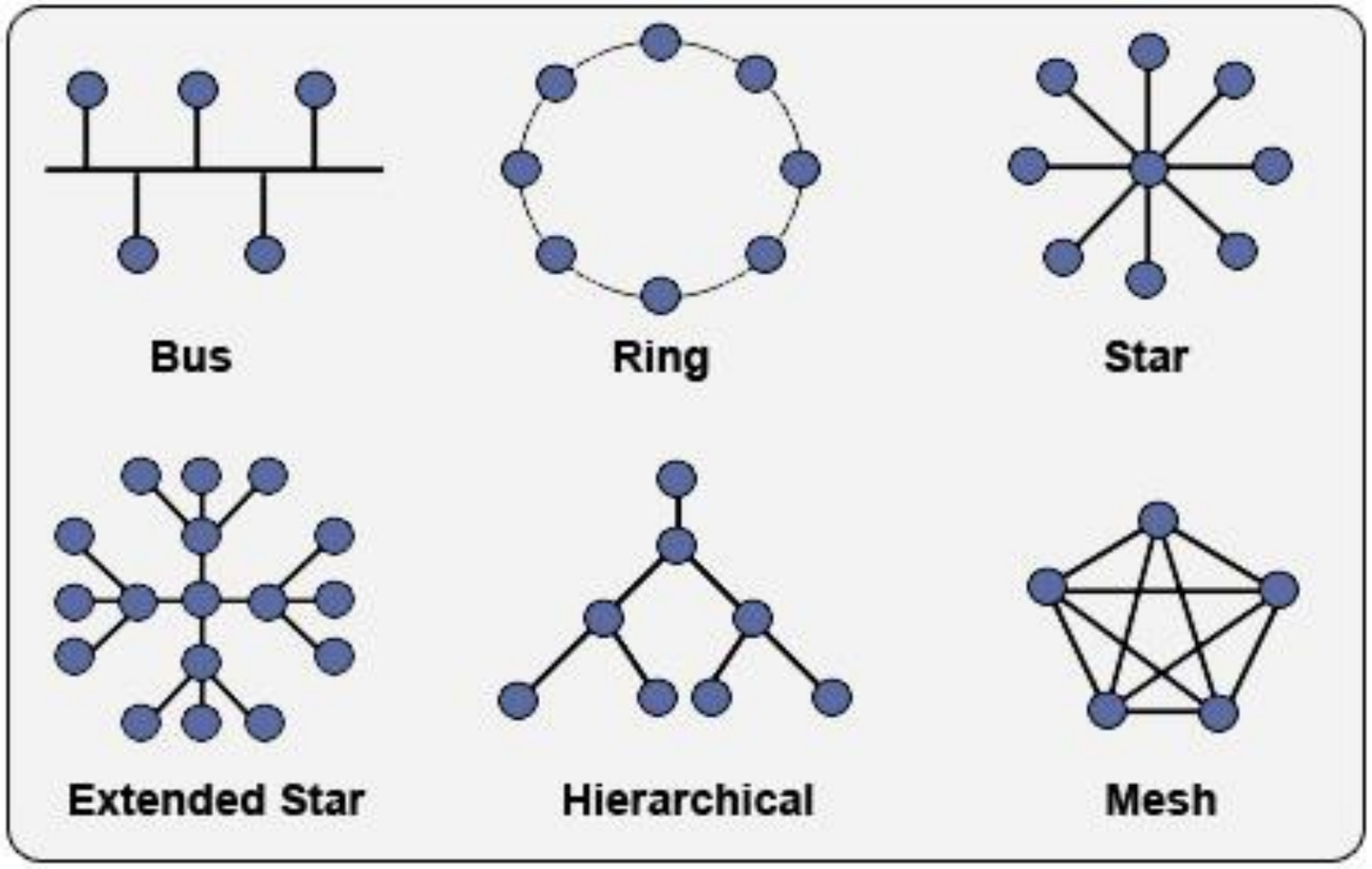
Link Layer

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



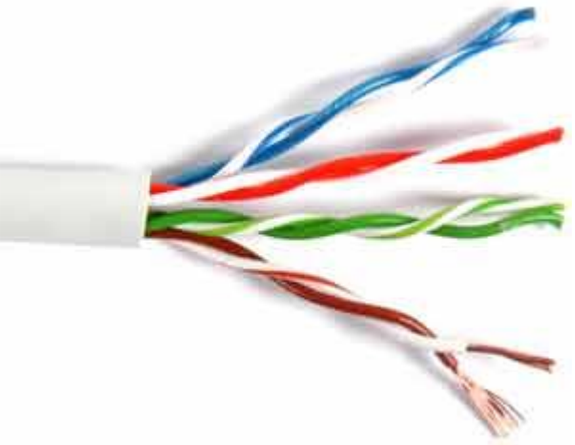
https://www.itprc.com/a-guide-to-network-topology/

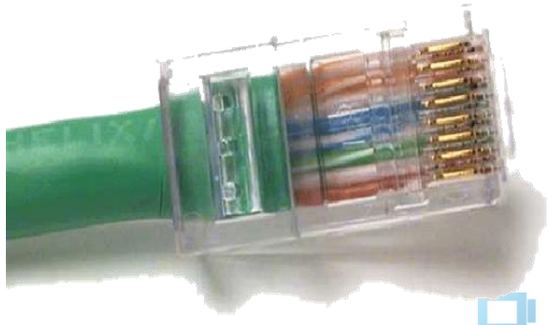
Network Interface and Hardware – Media

- 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

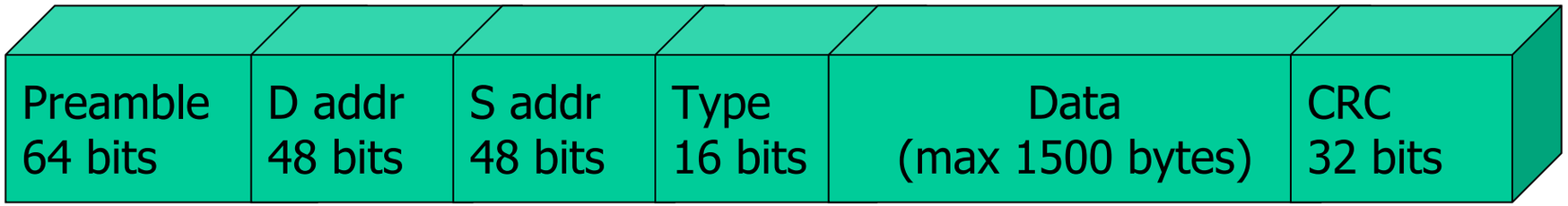
    - Straight-through v.s. Crossover
    - RJ-45 connector
  - Fiber Optic Cable
    - Multimode v.s. single mode
  - Wireless
    - IrDA, Radio (2.4GHz, 5GHz)





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

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
- E.g.,
  - NCTU
    - Class B address: 140.113.0.0
    - Network ID: 140.113
    - Number of hosts: 256*256 = 65536
- IP address category

Class	1st byte	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 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

The Network Layer

– Subnetting and Netmask (1)

- Subnetting
  - Borrow some bits from network ID to extends hosts ID
  - E.g.,
    - Class B address : 140.113.0.0

      = 256 Class C-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
  - E.g.:
    - 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
  - E.g.,
    - 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
- E.g.,

```
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
  - $ pkg install ipcalc
  - /usr/ports/net-mgmt/ipcalc

```
$ ipcalc 140.113.235.100/28

Address:   140.113.235.100      10001100.01110001.11101011.0110 0100
Netmask:   255.255.255.240 = 28 11111111.11111111.11111111.1111 0000
Wildcard:  0.0.0.15             00000000.00000000.00000000.0000 1111
=>
Network:   140.113.235.96/28    10001100.01110001.11101011.0110 0000
HostMin:   140.113.235.97       10001100.01110001.11101011.0110 0001
HostMax:   140.113.235.110      10001100.01110001.11101011.0110 1110
Broadcast: 140.113.235.111      10001100.01110001.11101011.0110 1111
Hosts/Net: 14                    Class B
```

The Network Layer

– Subnetting and Netmask (5)

- Network configuration for various lengths of netmask

Length	Host bits	Hosts/net	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

– IP address crisis

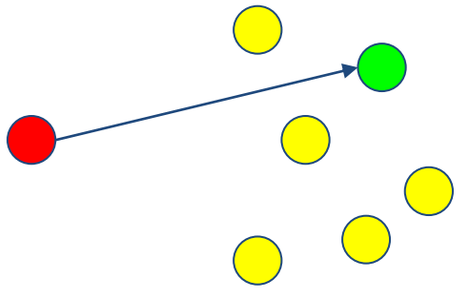
- IP address crisis
  - Run out of class B address
    - The most desirable ones for moderately large organizations
  - IP address were being allocated on a FCFS
    - With no locality of reference
- Solutions
  - Short term
    - Subnetting and CIDR (classless inter-domain routing)
    - NAT (network address translation)
  - Long term
    - IPv6

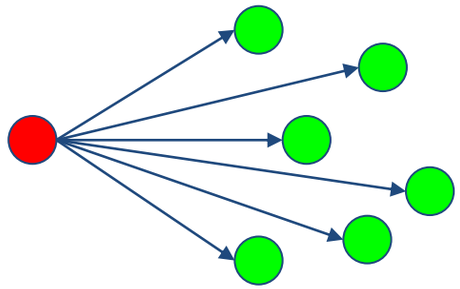
The Network Layer

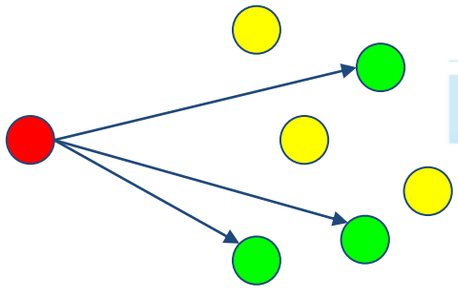
– NAT (1)

- Private Address
  - Packets with private address will not go out to the Internet
  - 3 private address ranges
    - 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







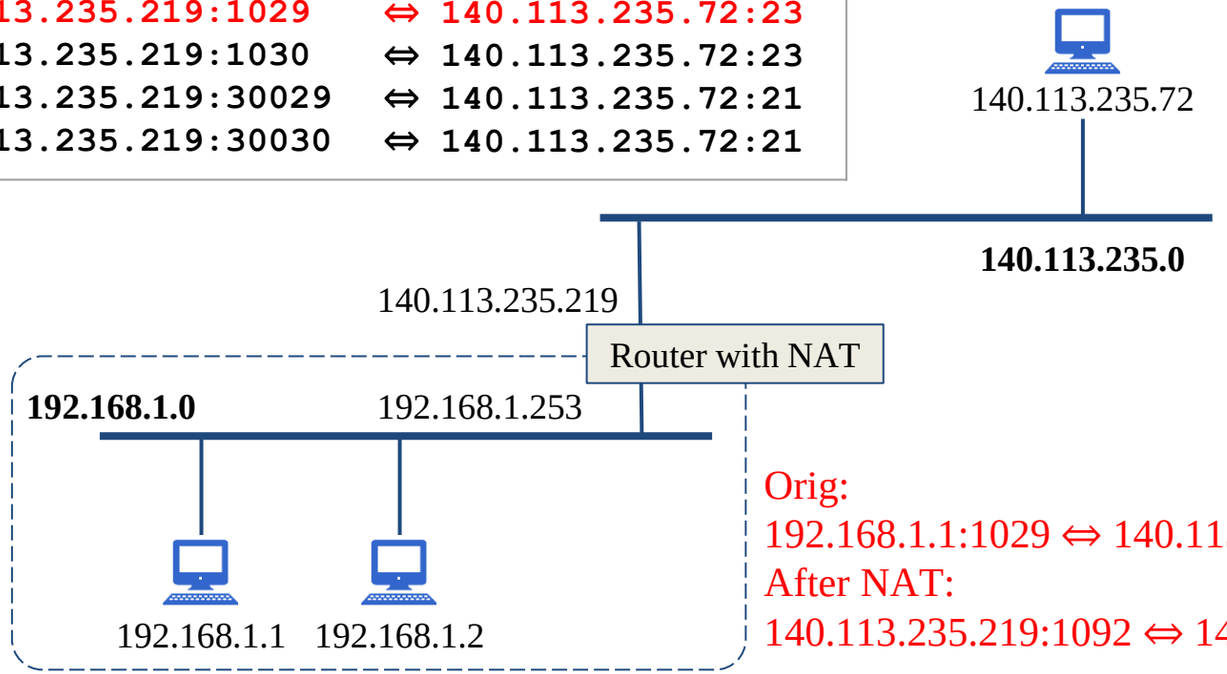
The Network Layer

– 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	140.113.235.219:1029	⇔ 140.113.235.72:23
192.168.1.1:1030	140.113.235.219:1030	⇔ 140.113.235.72:23
192.168.1.2:1029	140.113.235.219:30029	⇔ 140.113.235.72:21
192.168.1.2:1030	140.113.235.219:30030	⇔ 140.113.235.72:21



Orig:
192.168.1.1:1029 ⇔ 140.113.235.72:23
After NAT:
140.113.235.219:1092 ⇔ 140.113.235.72:23

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

```
$ 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
```

The Network Layer

– Routing (2)

- Static route
  - Statically configured by "route" command
  - E.g.:
    - $ 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"

```
$ 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

$ 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    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
```

IANA Service Name and Transport Protocol Port Number Registry

https://www.iana.org/assignments/service-names-port-numbers

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

```
$ 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
  - DNS

The Application Layer – inted

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

/etc/inetd.conf

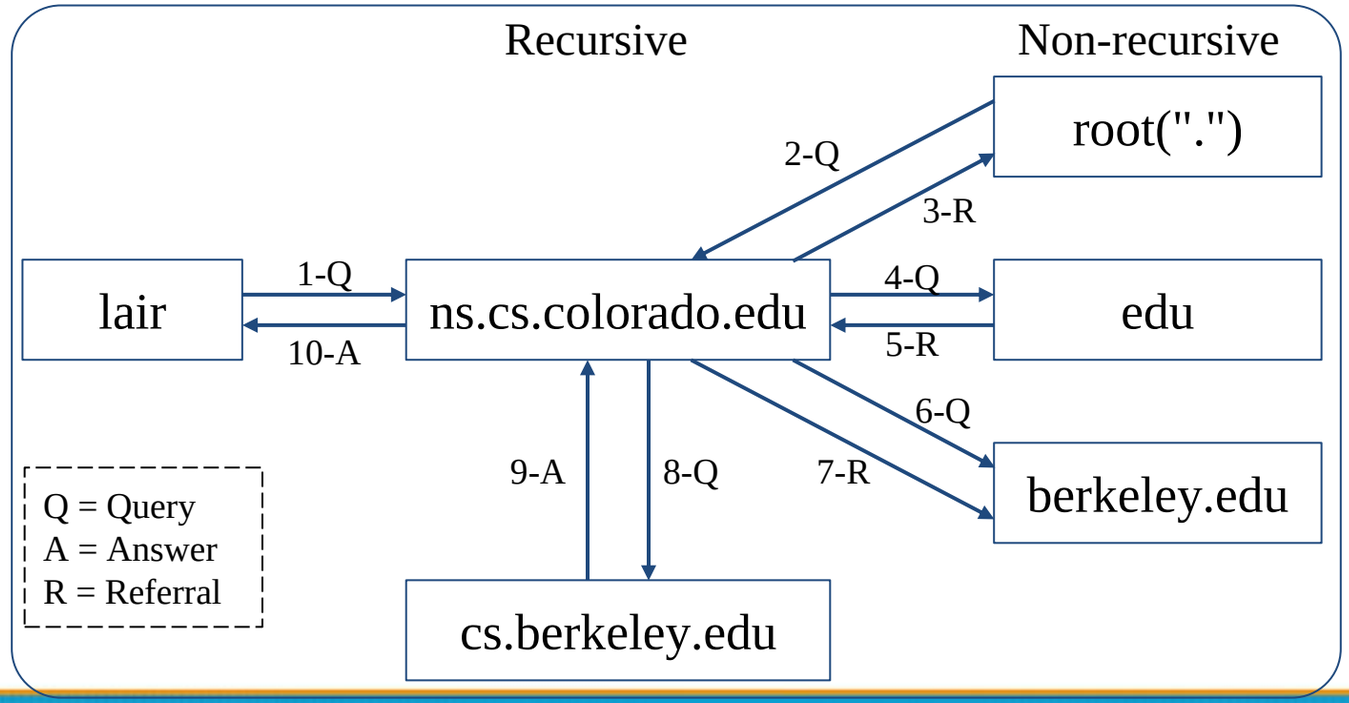
```
daytime   stream   tcp   nowait   root   internal
ftp       stream   tcp   nowait   root   /usr/libexec/ftpd           ftpd -l
ssh       stream   tcp   nowait   root   /usr/sbin/sshd              sshd -i -4
telnet    stream   tcp   nowait   root   /usr/libexec/telnetd        telnetd
pop3      stream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

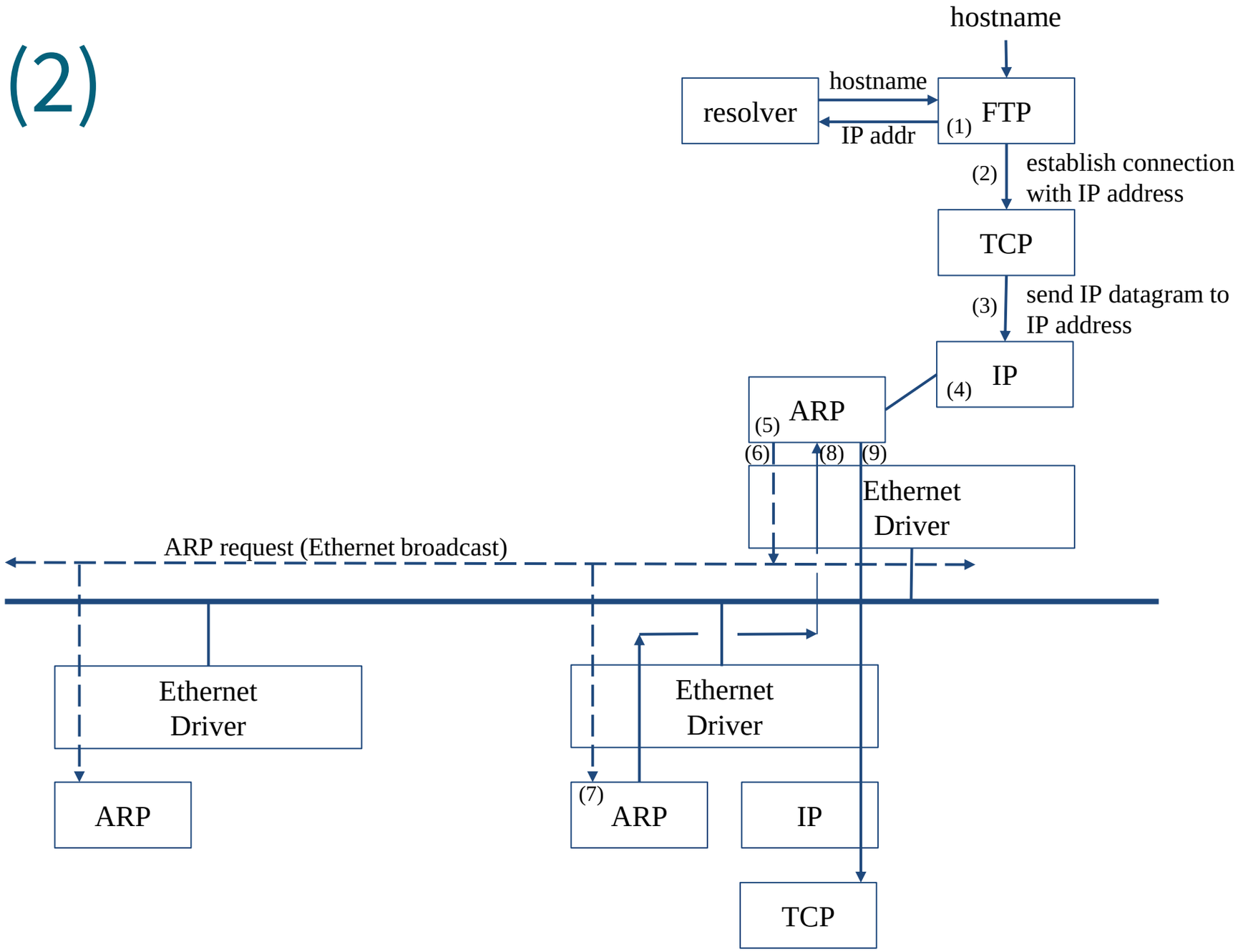
- Domain Name System
  - Record IP-hostname mapping
  - DNS query
    - "what is the IP of vangogh.cs.berkeley.edu" from lair.cs.colorado.edu
  - Hierarchical architecture



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)


hostname
resolver
hostname
IP addr
(1)
FTP
(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
  - E.g.:
    - $ arp -a
    - $ arp -da

```
$ 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

```
$ less /etc/hosts
127.0.0.1          localhost
140.113.209.72     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)

```
$ 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
```

```
$ /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
  - E.g.,
    - $ ifconfig fxp0 inet 140.113.235.4 netmask 255.255.255.0
    - $ ifconfig fxp0 up
    - $ ifconfig fxp0 down
  - Specify default route manually
    - E.g.,
      - $ route add default 140.113.235.254

Setup network connection – configuring DNS

- FreeBSD, Linux

/etc/resolv.conf

```
search cc.cs.nctu.edu.tw cs.nctu.edu.tw
nameserver 10.1.1.1
nameserver 140.113.235.1
```

- Host lookup order

/etc/nsswitch.conf

```
group: compat
group_compat: ldap nis
hosts: files dns
netgroup: ldap
networks: files
passwd: compat
passwd_compat: ldap nis
shells: files
services: compat
services_compat: nis
protocols: files
rpc: files
automount: ldap files
```

Utilities for network connection

- ping
  - Send ICMP ECHO_REQUEST to a host

```
$ 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

```
$ 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

- 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
  - NAT
  - DNS
  - Mail
  - …