Network/Internet Layer Protocols

Peerapon S.

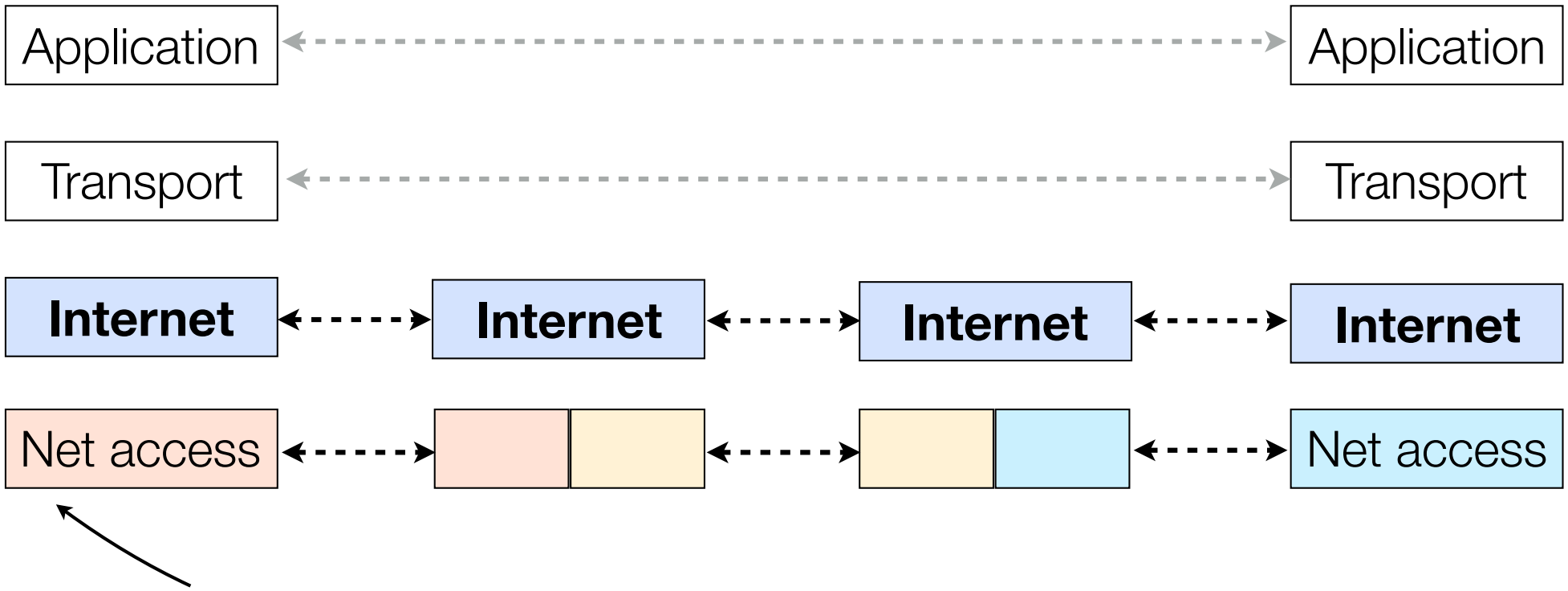
CPE 314: Computer Networks (2/61)

Topics

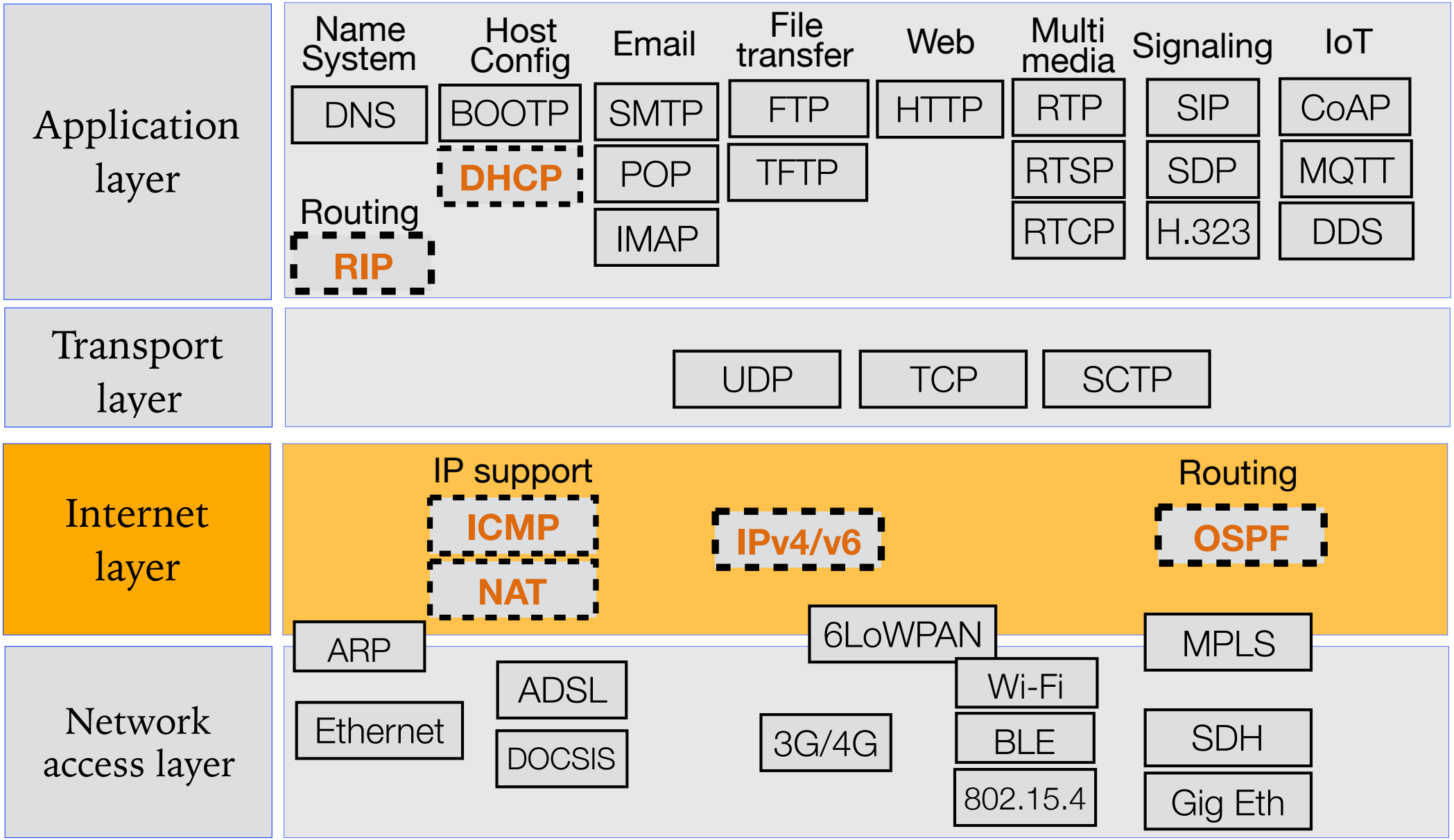
- What does the Internet/Network layer do ?
- Internet Protocol (IPv4)
  - Logical addressing
  - Packet forwarding
- IP address assignment with DHCP
- Network troubleshooting with ICMP
- Network address translation mechanism
- Network congestion and TCP congestion control

Internet/Network Layer Service

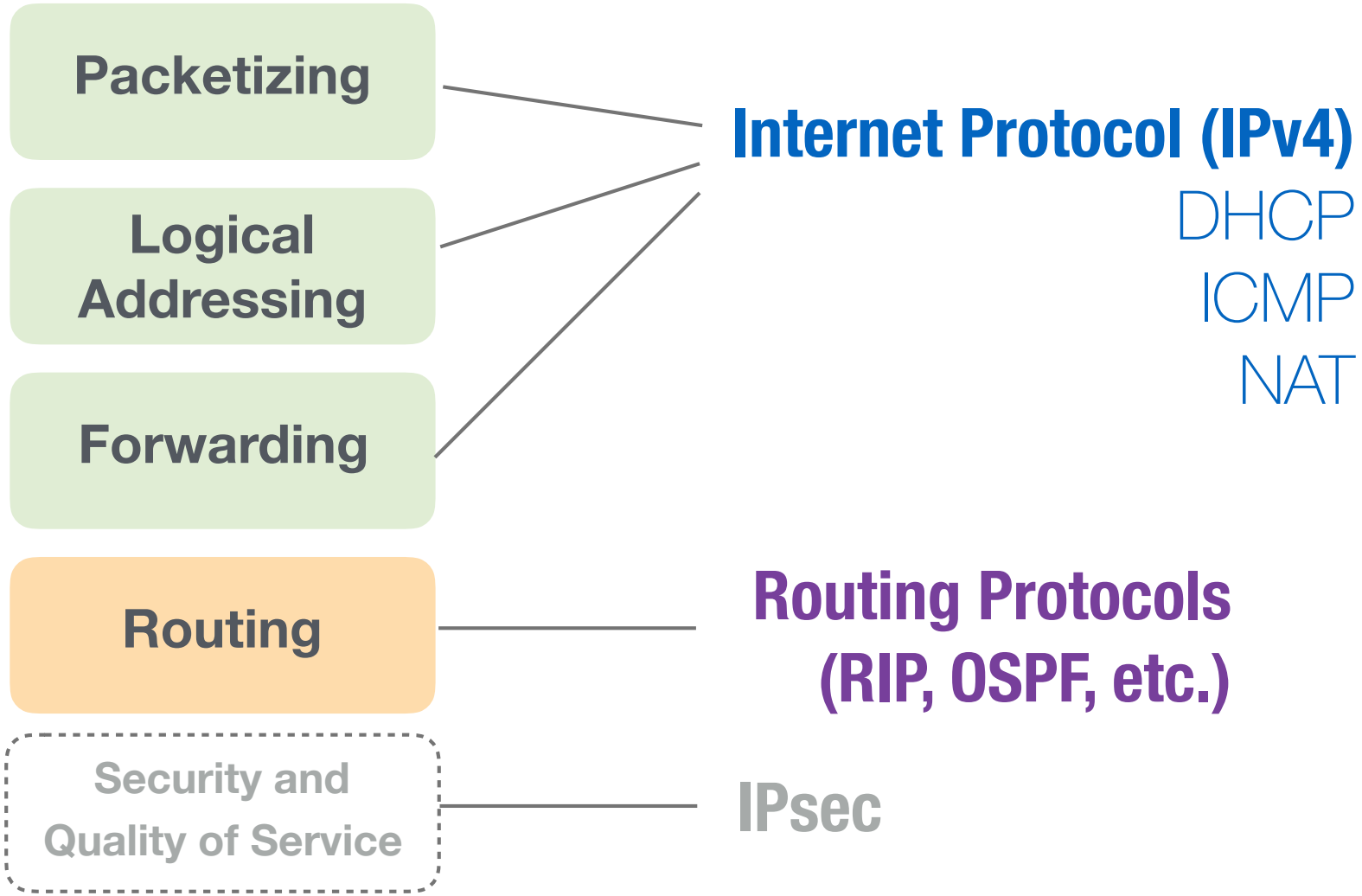
- *Host-to-host packet delivery service (over an internetwork)*

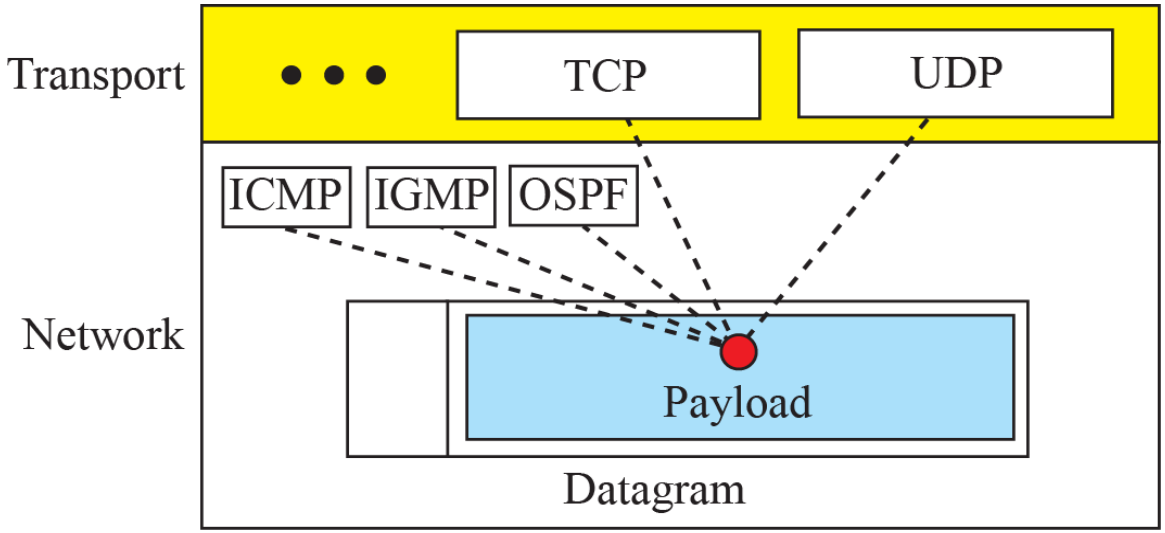


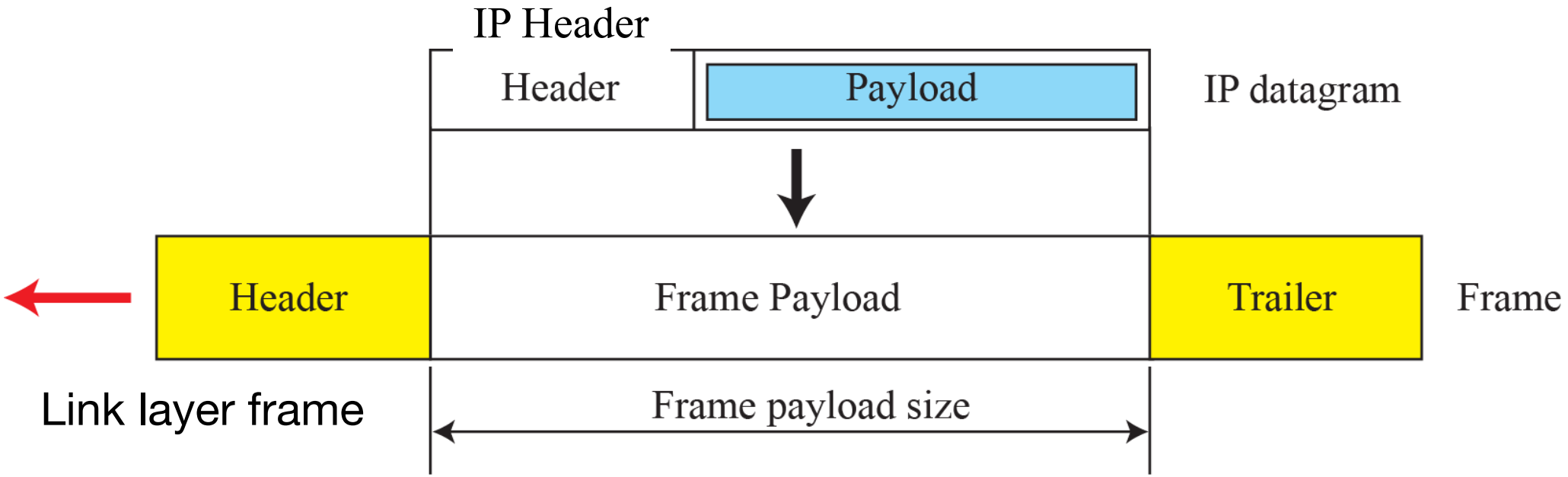
Protocols in TCP/IP Suite



Network Layer Functions

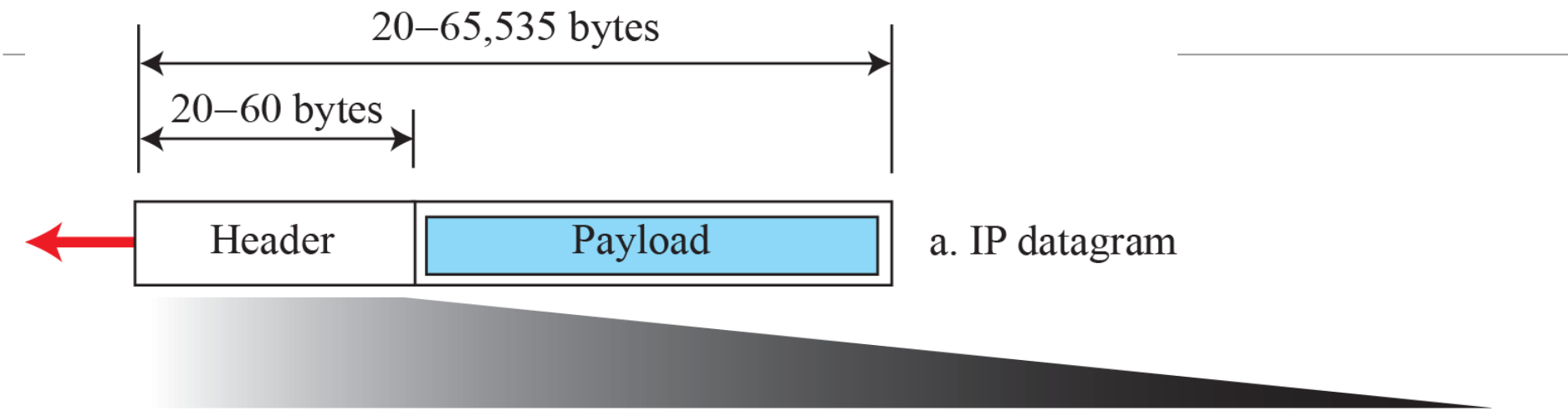


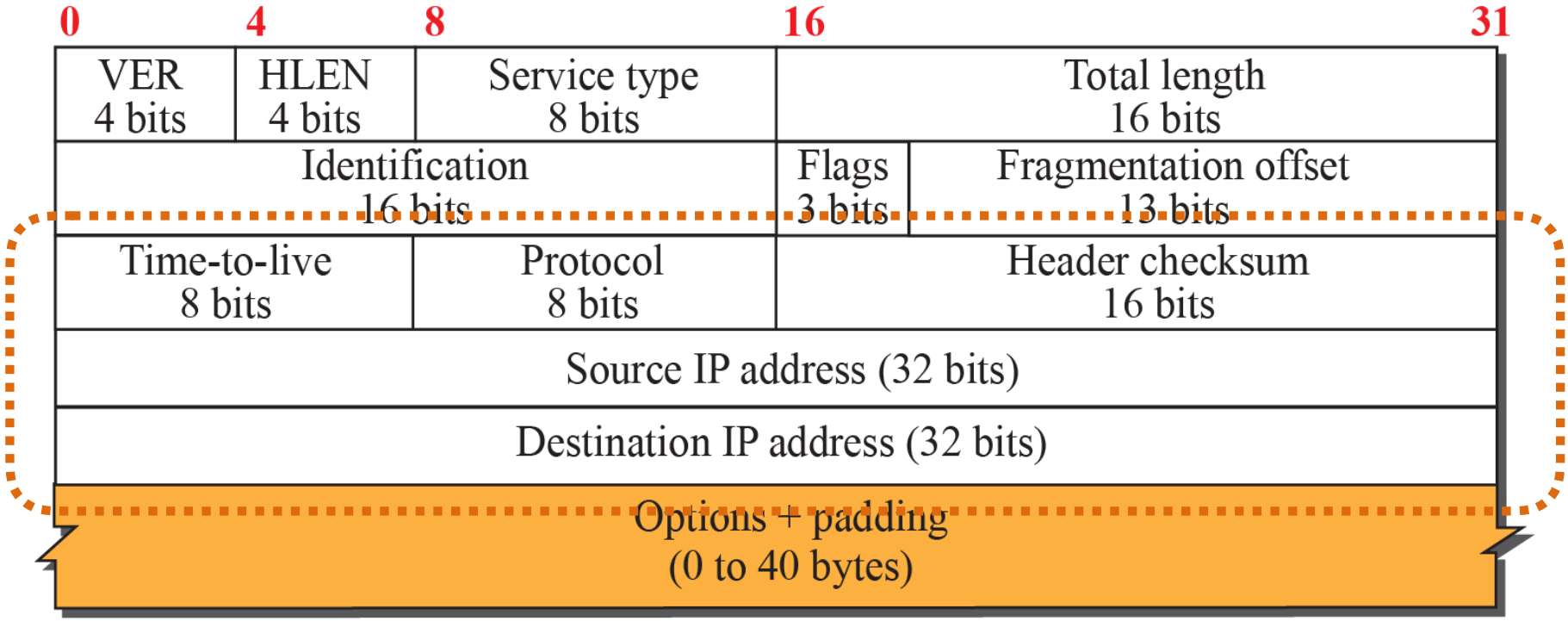




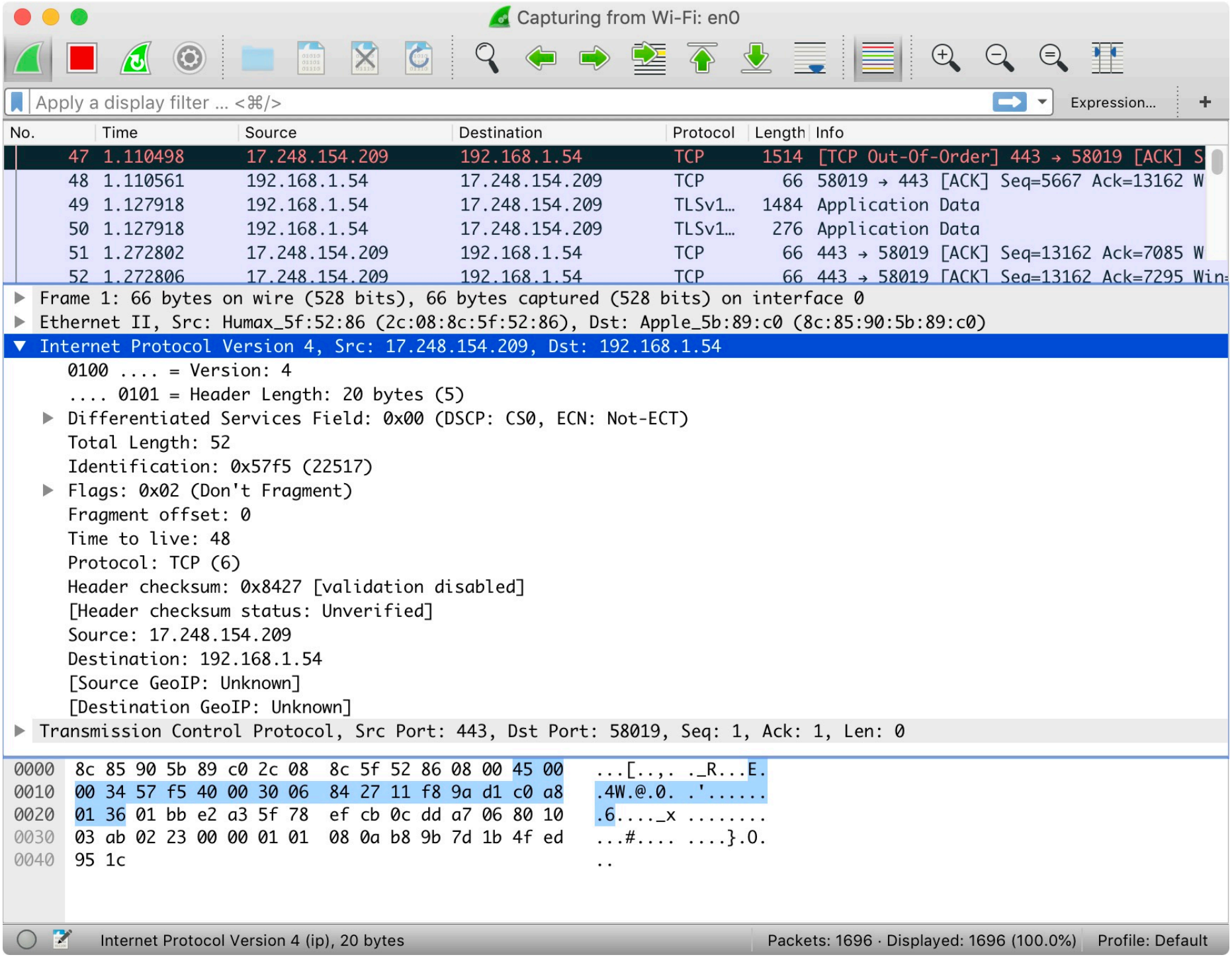
MTU: Maximum size of frame payload

IP Datagram

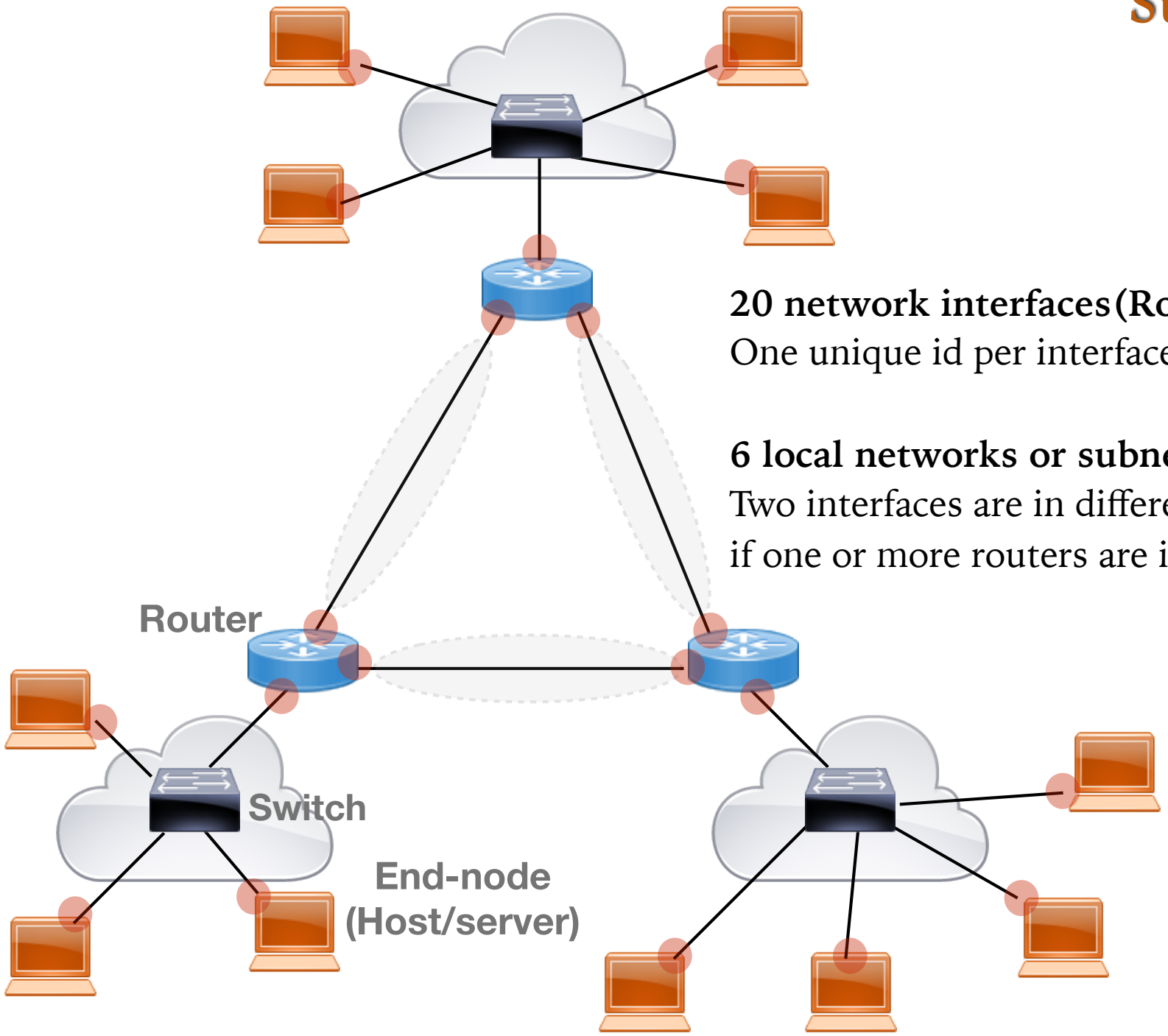




b. Header format


Capturing from Wi-Fi: en0
Apply a display filter ... <⌘/>
Expression...
No. Time Source Destination Protocol Length Info
47 1.110498 17.248.154.209 192.168.1.54 TCP 1514 [TCP Out-Of-Order] 443 → 58019 [ACK] S
48 1.110561 192.168.1.54 17.248.154.209 TCP 66 58019 → 443 [ACK] Seq=5667 Ack=13162 W
49 1.127918 192.168.1.54 17.248.154.209 TLSv1… 1484 Application Data
50 1.127918 192.168.1.54 17.248.154.209 TLSv1… 276 Application Data
51 1.272802 17.248.154.209 192.168.1.54 TCP 66 443 → 58019 [ACK] Seq=13162 Ack=7085 W
52 1.272806 17.248.154.209 192.168.1.54 TCP 66 443 → 58019 [ACK] Seq=13162 Ack=7295 Win
Frame 1: 66 bytes on wire (528 bits), 66 bytes captured (528 bits) on interface 0
Ethernet II, Src: Humax_5f:52:86 (2c:08:8c:5f:52:86), Dst: Apple_5b:89:c0 (8c:85:90:5b:89:c0)
Internet Protocol Version 4, Src: 17.248.154.209, Dst: 192.168.1.54
0100 .... = Version: 4
.... 0101 = Header Length: 20 bytes (5)
Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
Total Length: 52
Identification: 0x57f5 (22517)
Flags: 0x02 (Don't Fragment)
Fragment offset: 0
Time to live: 48
Protocol: TCP (6)
Header checksum: 0x8427 [validation disabled]
[Header checksum status: Unverified]
Source: 17.248.154.209
Destination: 192.168.1.54
[Source GeoIP: Unknown]
[Destination GeoIP: Unknown]
Transmission Control Protocol, Src Port: 443, Dst Port: 58019, Seq: 1, Ack: 1, Len: 0
0000 8c 85 90 5b 89 c0 2c 08 8c 5f 52 86 08 00 45 00 ...[..,. ._R...E.
0010 00 34 57 f5 40 00 30 06 84 27 11 f8 9a d1 c0 a8 .4W.@.0. .'......
0020 01 36 01 bb e2 a3 5f 78 ef cb 0c dd a7 06 80 10 .6...._x ....
0030 03 ab 02 23 00 00 01 01 08 0a b8 9b 7d 1b 4f ed ...#.... ....}.O.
0040 95 1c ..
Internet Protocol Version 4 (ip), 20 bytes
Packets: 1696 · Displayed: 1696 (100.0%)
Profile: Default

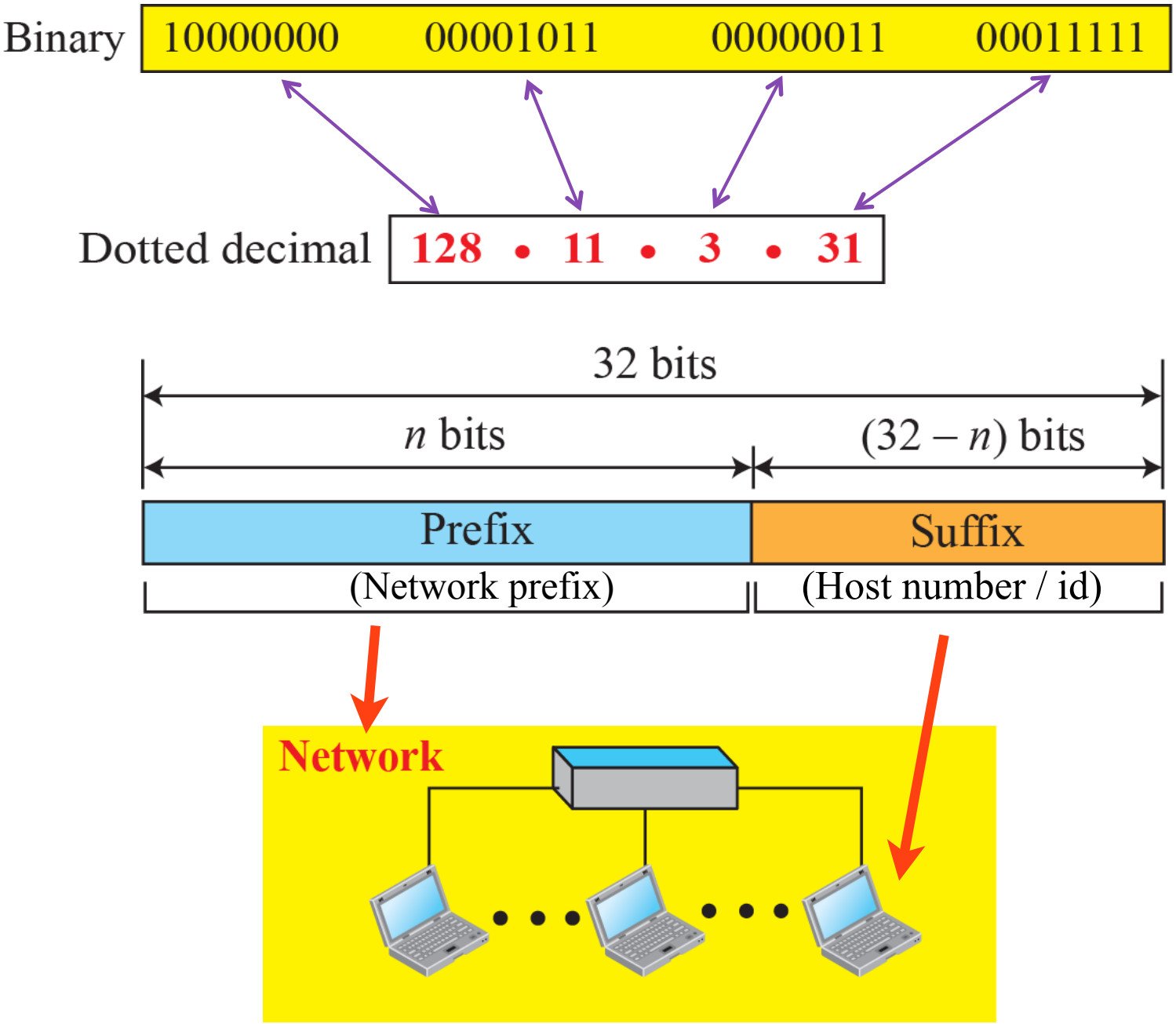
Local Network or Subnet(work)



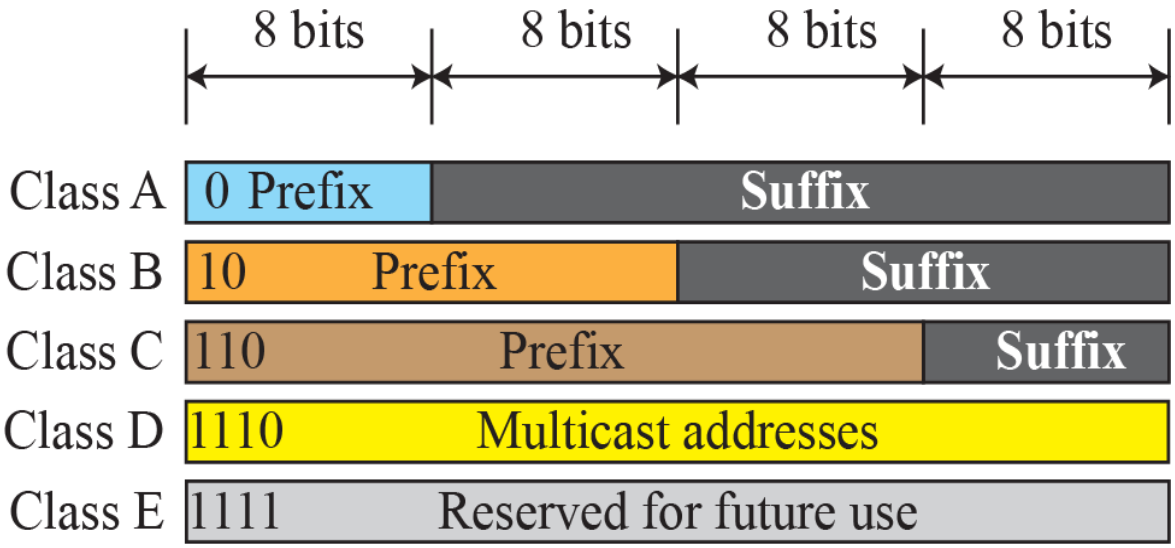
20 network interfaces (Routers + End-nodes)
One unique id per interface

6 local networks or subnets
Two interfaces are in different subnetworks if one or more routers are in between.

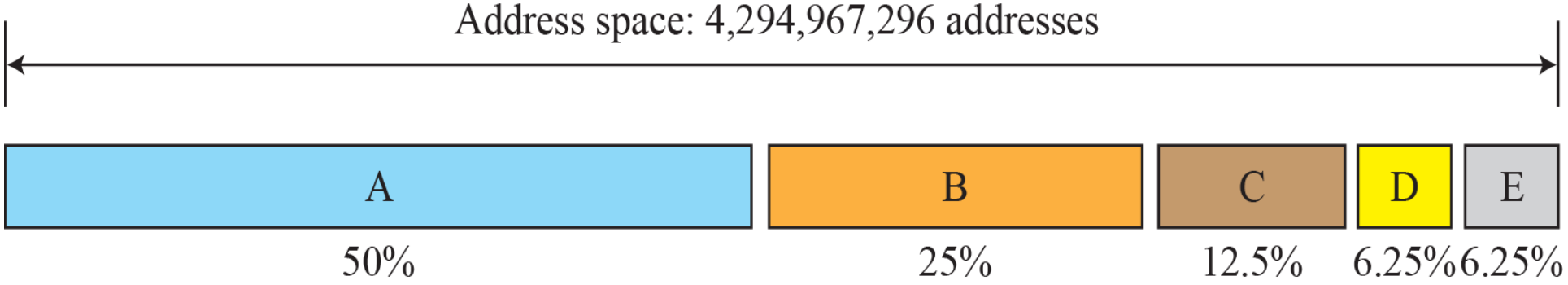
IPv4 Addressing



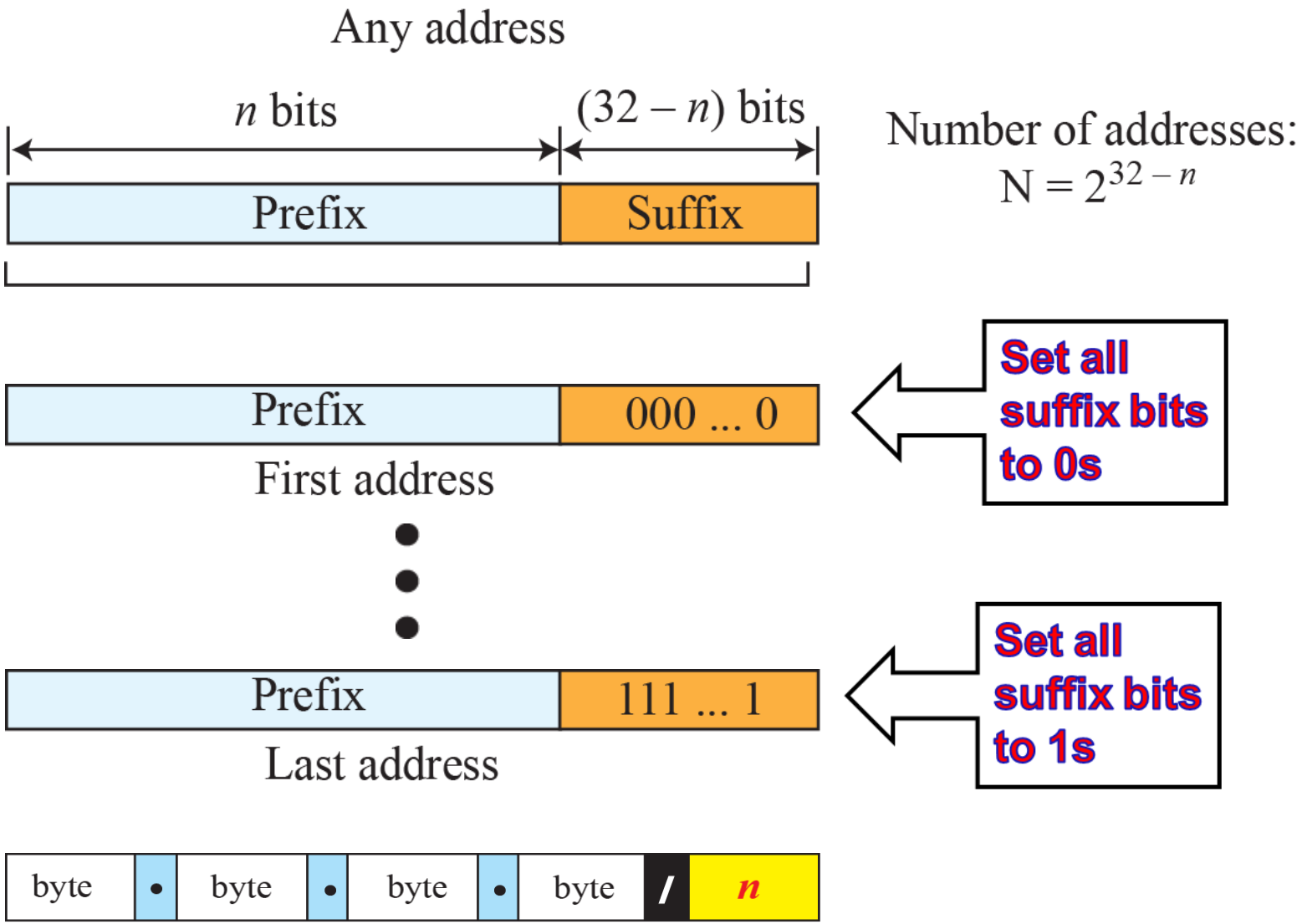
Classful Addressing (Obsolete)



Class	Prefixes	First byte
A	$n = 8$ bits	0 to 127
B	$n = 16$ bits	128 to 191
C	$n = 24$ bits	192 to 223
D	Not applicable	224 to 239
E	Not applicable	240 to 255



Classless Addressing



Classless InterDomain Routing (CIDR) or Slash notation

Dotted Decimal Notation

Network prefix | Host number

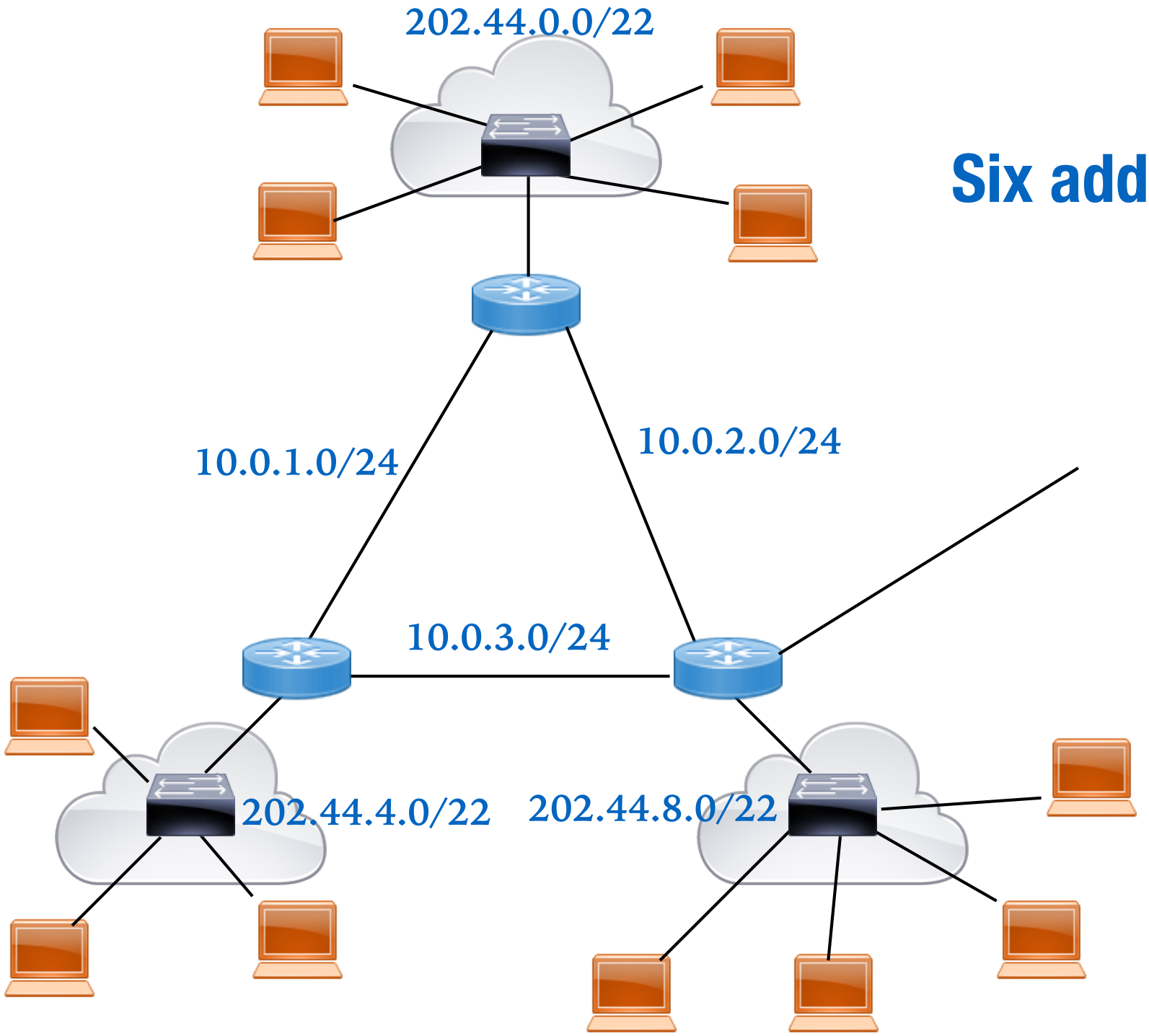
`10100111 11000111 10101010 010` | `10010`

Dotted decimal notation:

```
167.199.170.82 / 27 or
    167.199.170.82
with netmask 255.255.255.224
```

```
First: 167.199.170.64/27   10100111 11000111 10101010 01000000
                           (Network address)

Last:  167.199.170.95/27   10100111 11000111 10101010 01011111
                           (Broadcast address)
```



Six address blocks

Self Test

- What is the maximum number of network interfaces that can be configured in an address block 202.44.12.0 / 26 ?

  A. 30

  B. 32

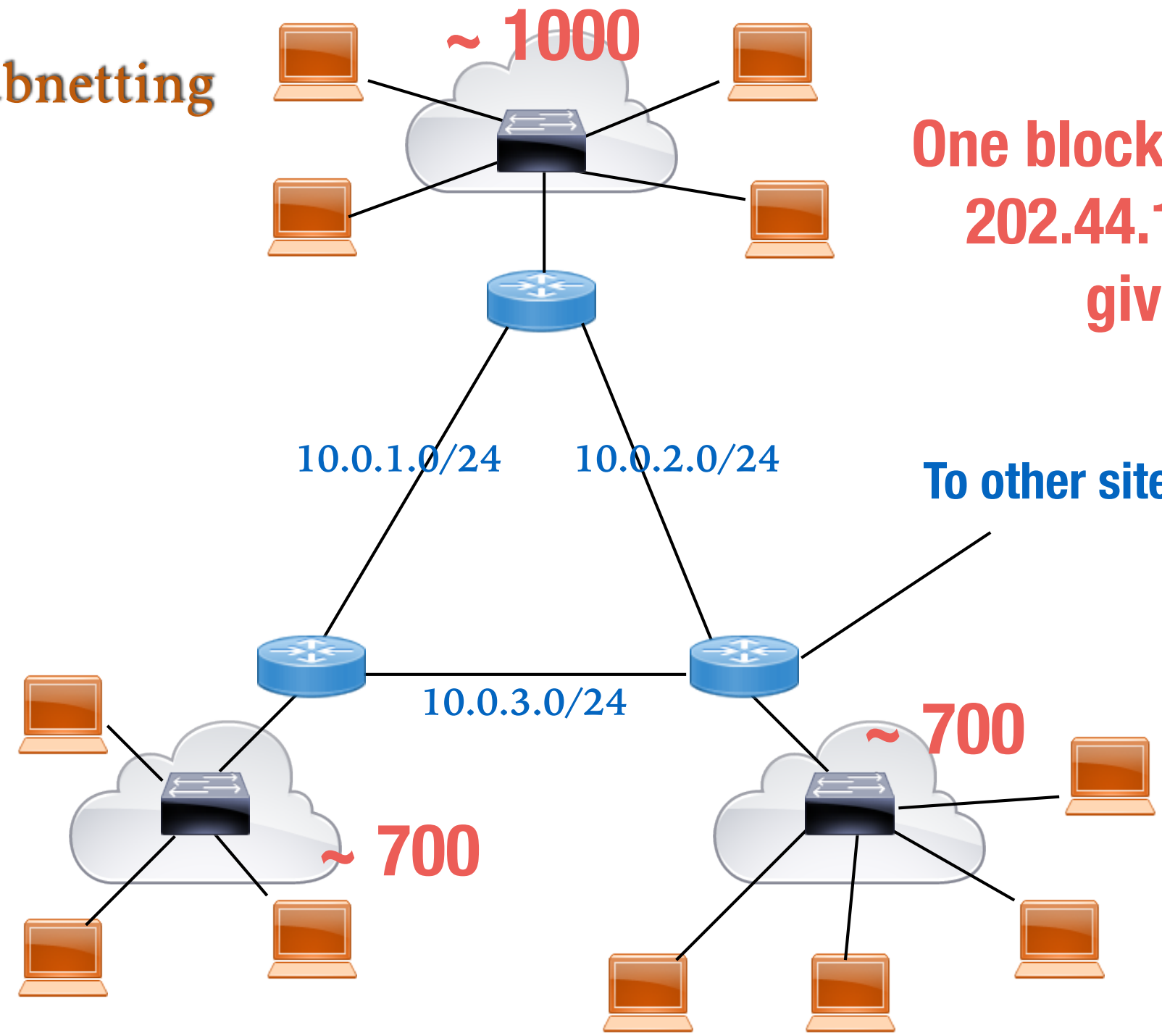
  C. 62

  D. 64

Some Special IP Address Blocks

- 127.0.0.0/8 are **loopback addresses** (only 127.0.0.1 in MacOS)
  - (Virtual) interface lo0 with IP address 127.0.0.1.
  - For debugging network program locally
- **Private network addresses**
  - 10.0.0.0/8 ≈ 16M addresses
  - 172.16.0.0/12
  - 192.168.0.0/16

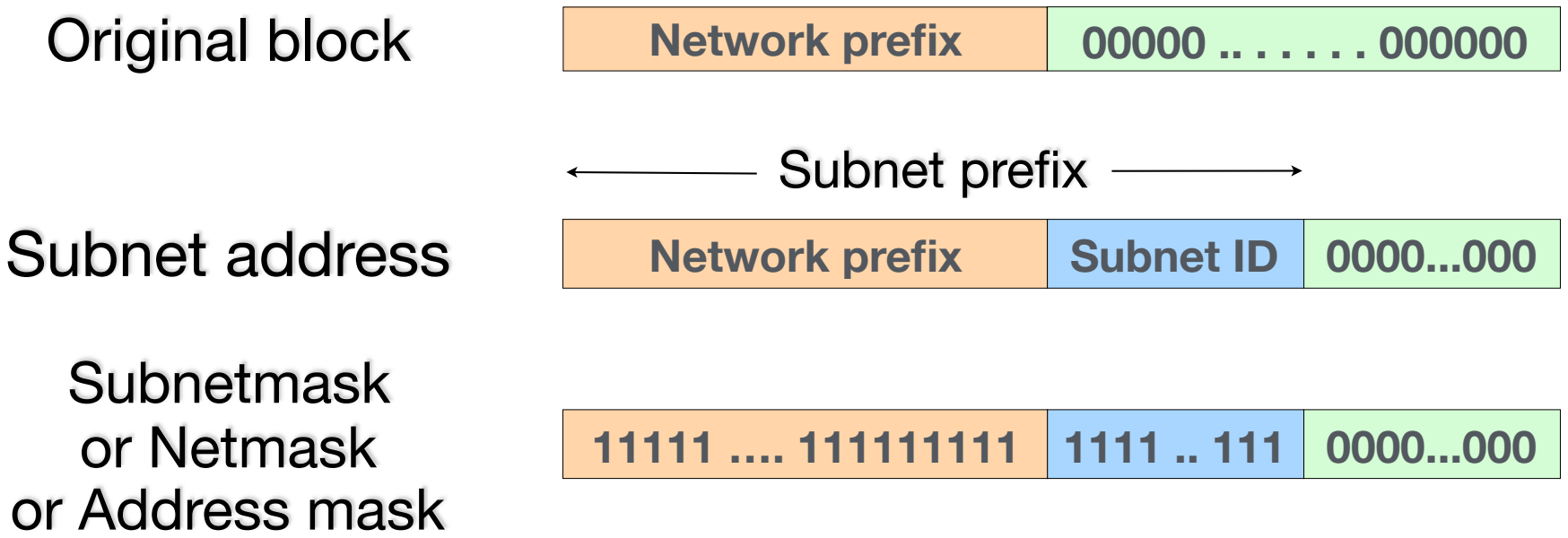
Subnetting



One block or prefix
202.44.12.0/20
given

- Address block can be divided and allocated to smaller subnetworks.

```
First: 202.44.0.0/20     11001010 00101100 00000000 00000000
Last:  202.44.15.255/20  11001010 00101100 00001111 11111111
```



ควรเป็น 2^11 -> 2048
ไว้กรณีขนาดมันขยายขึ้น

ขนาดของblockต้องเป็น2^n -> address
ที่ใกล้ที่สุดคือ 2^10 -> 1024

Faculty	Addresses needed	Addresses Allocated	Subnet blocks
Engineering	1000	1024	11001010 00101100 0000
Industrial Edu.	700	1024	11001010 00101100 0000
IT	700	1024	11001010 00101100 0000

```
Original block: 202.44.0.0/20
     11001010 00101100 00000000 00000000
```

Addresses Allocated	Bits in host address	เลขsubblock ที่ขึ้นมา
1024	10	11001010 00101100 0000 0000 00000000
1024	10	11001010 00101100 0000 0100 00000000
1024	10	11001010 00101100 0000 1000 00000000

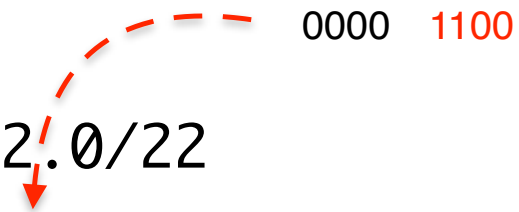
Original block: 202.44.0.0/20

11001010 00101100 00000000 00000000

Faculty		Address block
Engineering	.... 0000 00000000	202.44.0.0/22
Industrial Edu.	.... 0100 00000000	202.44.4.0/22
IT	.... 1000 00000000	202.44.8.0/22

Original block: 202.44.0.0/20

11001010 00101100 00000000 00000000



Remaining block: 202.44.12.0/22

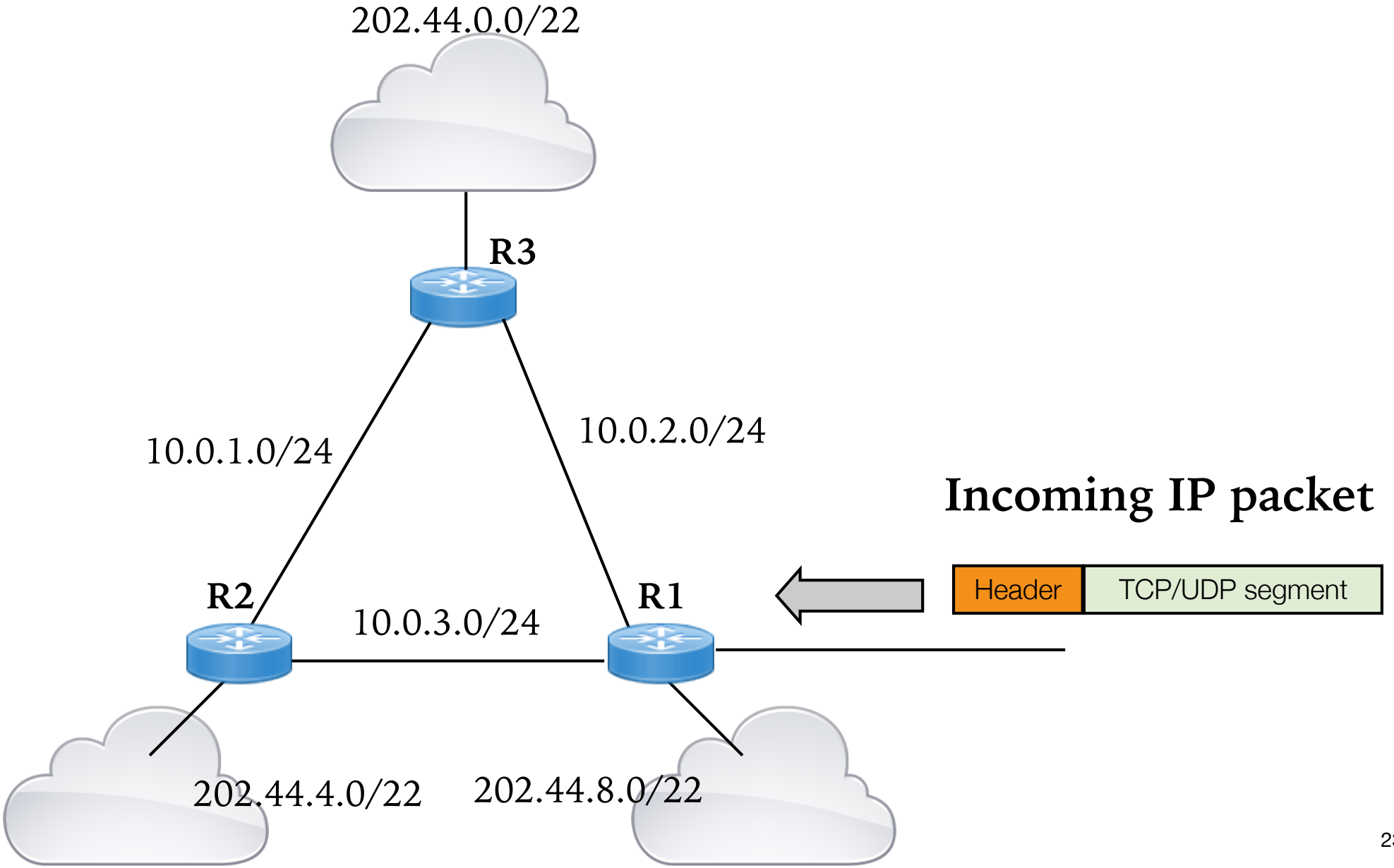
11001010 00101100 00001111100 00000000

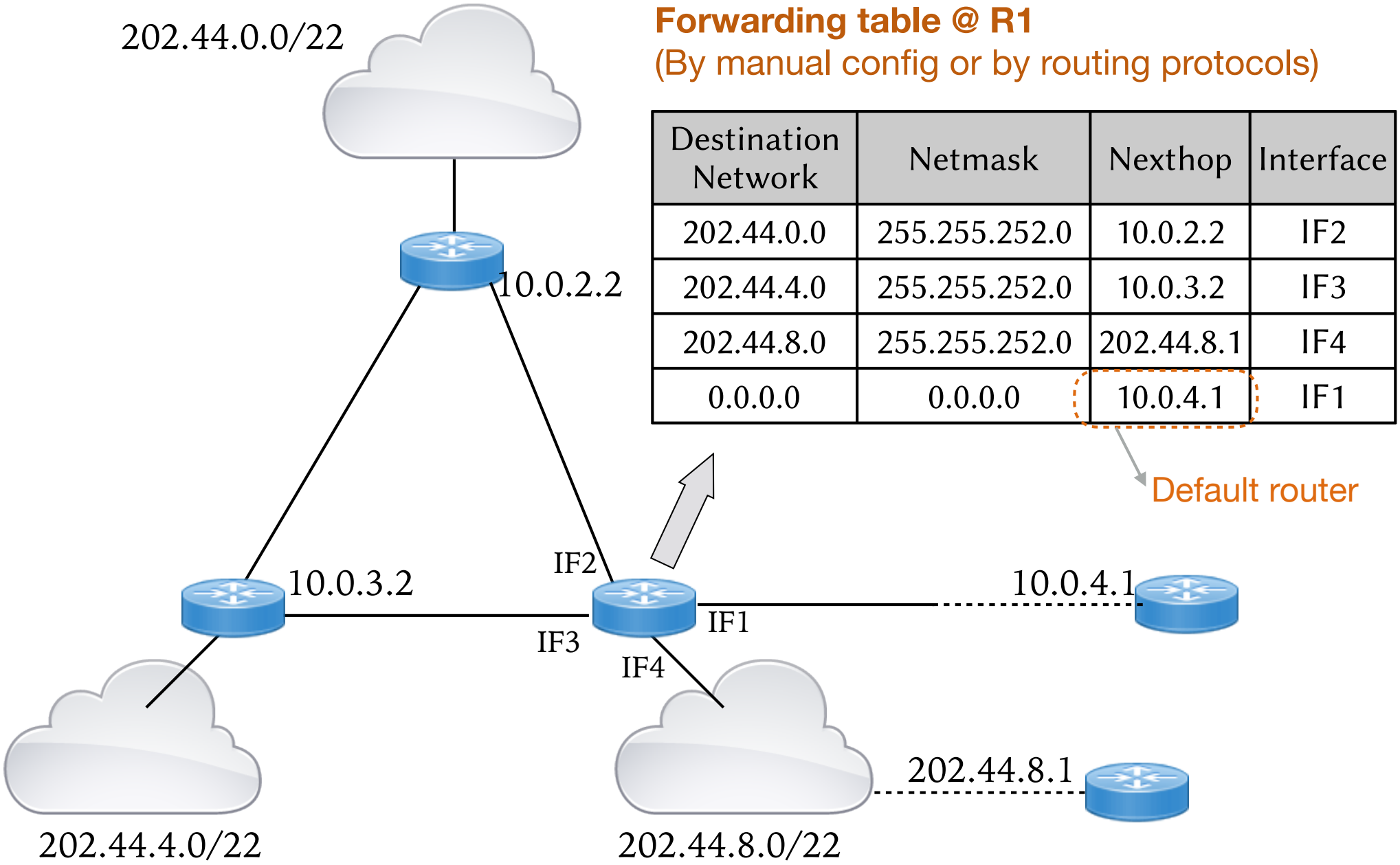
can be further split if necessary

Why Subnetting?

- Performance
  - Broadcast traffic limit
  - Load separation
- Administration
  - Access control list
  - Policy enforcement
- Security
  - Servers better protected if hosts are compromised.

IP Packet Forwarding





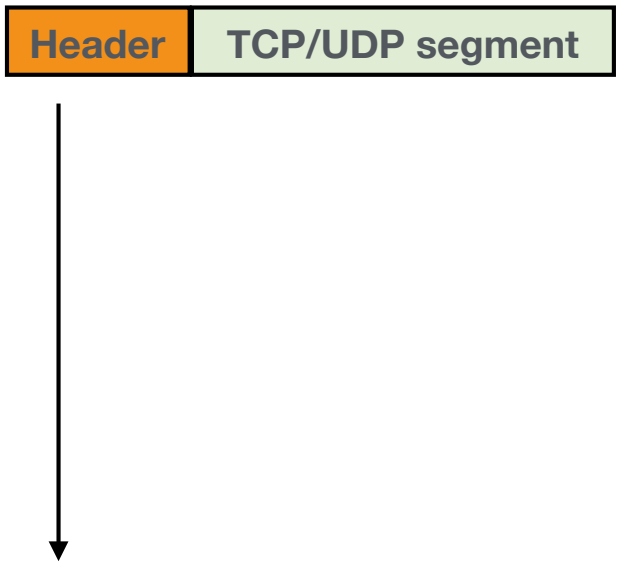
Forwarding table @ R1

(By manual config or by routing protocols)

Destination Network	Netmask	Nexthop	Interface
202.44.0.0	255.255.252.0	10.0.2.2	IF2
202.44.4.0	255.255.252.0	10.0.3.2	IF3
202.44.8.0	255.255.252.0	202.44.8.1	IF4
0.0.0.0	0.0.0.0	10.0.4.1	IF1

Default router

Incoming IP packet



Destination IP address
202.44.8.5

Forwarding table @ R1

Destination Network	Netmask	Nexthop	Interface
202.44.0.0	255.255.252.0	10.0.2.2	IF2
202.44.4.0	255.255.252.0	10.0.3.2	IF3
202.44.8.0	255.255.252.0	202.44.8.1	IF4
0.0.0.0	0.0.0.0	10.0.4.1	IF1

AND 255.255.252.0 = 202.44.8.0 (not matched)

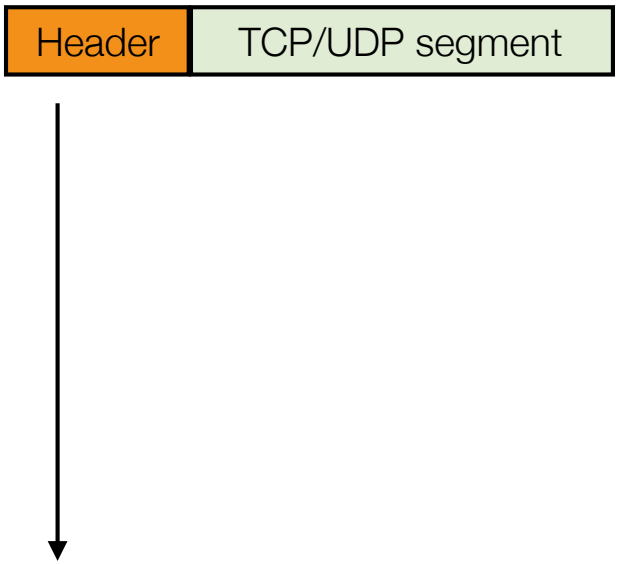
AND 255.255.252.0 = 202.44.8.0 (not matched)

AND 255.255.252.0 = 202.44.8.0 (matched)

AND 0.0.0.0 = 0.0.0.0 (matched)

Longest-Prefix Matching

Incoming IP packet



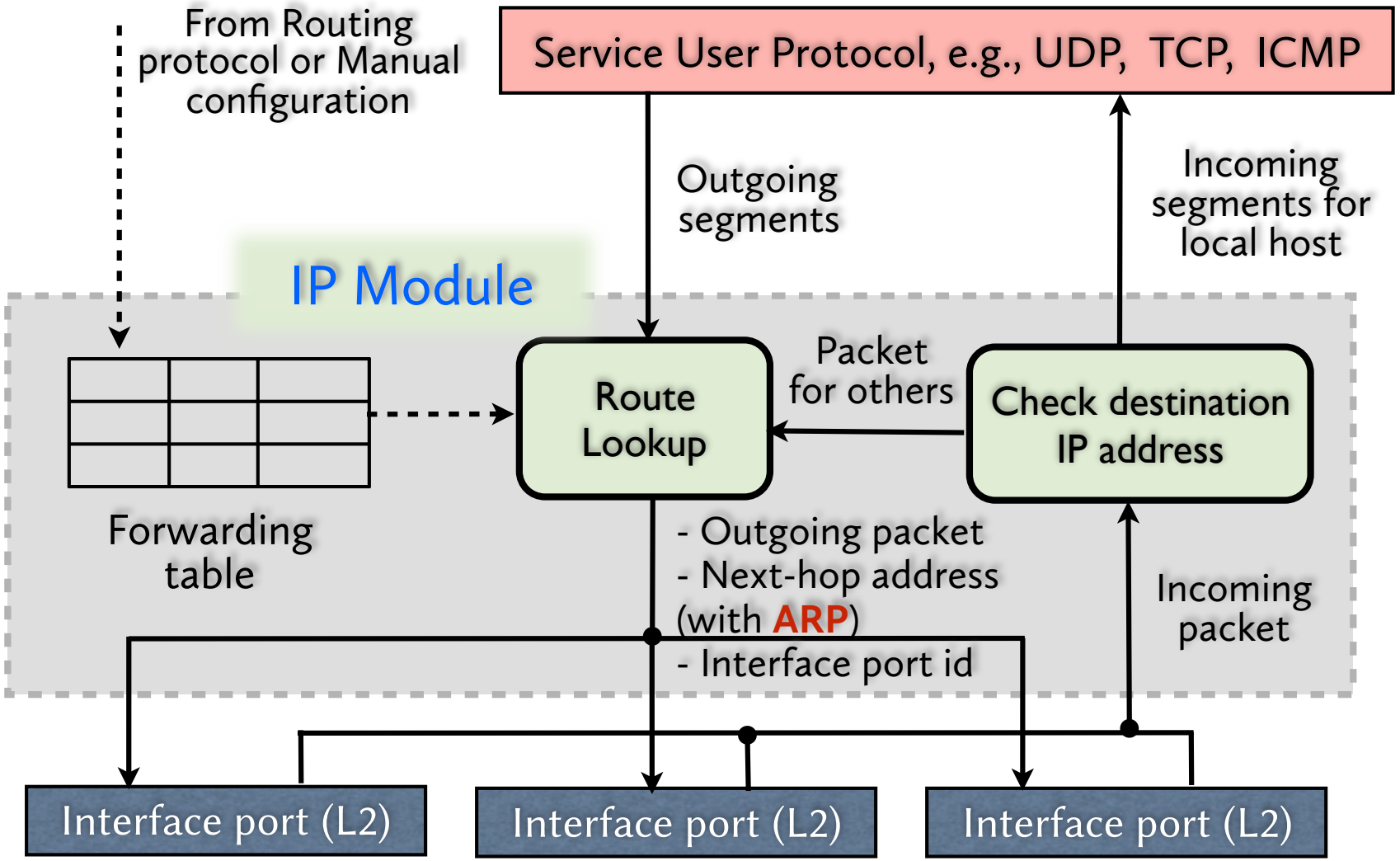
Destination Network	Netmask	Nexthop	Interface
137.204.57.64	255.255.255.192	37.48.5.24	IF1
137.204.57.0	255.255.255.0	155.148.27.34	IF2
0.0.0.0	0.0.0.0	67.28.141.18	IF3

AND 255.255.252.192 = 137.204.57.192 (not matched)

AND 255.255.255.0 = 137.204.57.0 (matched)

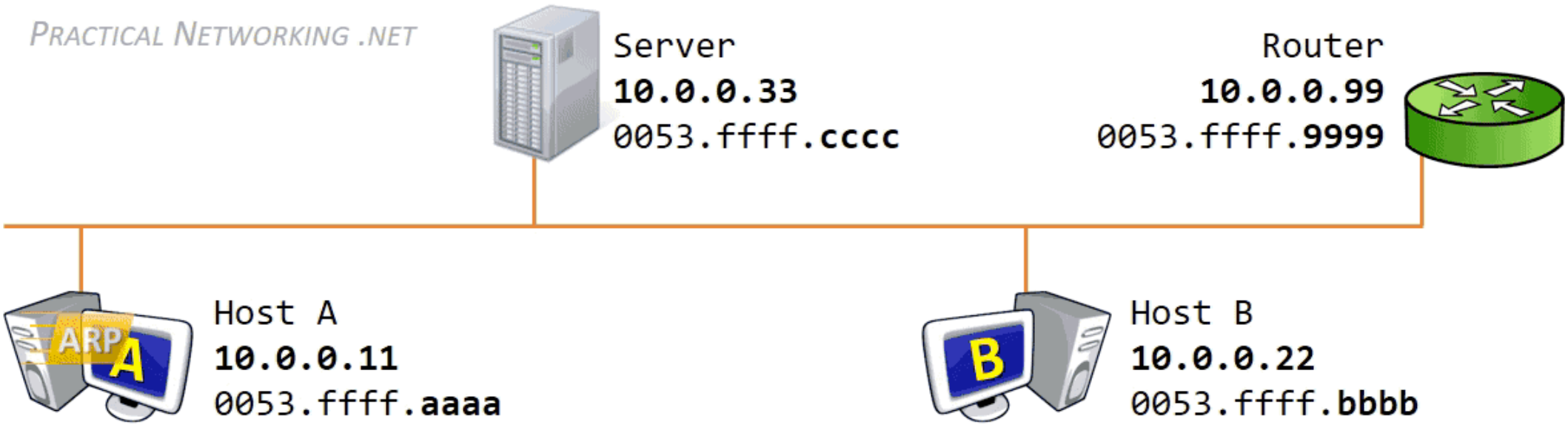
AND 0.0.0.0 = 0.0.0.0 (matched)

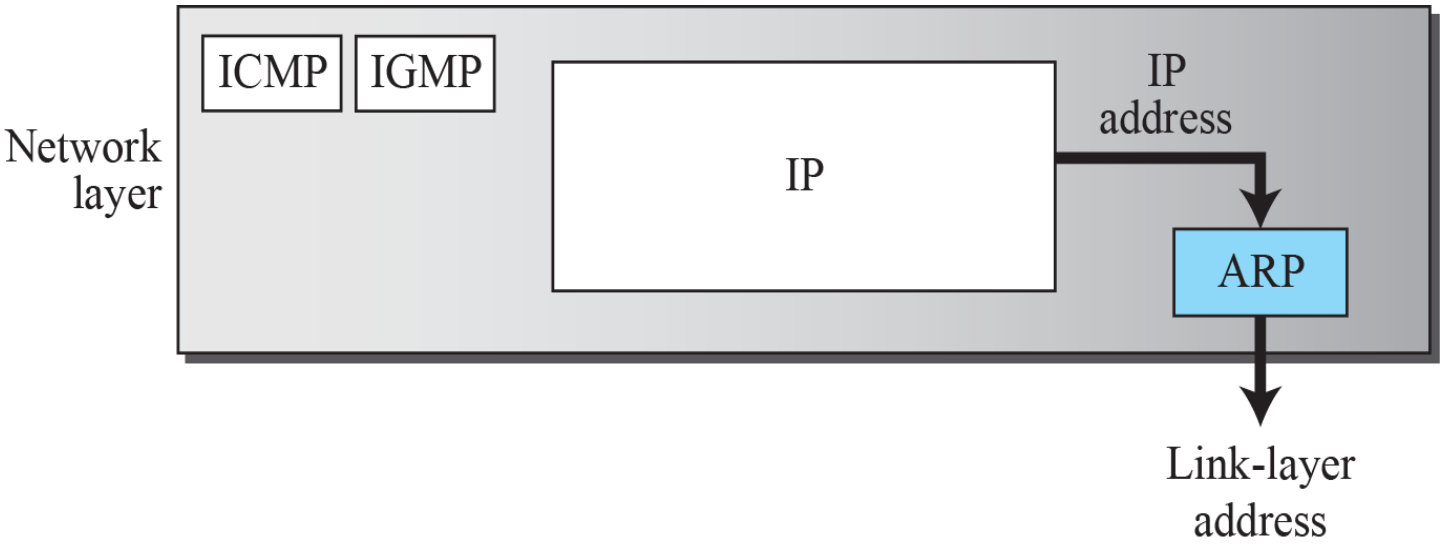
Processing of IP Datagram

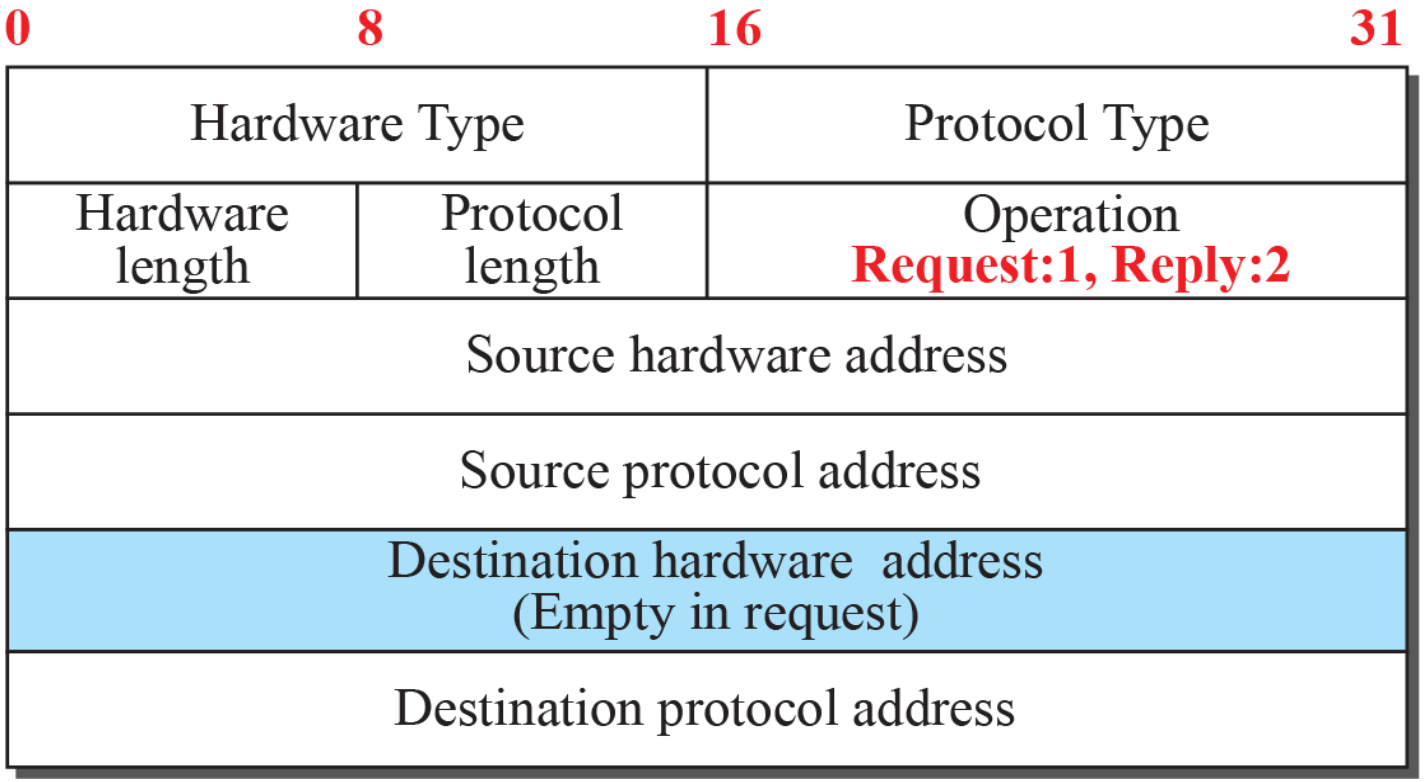


Address Resolution Protocol (ARP)

- Resolve a hardware address from a given IP address

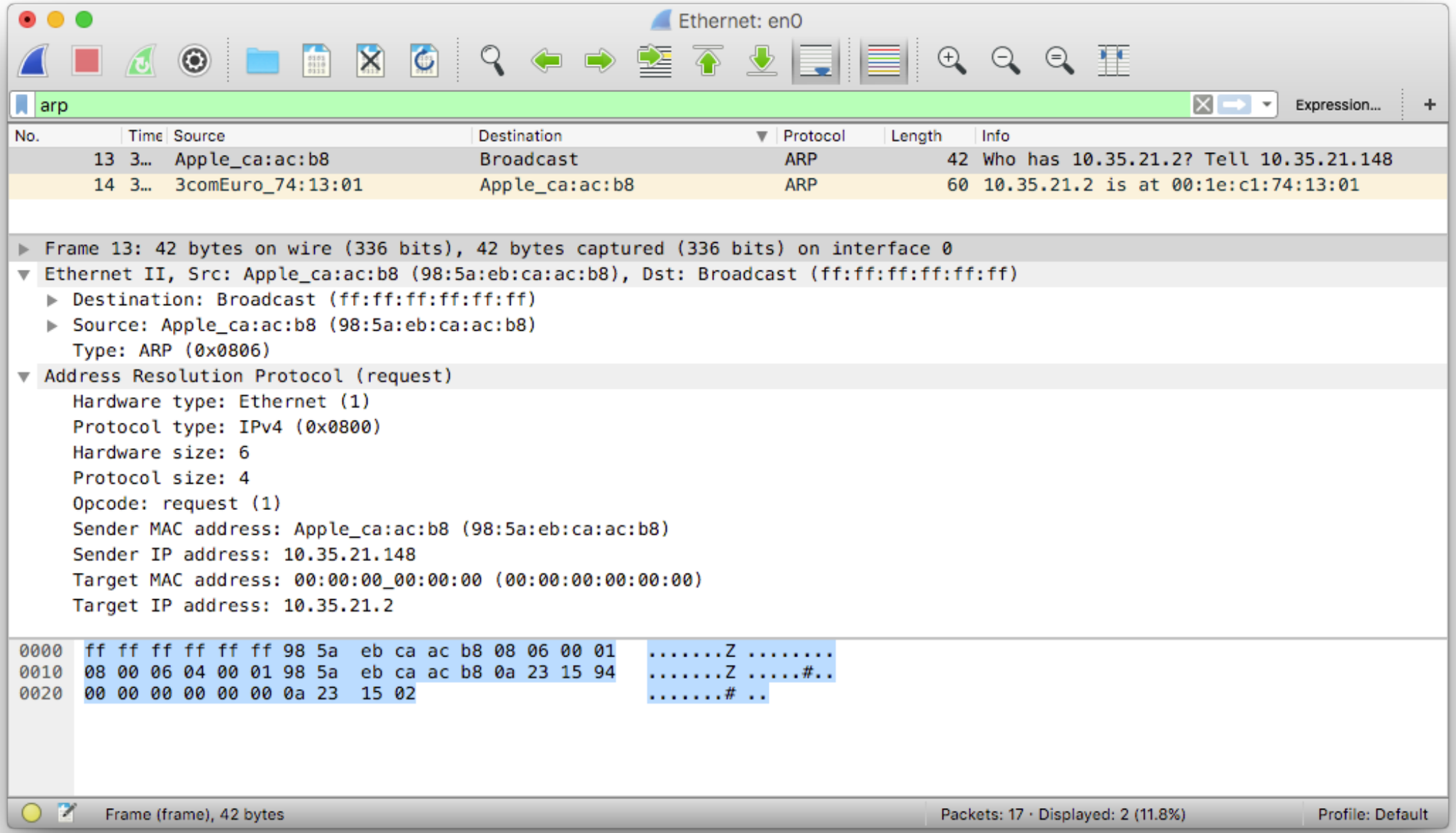




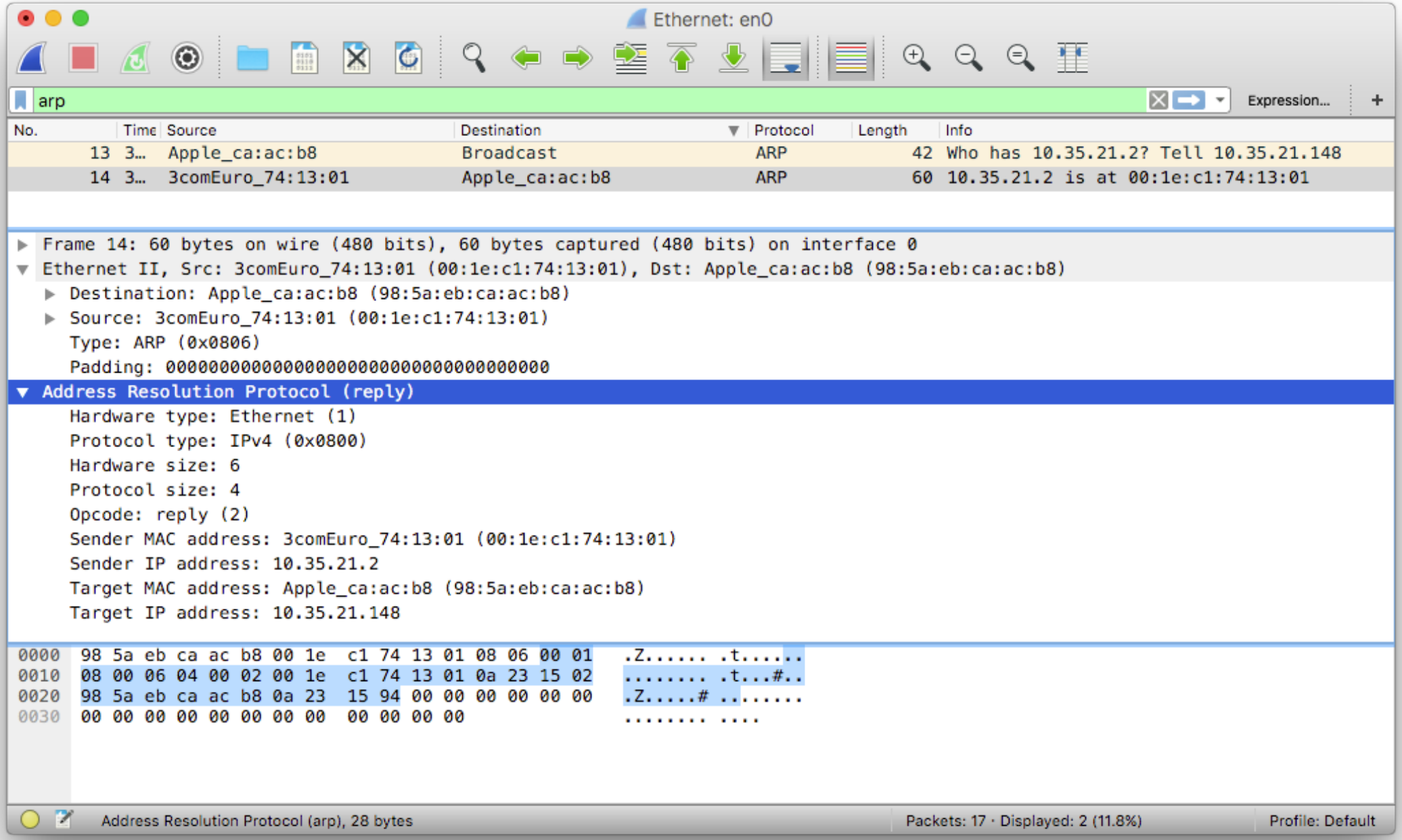


Hardware: LAN or WAN protocol
Protocol: Network-layer protocol

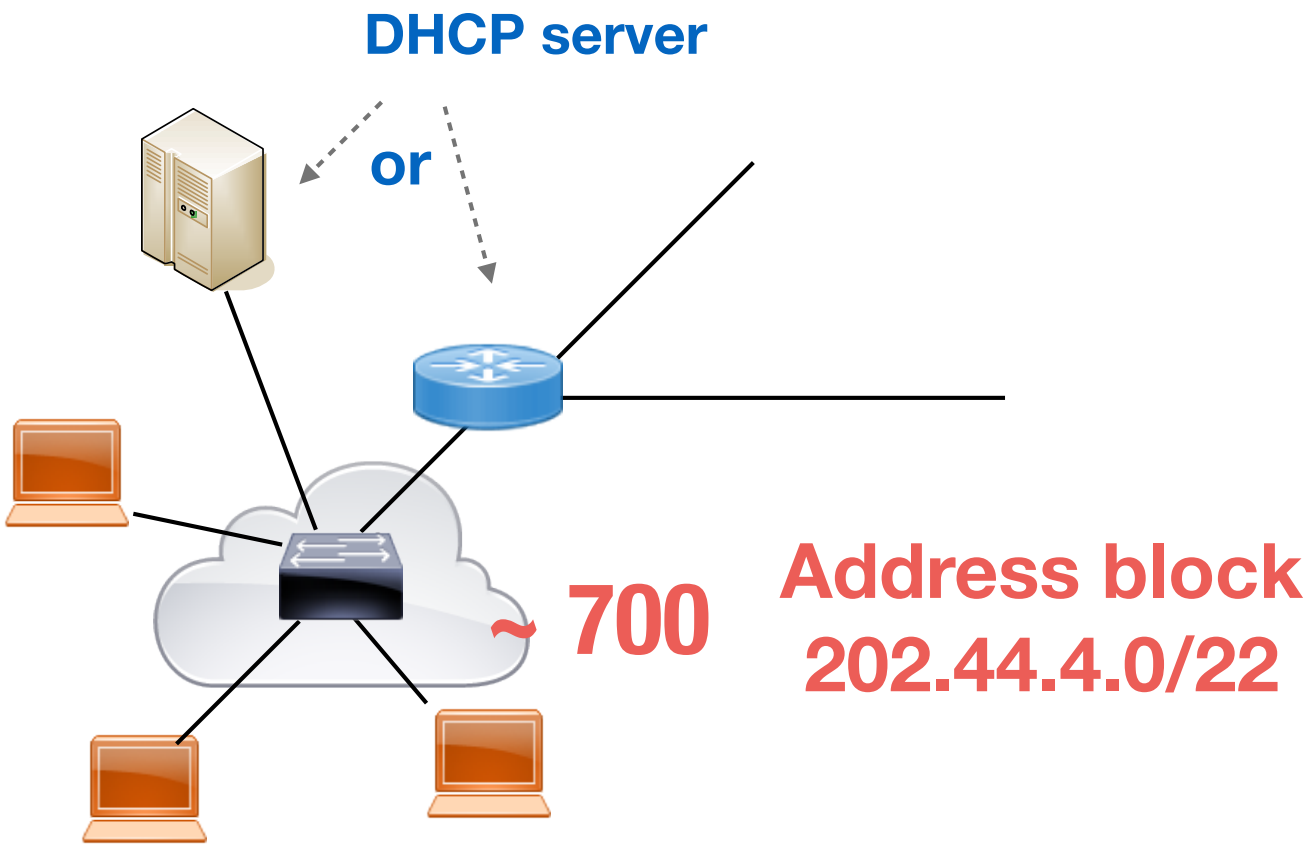
ARP Request


Ethernet: en0
arp
Expression...
No. Time Source Destination Protocol Length Info
13 3... Apple_ca:ac:b8 Broadcast ARP 42 Who has 10.35.21.2? Tell 10.35.21.148
14 3... 3comEuro_74:13:01 Apple_ca:ac:b8 ARP 60 10.35.21.2 is at 00:1e:c1:74:13:01
Frame 13: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
Ethernet II, Src: Apple_ca:ac:b8 (98:5a:eb:ca:ac:b8), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
Destination: Broadcast (ff:ff:ff:ff:ff:ff)
Source: Apple_ca:ac:b8 (98:5a:eb:ca:ac:b8)
Type: ARP (0x0806)
Address Resolution Protocol (request)
Hardware type: Ethernet (1)
Protocol type: IPv4 (0x0800)
Hardware size: 6
Protocol size: 4
Opcode: request (1)
Sender MAC address: Apple_ca:ac:b8 (98:5a:eb:ca:ac:b8)
Sender IP address: 10.35.21.148
Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
Target IP address: 10.35.21.2
0000 ff ff ff ff ff ff 98 5a eb ca ac b8 08 06 00 01 .....Z .....
0010 08 00 06 04 00 01 98 5a eb ca ac b8 0a 23 15 94 .....Z .....#..
0020 00 00 00 00 00 00 0a 23 15 02 .....# ..
Frame (frame), 42 bytes
Packets: 17 · Displayed: 2 (11.8%)
Profile: Default

ARP Reply


Ethernet: en0
arp
Expression...
No. Time Source Destination Protocol Length Info
13 3... Apple_ca:ac:b8 Broadcast ARP 42 Who has 10.35.21.2? Tell 10.35.21.148
14 3... 3comEuro_74:13:01 Apple_ca:ac:b8 ARP 60 10.35.21.2 is at 00:1e:c1:74:13:01
Frame 14: 60 bytes on wire (480 bits), 60 bytes captured (480 bits) on interface 0
Ethernet II, Src: 3comEuro_74:13:01 (00:1e:c1:74:13:01), Dst: Apple_ca:ac:b8 (98:5a:eb:ca:ac:b8)
Destination: Apple_ca:ac:b8 (98:5a:eb:ca:ac:b8)
Source: 3comEuro_74:13:01 (00:1e:c1:74:13:01)
Type: ARP (0x0806)
Padding: 000000000000000000000000000000000000
Address Resolution Protocol (reply)
Hardware type: Ethernet (1)
Protocol type: IPv4 (0x0800)
Hardware size: 6
Protocol size: 4
Opcode: reply (2)
Sender MAC address: 3comEuro_74:13:01 (00:1e:c1:74:13:01)
Sender IP address: 10.35.21.2
Target MAC address: Apple_ca:ac:b8 (98:5a:eb:ca:ac:b8)
Target IP address: 10.35.21.148
0000 98 5a eb ca ac b8 00 1e c1 74 13 01 08 06 00 01 .Z..... .t.....
0010 08 00 06 04 00 02 00 1e c1 74 13 01 0a 23 15 02 ..... .t...#..
0020 98 5a eb ca ac b8 0a 23 15 94 00 00 00 00 00 00 .Z.....# .....
0030 00 00 00 00 00 00 00 00 00 00 00 00 ....
Address Resolution Protocol (arp), 28 bytes
Packets: 17 · Displayed: 2 (11.8%)
Profile: Default

Dynamic Host Configuration Protocol (DHCP)



Network Setup (LAN)

Gateway IP

Local IP Address: 192 . 168 . 1 . 1

Subnet Mask: 255 . 255 . 255 . 0

Warning: Changes to LAN IP network settings may require reconfiguration of all attached devices. Some network devices may be out of service until the change is detected.

Network Address Server Settings (DHCP)

DHCP Server: (•) Enable ( ) Disable

Connected Devices Summary

Pre-assigned DHCP IP Addresses

Starting IP Address: 192.168.1. 41

Maximum Number of DHCP Users: 128

Client Lease Time: 1440 minutes (0 means one day)

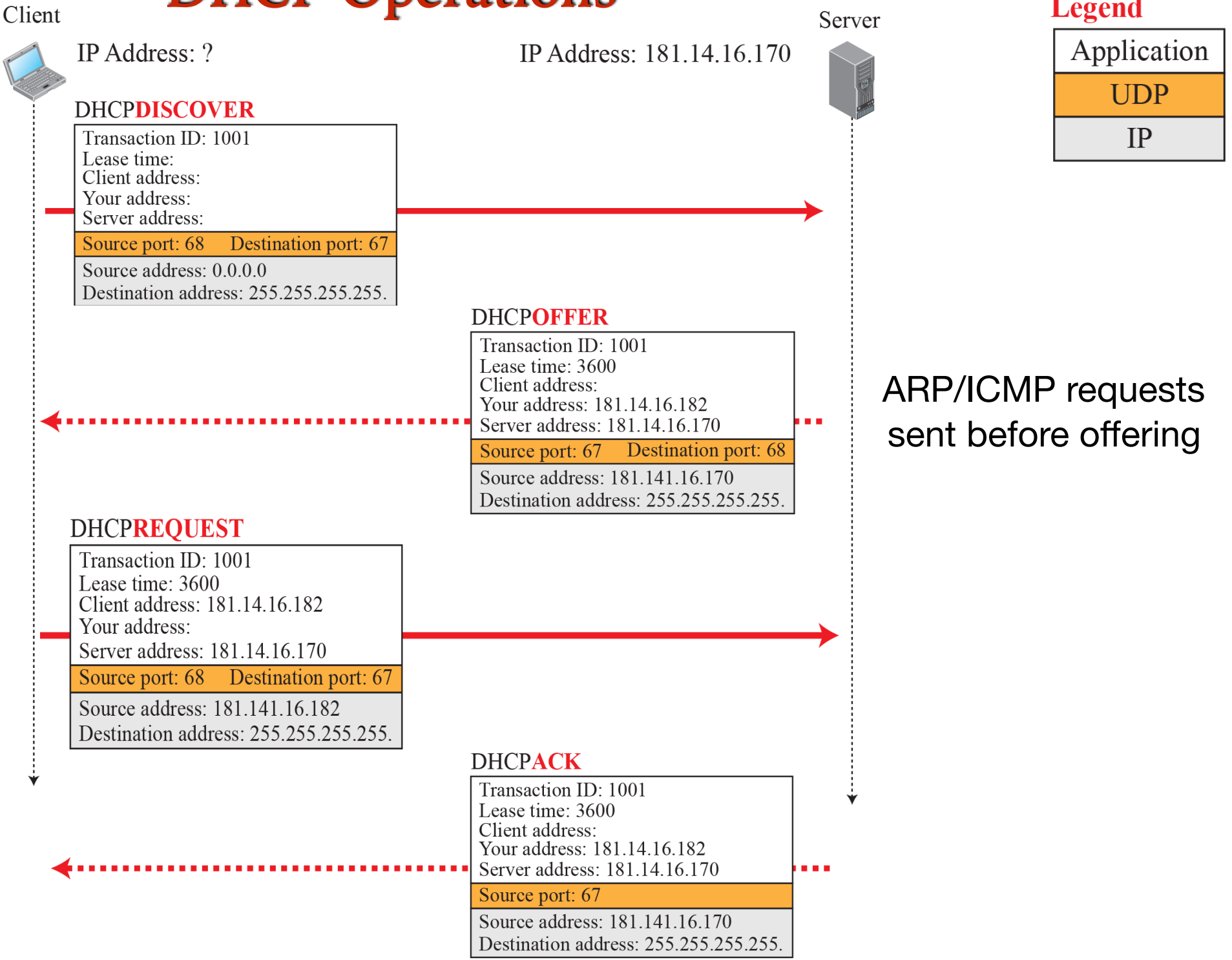
LAN 1 Static DNS 1: 0 . 0 . 0 . 0

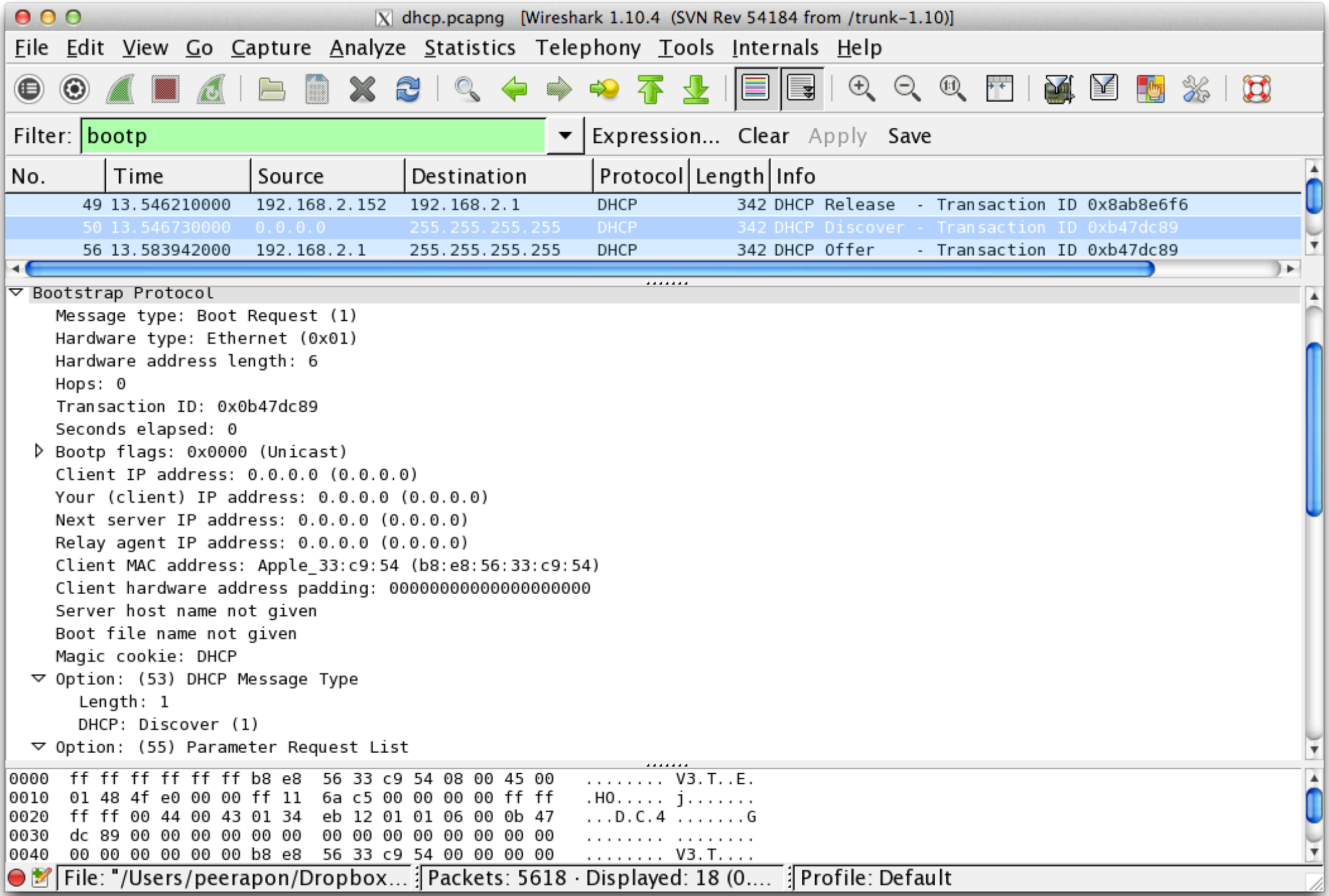
LAN 1 Static DNS 2: 0 . 0 . 0 . 0

LAN 1 Static DNS 3: 0 . 0 . 0 . 0

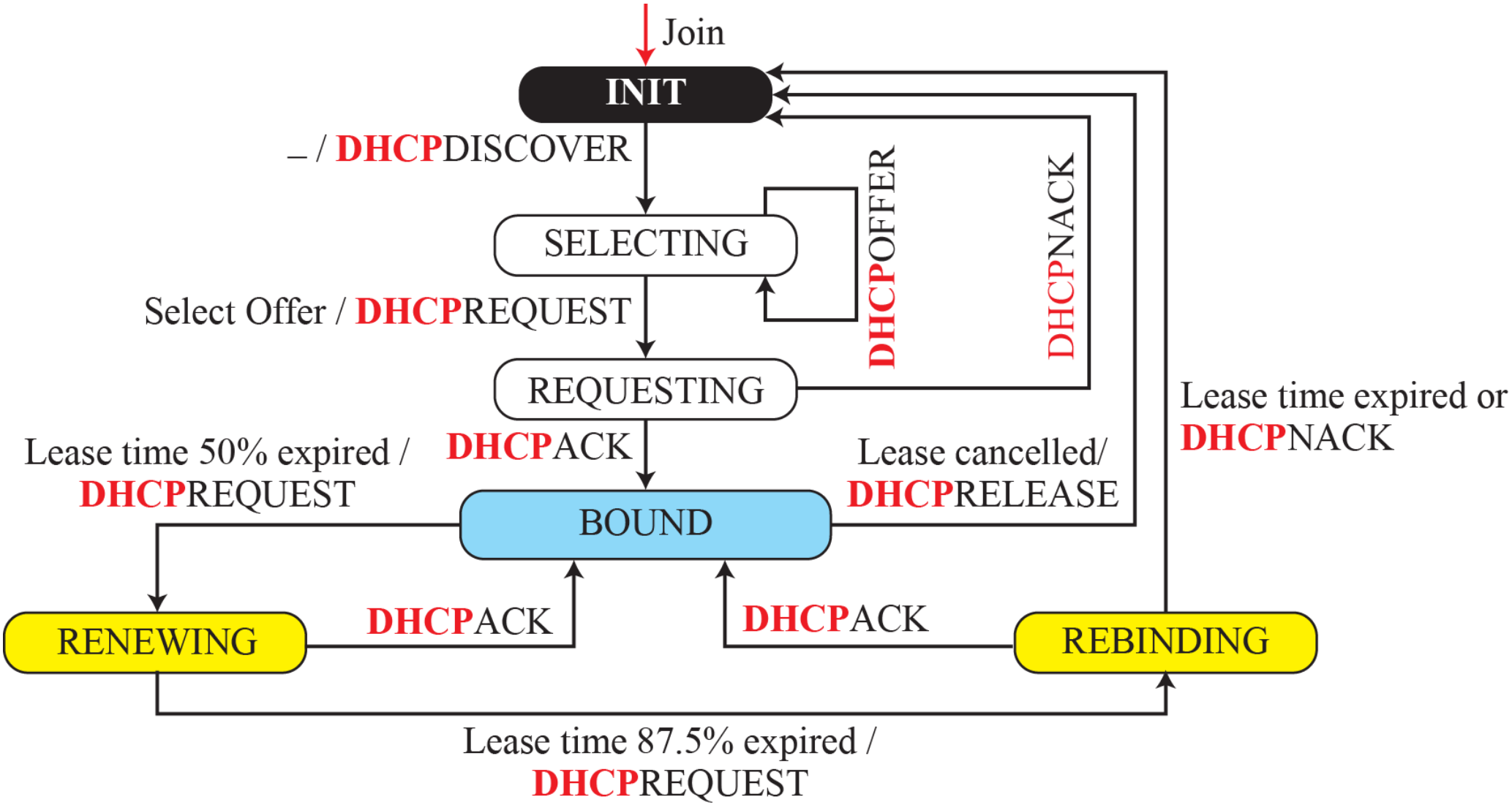
Display a menu

DHCP Operations




dhcp.pcapng [Wireshark 1.10.4 (SVN Rev 54184 from /trunk-1.10)]
File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help
Filter: bootp
Expression... Clear Apply Save
No. Time Source Destination Protocol Length Info
49 13.546210000 192.168.2.152 192.168.2.1 DHCP 342 DHCP Release - Transaction ID 0x8ab8e6f6
50 13.546730000 0.0.0.0 255.255.255.255 DHCP 342 DHCP Discover - Transaction ID 0xb47dc89
56 13.583942000 192.168.2.1 255.255.255.255 DHCP 342 DHCP Offer - Transaction ID 0xb47dc89
Bootstrap Protocol
Message type: Boot Request (1)
Hardware type: Ethernet (0x01)
Hardware address length: 6
Hops: 0
Transaction ID: 0x0b47dc89
Seconds elapsed: 0
Bootp flags: 0x0000 (Unicast)
Client IP address: 0.0.0.0 (0.0.0.0)
Your (client) IP address: 0.0.0.0 (0.0.0.0)
Next server IP address: 0.0.0.0 (0.0.0.0)
Relay agent IP address: 0.0.0.0 (0.0.0.0)
Client MAC address: Apple_33:c9:54 (b8:e8:56:33:c9:54)
Client hardware address padding: 00000000000000000000
Server host name not given
Boot file name not given
Magic cookie: DHCP
Option: (53) DHCP Message Type
Length: 1
DHCP: Discover (1)
Option: (55) Parameter Request List
0000 ff ff ff ff ff ff b8 e8 56 33 c9 54 08 00 45 00 .... V3.T..E.
0010 01 48 4f e0 00 00 ff 11 6a c5 00 00 00 00 ff ff .HO..... j.......
0020 ff ff 00 44 00 43 01 34 eb 12 01 01 06 00 0b 47 ...D.C.4 ....G
0030 dc 89 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ....
0040 00 00 00 00 00 00 b8 e8 56 33 c9 54 00 00 00 00 .... V3.T....
File: "/Users/peerapon/Dropbox...
Packets: 5618 · Displayed: 18 (0....
Profile: Default

Finite State Machine (FSM) of DHCP

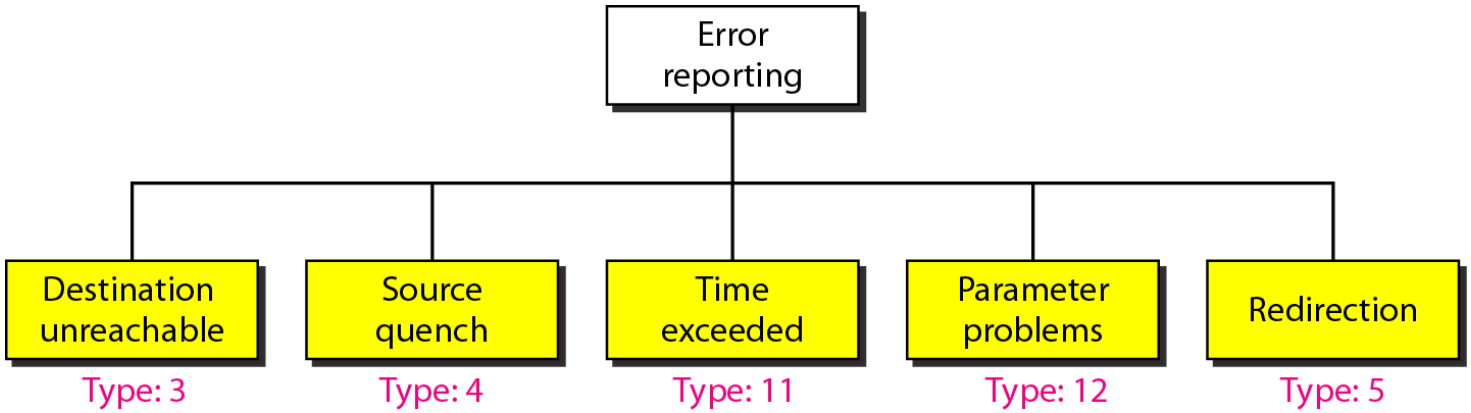


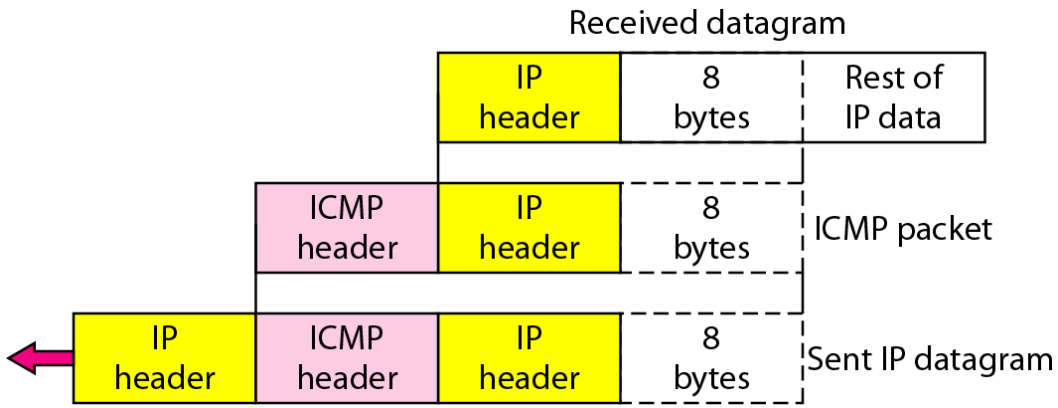
Internet Control Message Protocol (ICMP)

- Supplementary L3 protocol to report problems and communicate network-layer information.
- Two broad categories of ICMP messages
  - Error reporting: unreachable host, network, port, protocol
  - Query: diagnose network problems, connectivity, interface status.
- Network utility tools based on ICMP
  - Ping
  - Traceroute (MS Windows)

ICMP Error Report Messages

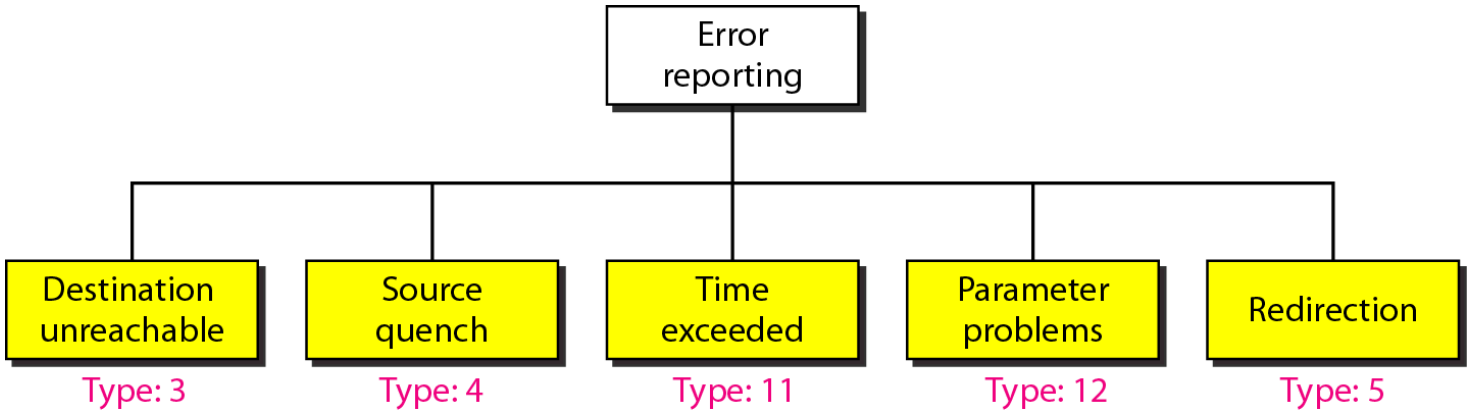
- ICMP Error report message contains "type", "code", and first 8 bytes of the IP datagram causing error.

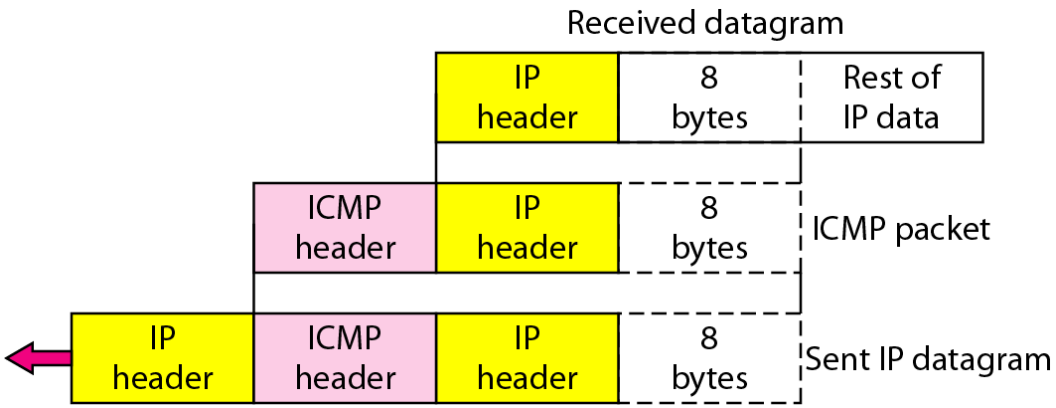




ICMP Error Report Messages

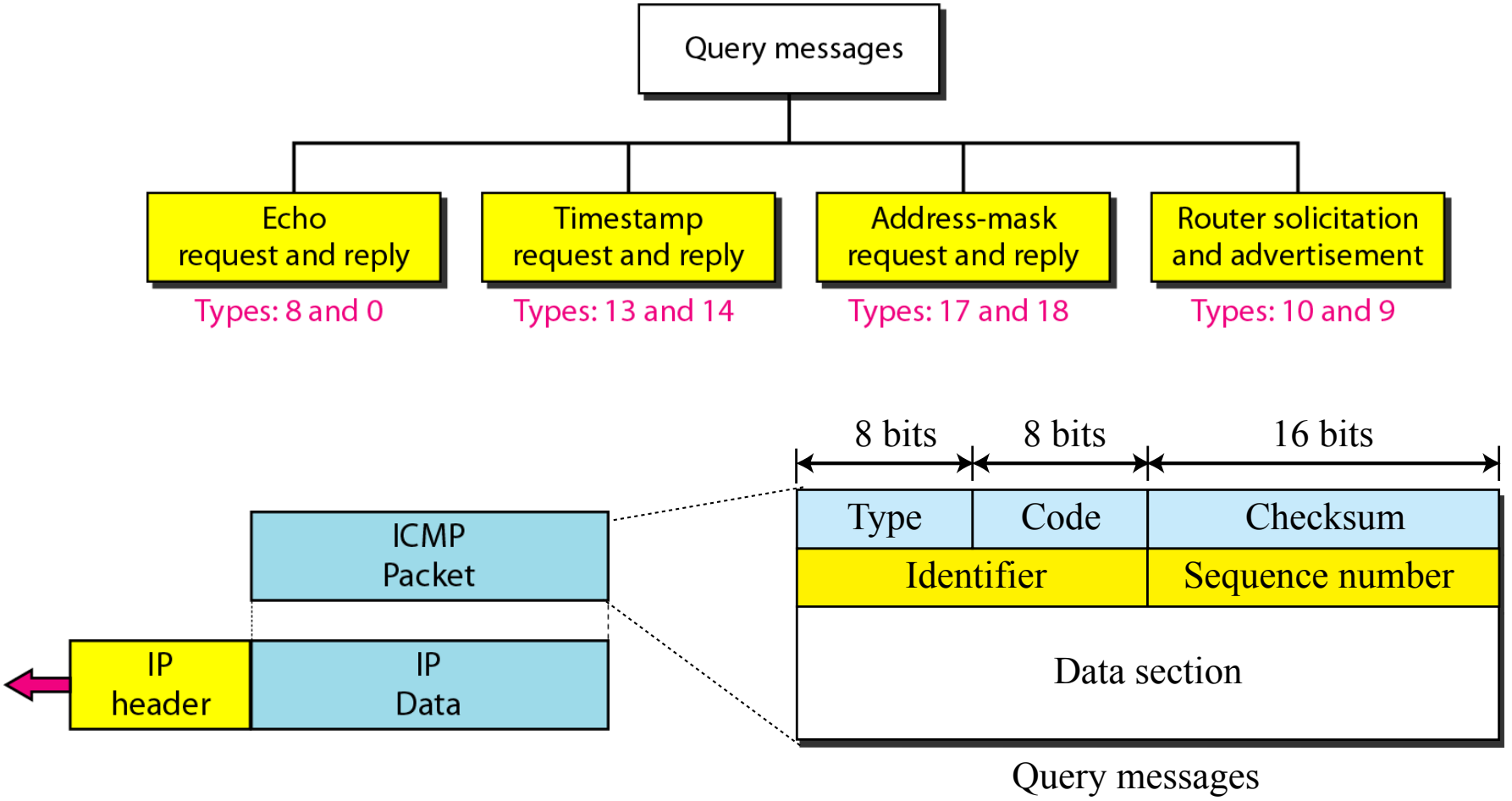
- ICMP Error report message contains "type", "code", and first 8 bytes of the IP datagram causing error.



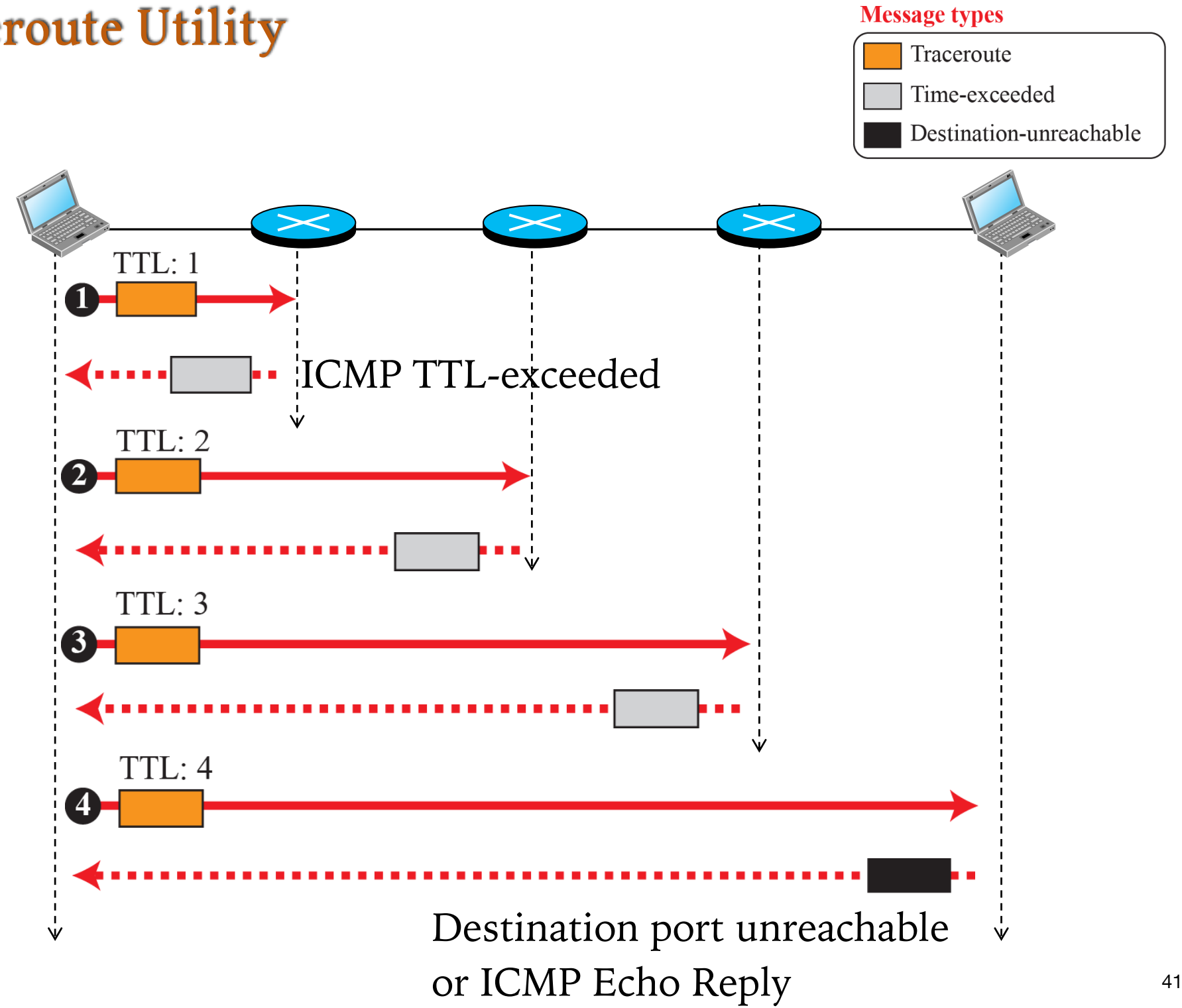


ICMP Query Messages

- The ping utility uses Echo request and reply to check the network connectivity.



Traceroute Utility



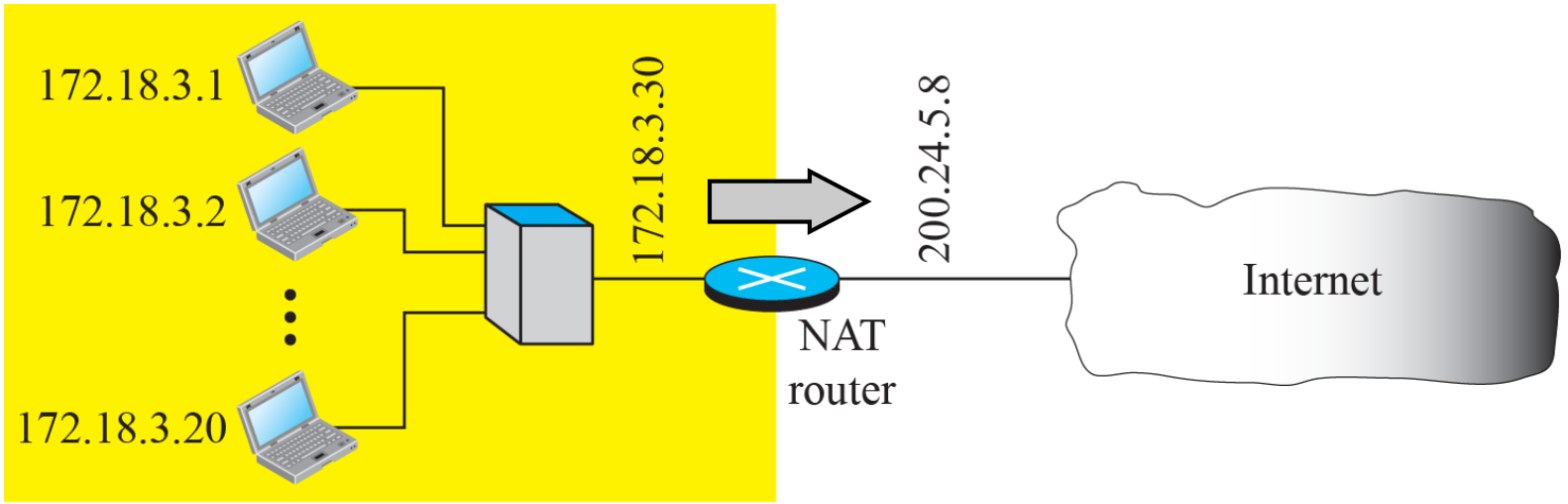
Some ICMP Types and Codes

Type	Code	Description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable (UDP)
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header

Network Address Translation RFC 3022

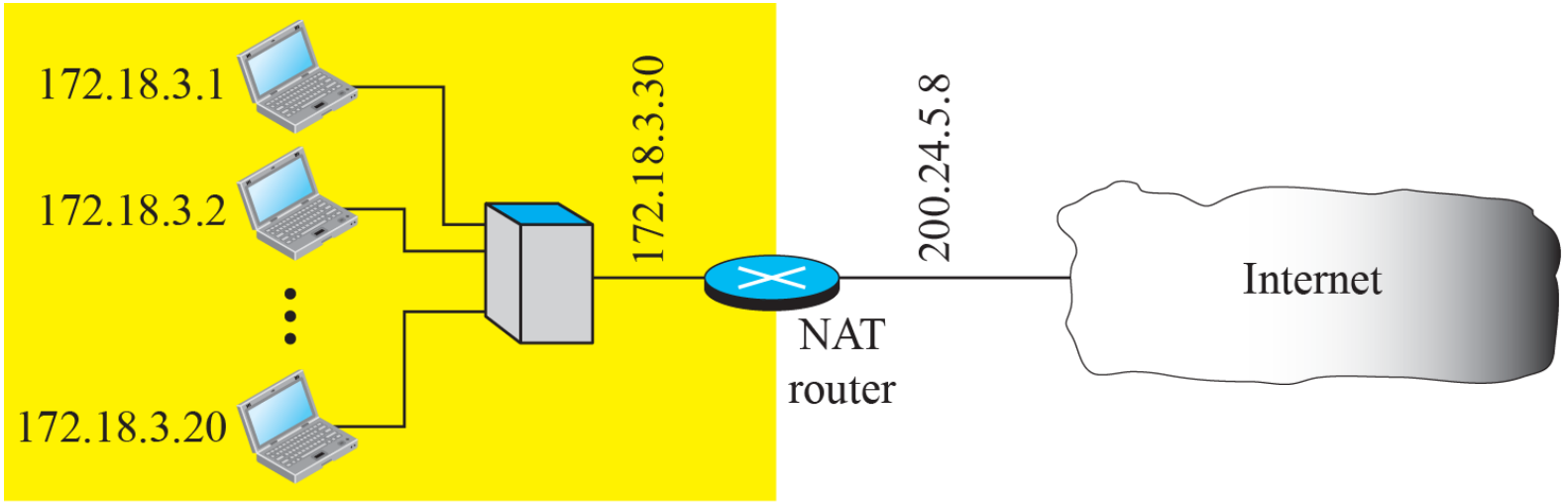
- Too many interfaces, too few IP addresses
- Allow many private hosts to share a public IP address
  - 10.0.0.0 to 10.255.255.255 (10.0.0.0/8) ~ 16M
  - 172.16.0.0 to 172.31.255.255 (172.16.0.0/12) ~ 1M
  - 192.168.0.0 to 192.168.255.255 (192.168.0.0/16, in home LANs) ~ 64k

Network Address (and Port) Translation: NAT (NAPT)



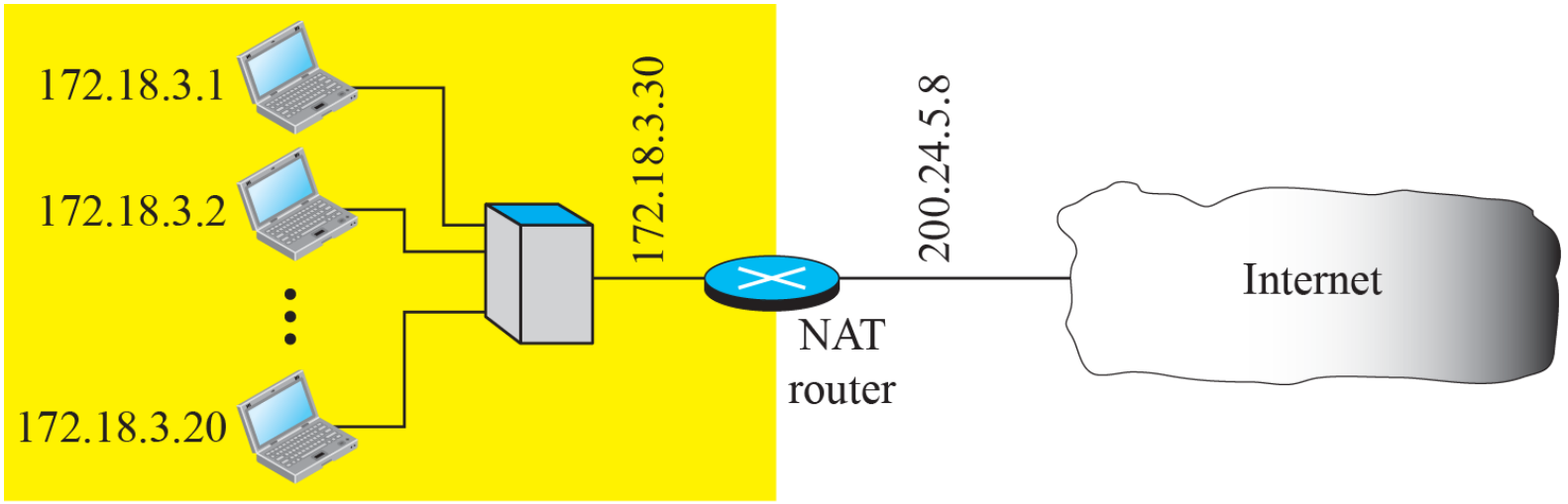
Site using private addresses

Private network		External network	
IP address	Port number	IP address	Port number



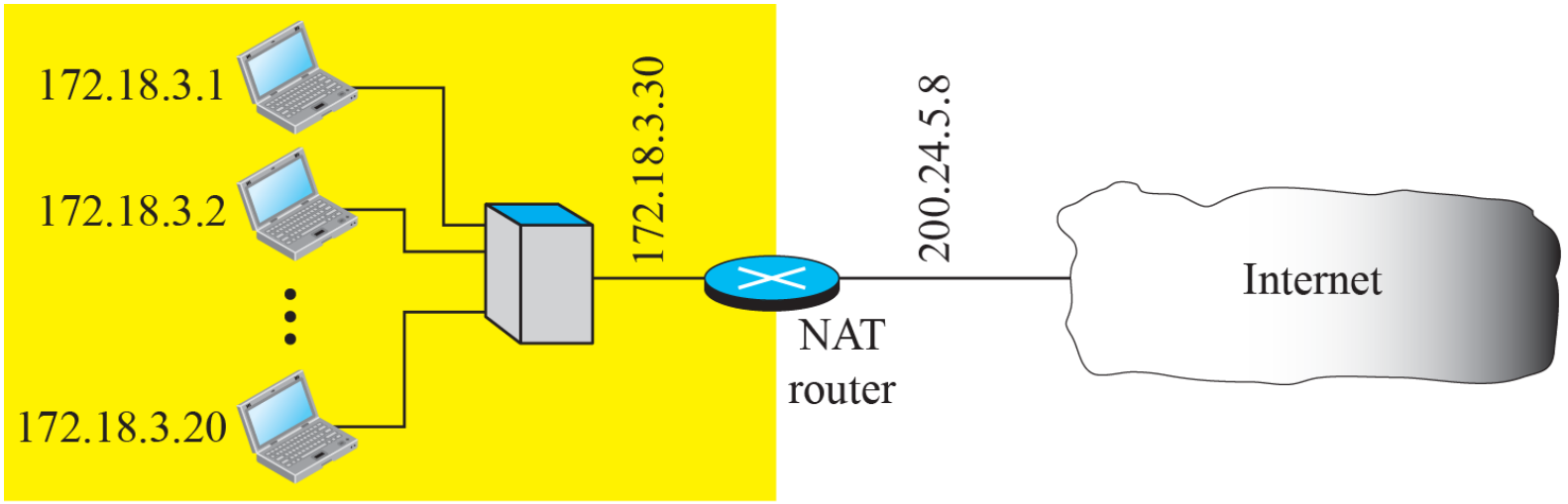
Site using private addresses

Private network		External network	
IP address	Port number	IP address	Port number
172.18.3.1	1400		



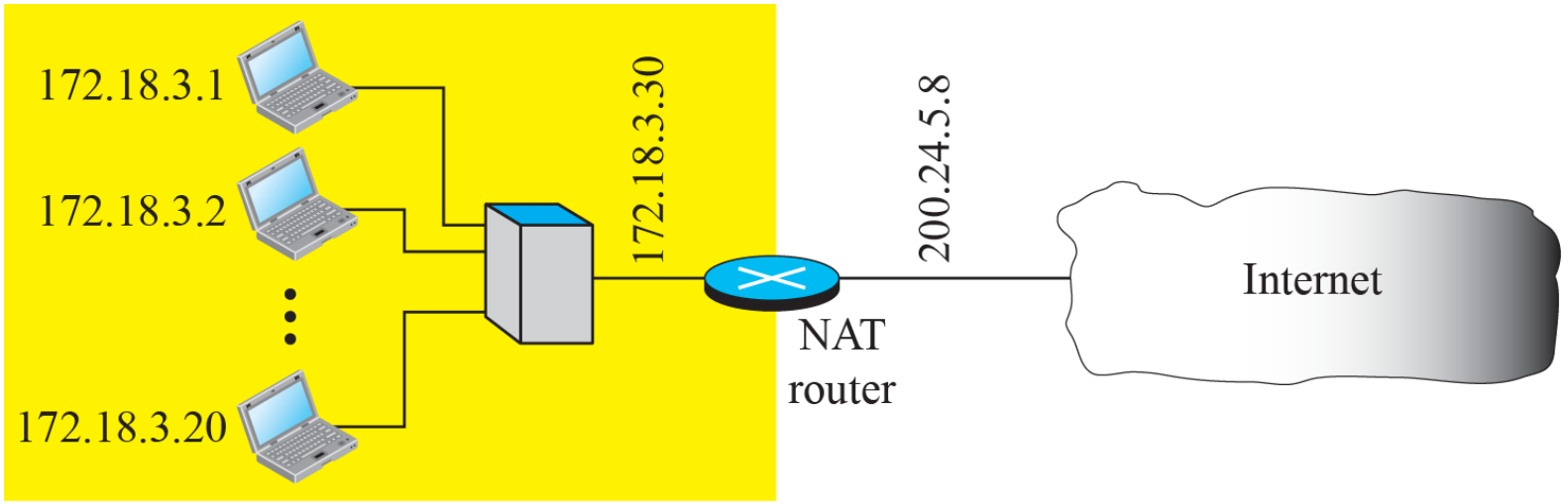
Site using private addresses

Private network		External network	
IP address	Port number	IP address	Port number
172.18.3.1	1400	200.24.5.8	2567



Site using private addresses

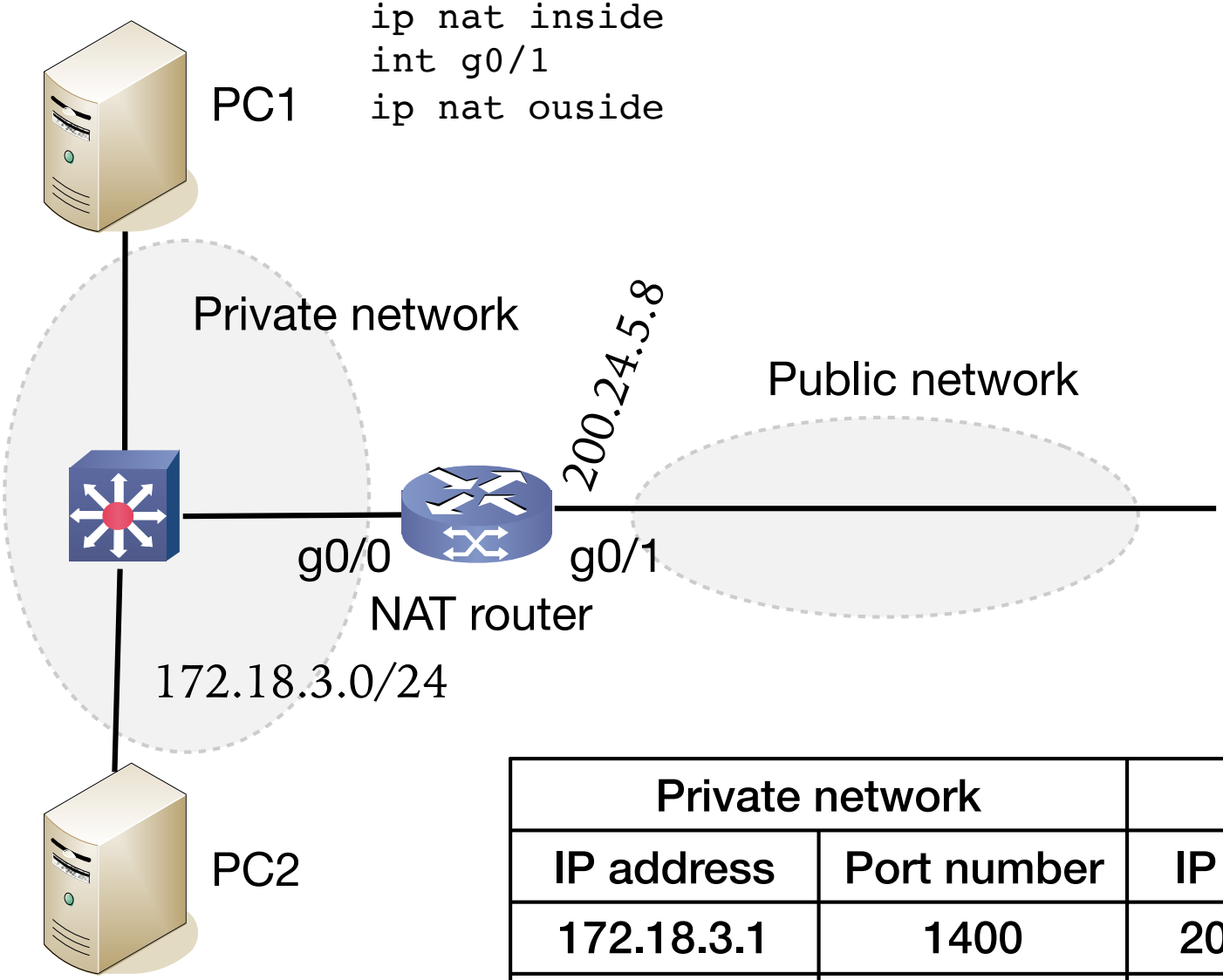
Private network		External network	
IP address	Port number	IP address	Port number
172.18.3.1	1400	200.24.5.8	2567
172.18.3.2	1401		



Site using private addresses

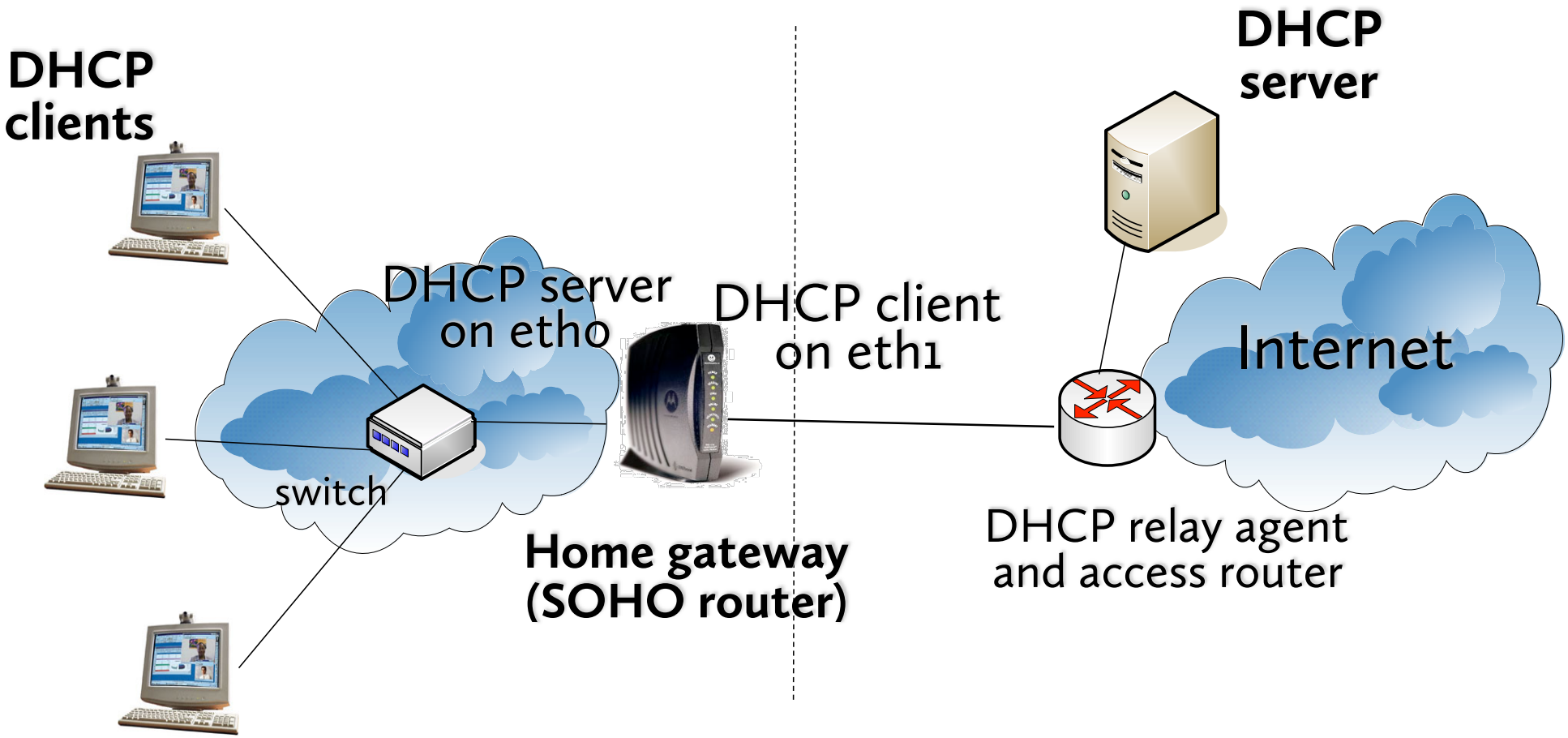
Private network		External network	
IP address	Port number	IP address	Port number
172.18.3.1	1400	200.24.5.8	2567
172.18.3.2	1401	200.24.5.8	3345

```
ip nat pool net-172 200.24.5.8 200.24.5.223 prefix-length 24
access-list 1 permit 172.18.3.0 0.0.0.255
ip nat inside source list 1 pool net-172
int g0/0
ip nat inside
int g0/1
ip nat ouside
```



Private network		External network	
IP address	Port number	IP address	Port number
172.18.3.1	1400	200.24.5.8	2567
172.18.3.2	1401	200.24.5.8	3345

Example: SOHO Network

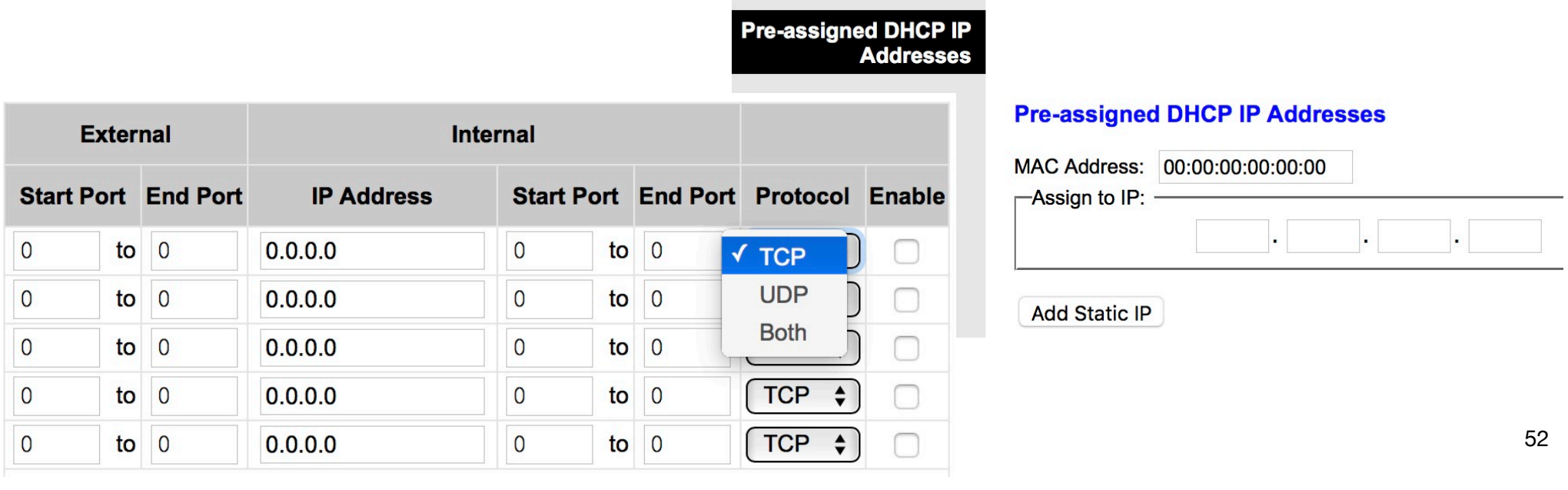


Notes

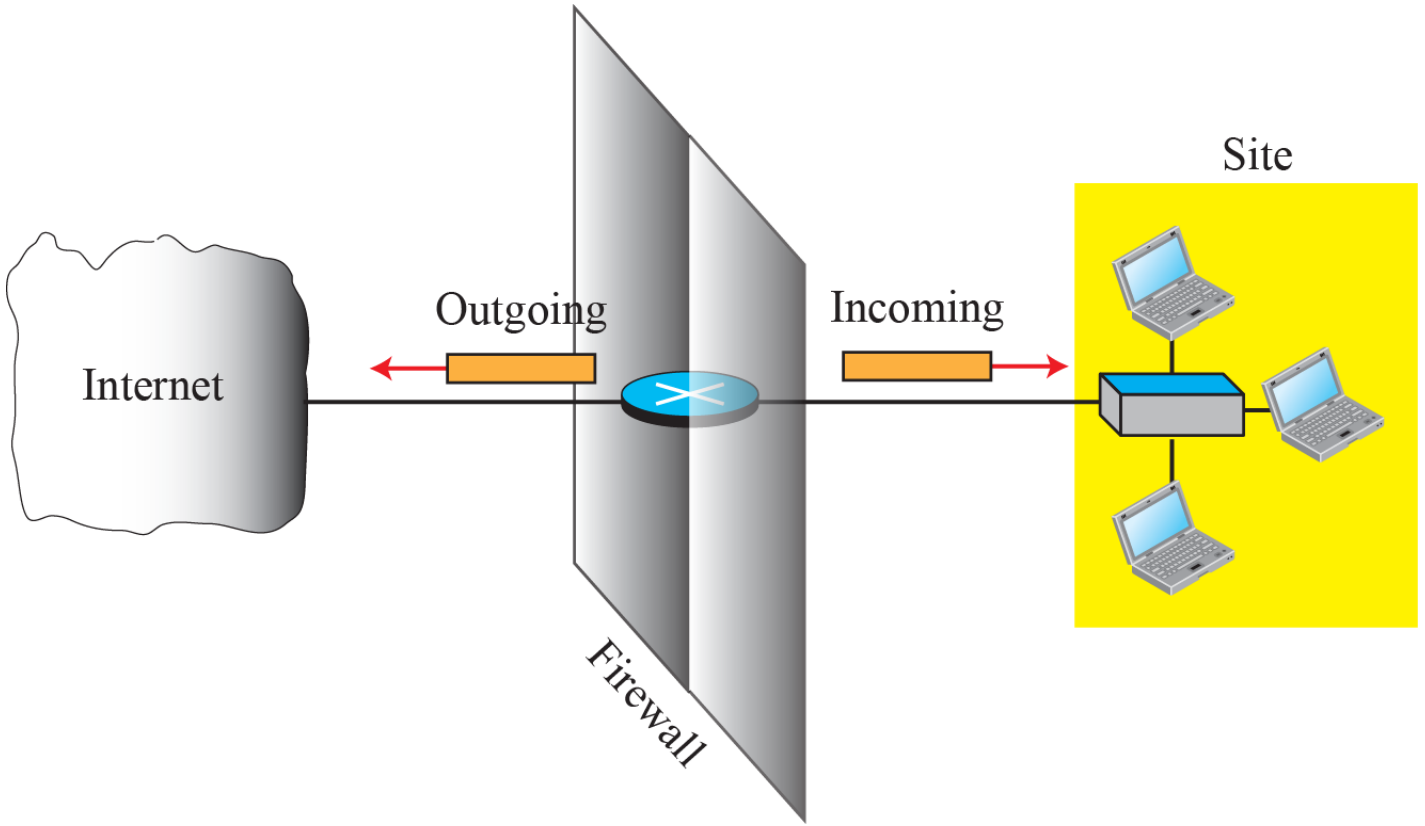
- Advantages of NAT
  - Address space saving, Independent of ISPs
  - Local reconfigurable without side effect
  - Security
- Issues
  - ICMP packets have no port number
  - Server also runs behind a NAT -- **Port redirection**
  - Some apps encode IP address/port in app layer

Port Redirection/Forwarding

- Allow to run servers behind NAT
- Request for a given port number is mapped to a specific internal (private) IP address and internal port number.

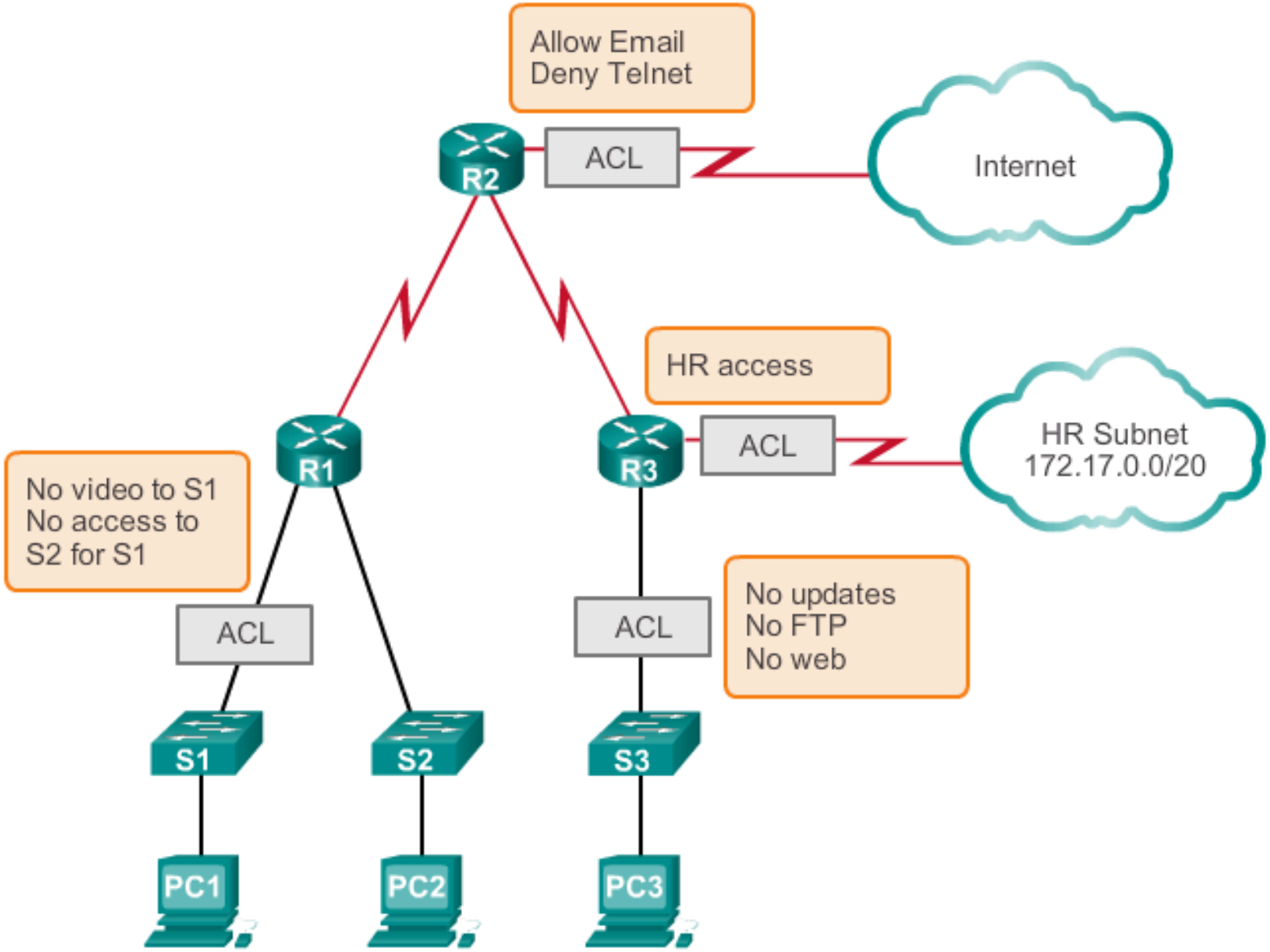


Packet Filtering



Interface	Source IP	Source port	Destination IP	Destination port
1	131.34.0.0	*	*	*
1	*	*	*	23
1	*	*	194.78.20.8	*
2	*	*	*	80

Access Control List (ACL)



Cisco ACL Implementation

- Standard ACLs

```
access-list 10 permit 192.168.30.0 0.0.0.255
```

  - Range (1-99) and (1300-1999)
  - Based on source addresses only

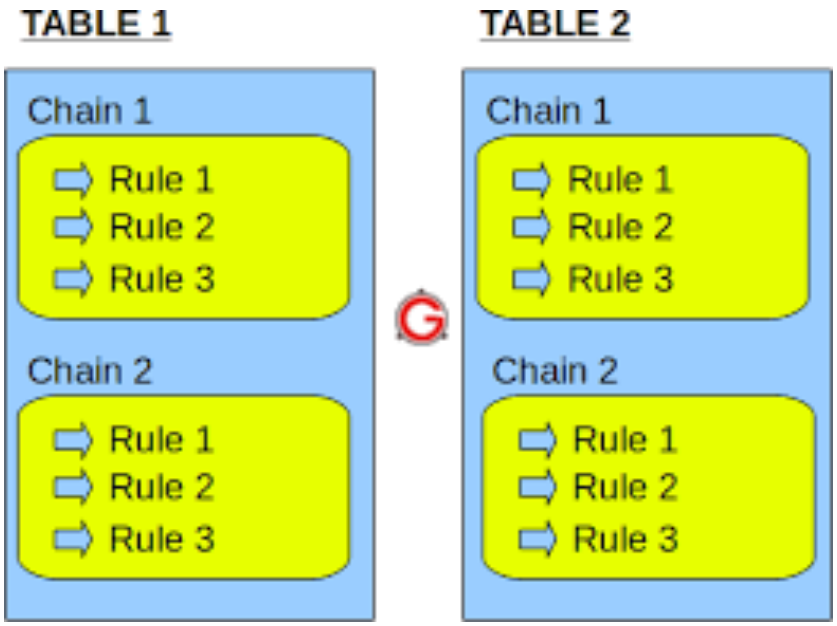
- Extended ACLs

```
access-list 103 permit tcp 192.168.30.0 0.0.0.255 any eq 80
access-list 103 deny ip any 192.168.0.0 0.0.255.255
access-list 103 permit any any
```

  - Range (100-199) and (2000 -2699)
  - Based on addresses, ports, protocol types.

Iptables (Netfilter Project)

- Command line utility for Linux firewall in kernel.

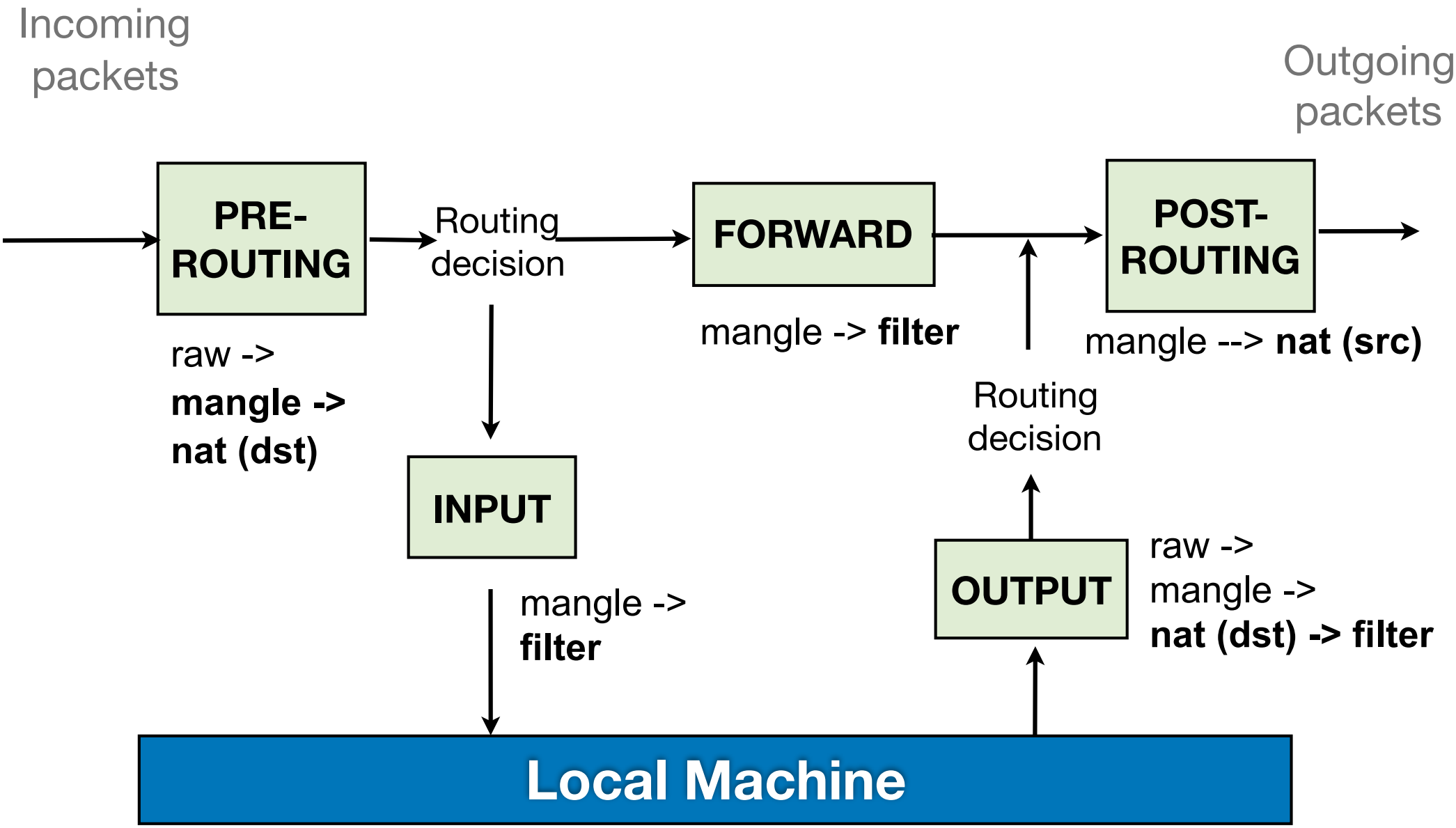


Rule = Condition + Action to apply

Source IP	ACCEPT
Dest IP	DROP
Source port	DNAT
Dest port	SNET
Incoming intf	
Outgoing intf	

Tables: raw, mangle, filter, nat

Chains: PREROUTING, INPUT, OUTPUT, FORWARD, POSTROUTING


Incoming packets
Outgoing packets
PRE-ROUTING
raw ->
mangle ->
nat (dst)
Routing decision
INPUT
mangle ->
filter
FORWARD
mangle -> filter
POST-ROUTING
mangle --> nat (src)
Routing decision
OUTPUT
raw ->
mangle ->
nat (dst) -> filter
Local Machine

```
iptables -A INPUT  -i eth1 -s 10.0.0.0/8 -j DROP
```

Add rule to **INPUT** chain in **filter** table
Drop packet with source ip address 10.0.0.0/8 coming at eth1

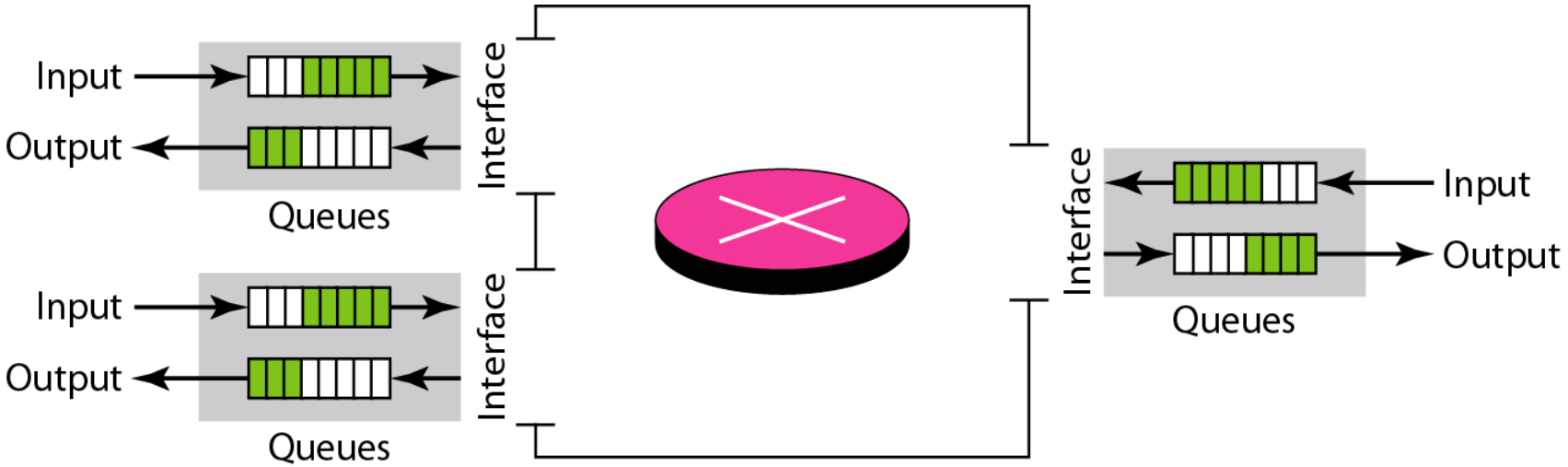
```
iptables -A INPUT  -i eth1 -d 10.0.0.0/8 -j DROP
```

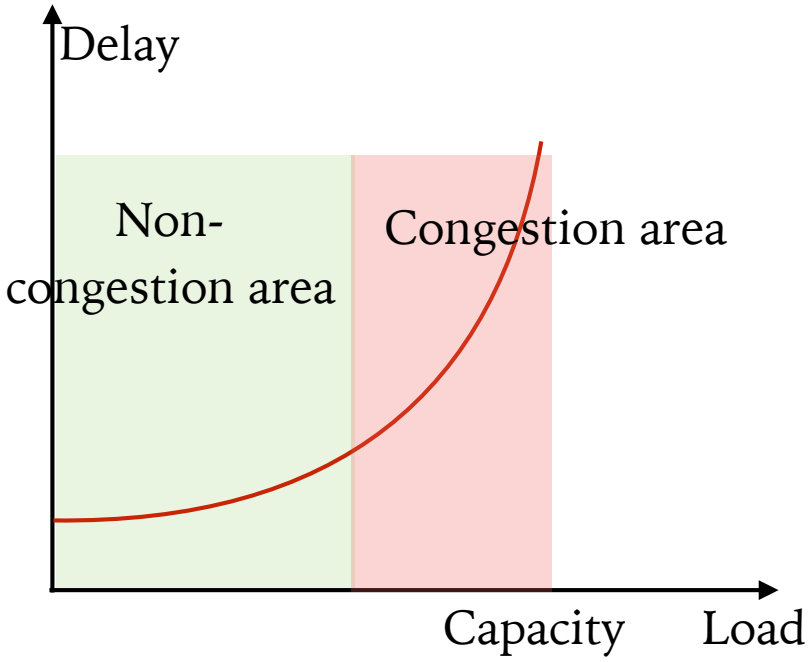
Add rule to **INPUT** chain in **filter** table
Drop packet with dest ip address 10.0.0.0/8 coming at eth1

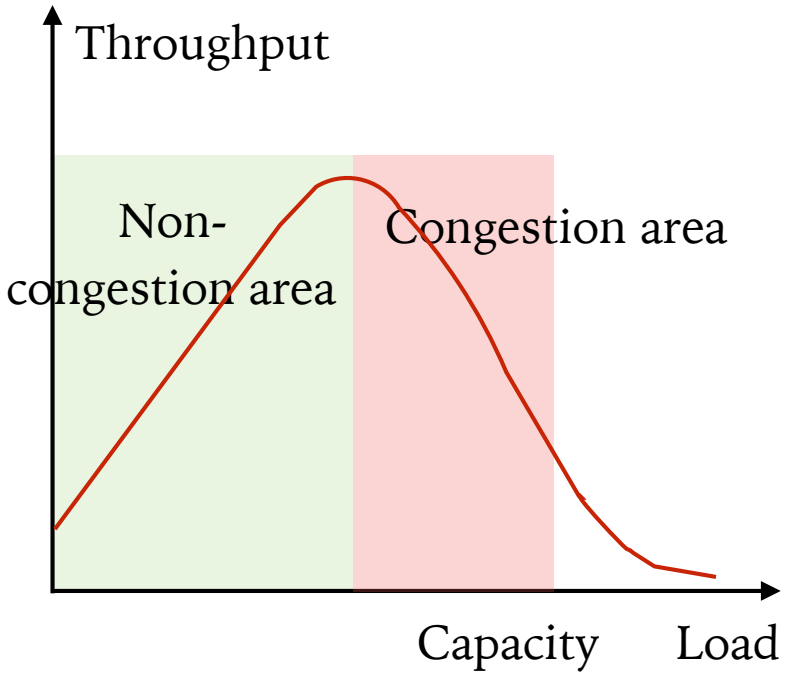
```
iptables -t nat -A POSTROUTING -j MASQUERADE -s 10.0.1.0/24
```

Add rule to **POSTROUTING** chain in **nat** table
NAT source ip address 10.0.0.1/24 to that of the outgoing interface.

Network Congestion







TCP Congestion Control RFC 2581

- Sender limits transmission by maintaining that:

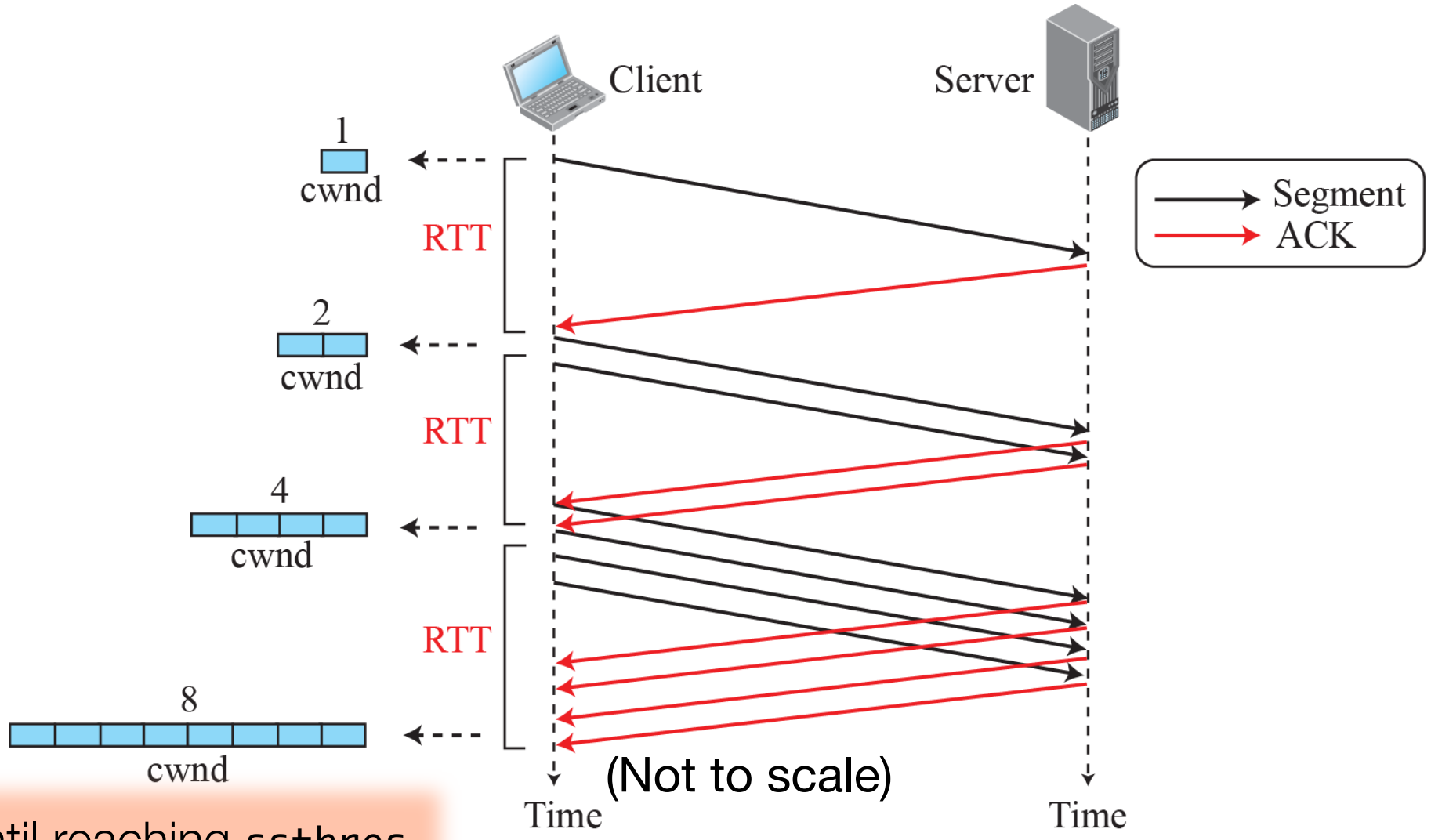
  `LastByteSent - LastByteAcked ≤ min (cwnd*MSS, rwnd)`

  - `MSS` : maximum segment size (in bytes)
  - `cwnd` (Congestion Window) : Dynamic fn. of perceived network congestion (unit MSS).

- Assuming a very large receiver buffer,

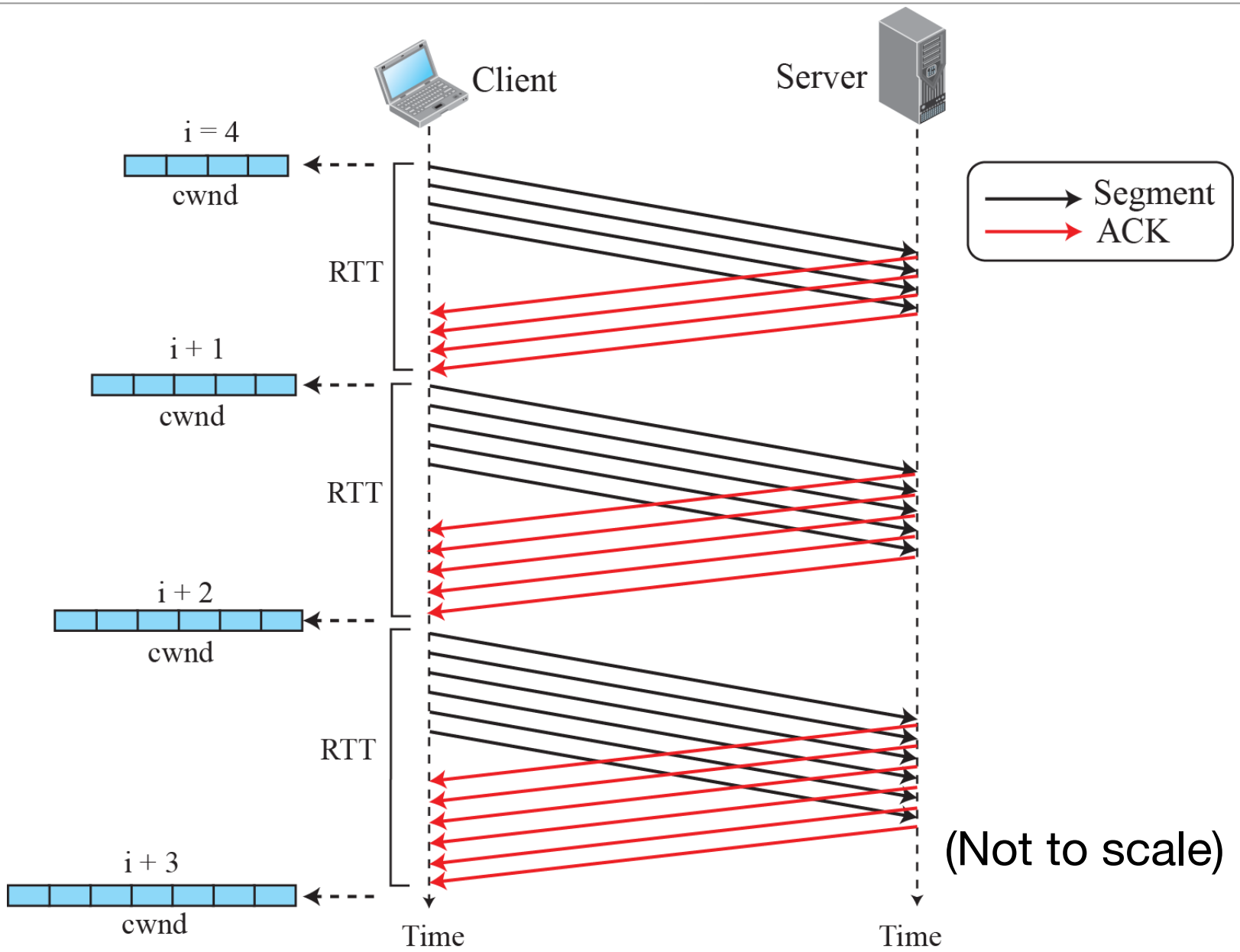
$$\textbf{Avg. Rate} \approx \frac{\text{Avg cwnd} * \text{MSS}}{\text{RTT}} \text{ Bytes/sec}$$

TCP Slow Start (Bandwidth Probing)



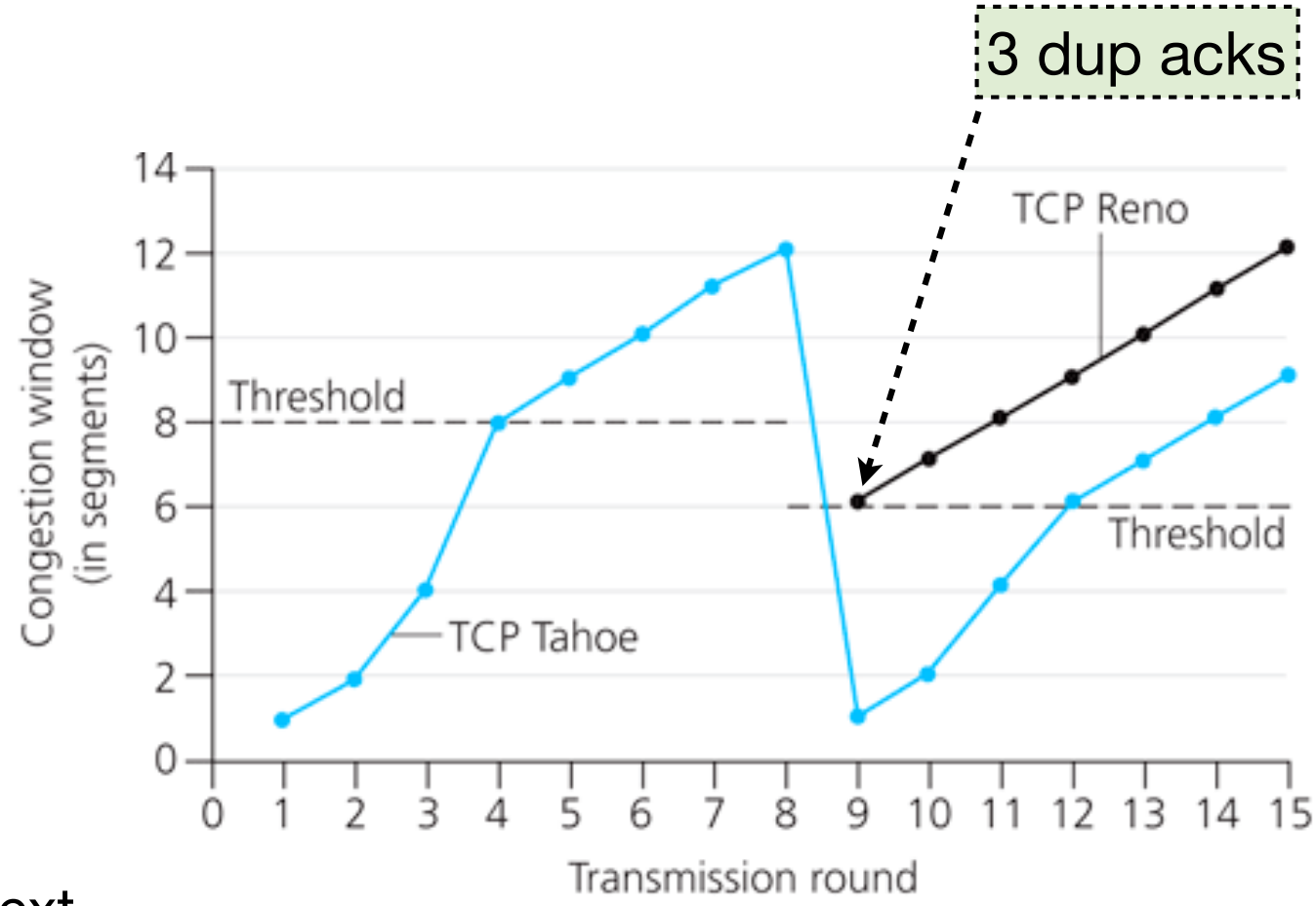
Until reaching `ssthres`
(Slow start threshold)

Congestion Avoidance : Additive Increase (AI)



Congestion Avoidance : Multiplicative Decrease (MD)

- Decrease cwnd when a "loss event" occurs.
  - Two versions: Tahoe and Reno

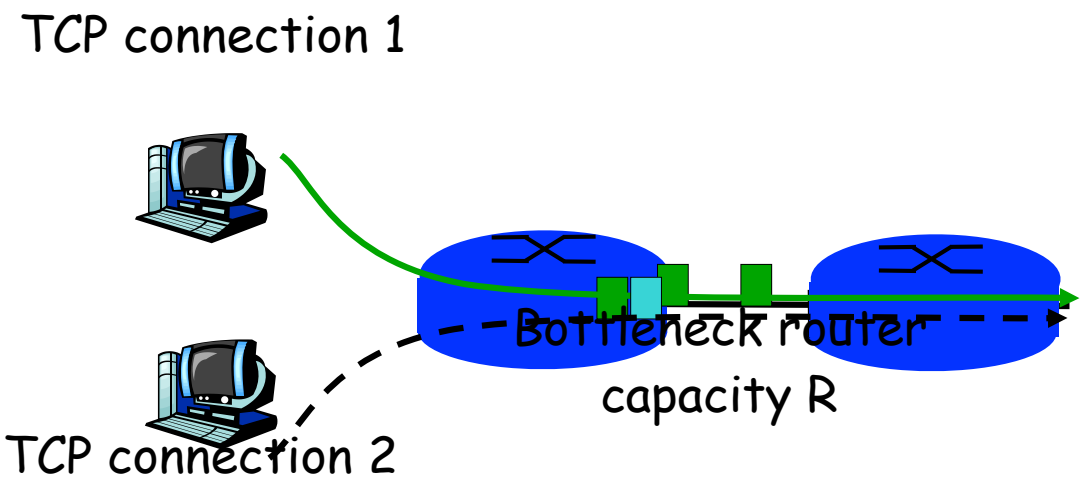


Kurose text

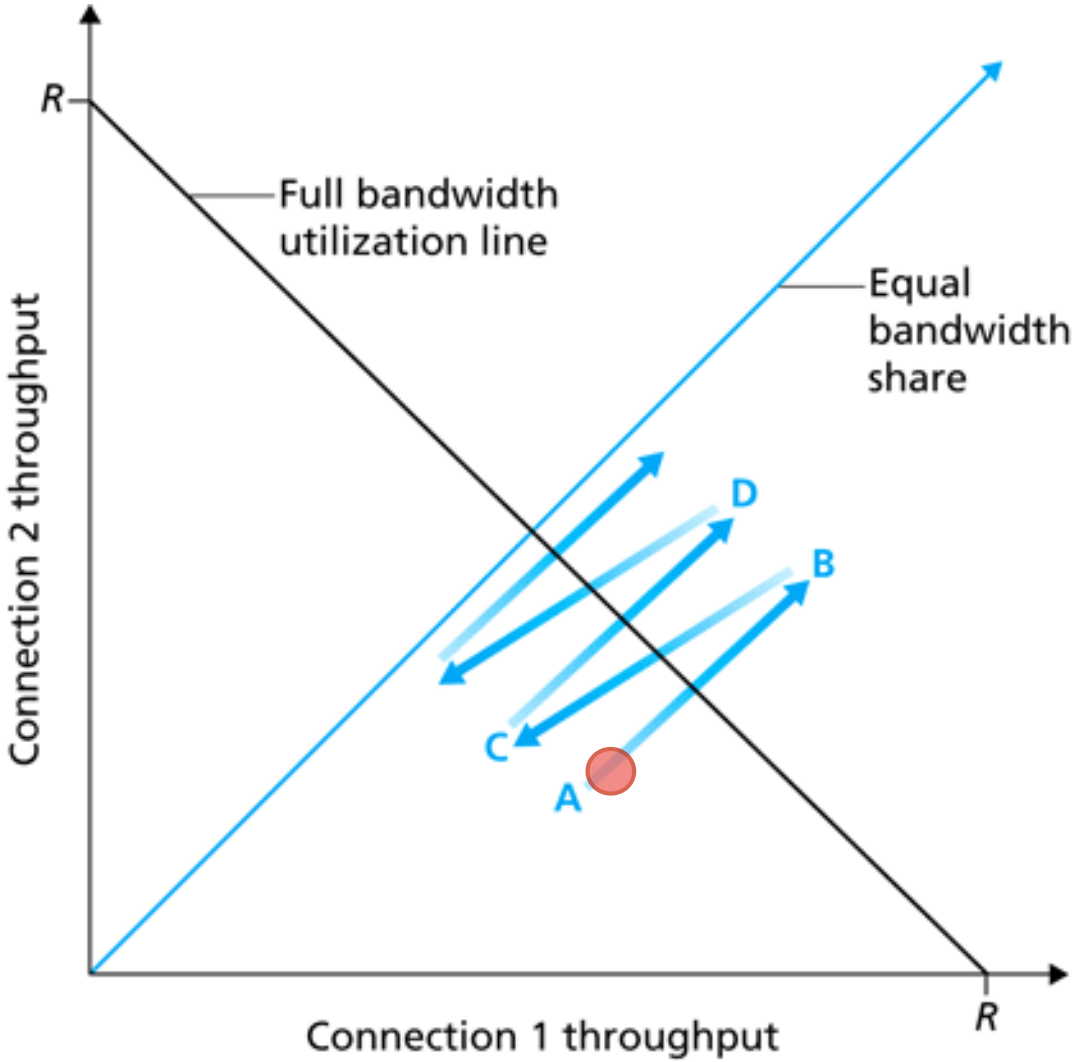
Figure 3.53 ♦ Evolution of TCP's congestion window (Tahoe and Reno)

TCP Fairness

- **Fairness goal:** if K TCP sessions share the same bottleneck link of bandwidth R, each should get an average rate of R/K.



Why is TCP fair?



Fairness property can be exploited by malicious hosts.

Figure 3.55 ♦ Throughput realized by TCP connections 1 and 2

Highly Simplified TCP throughput

- Macroscopic observation
  - Long-run approximate behavior
  - Ignore slow start (very short)

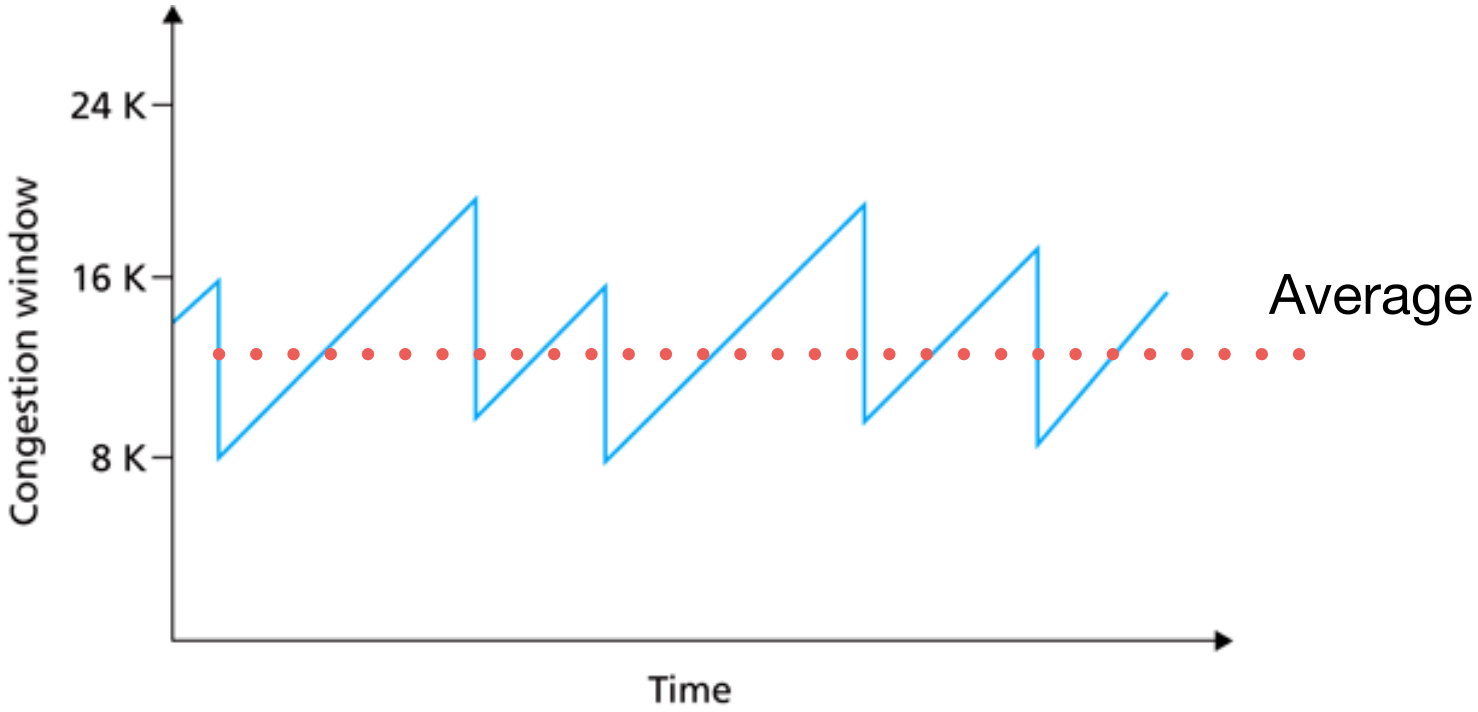
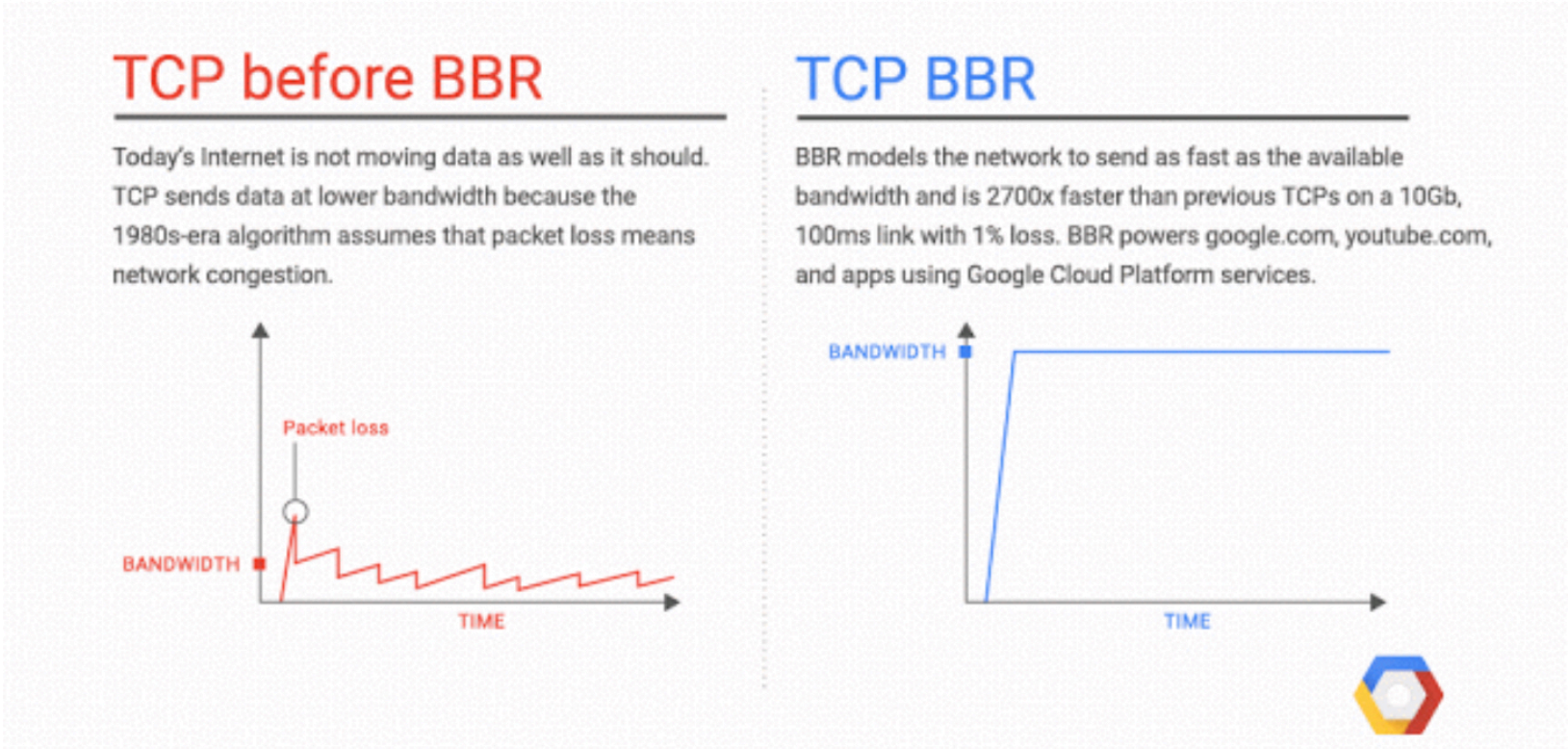


Figure 3.51 ♦ Additive-increase, multiplicative-decrease congestion control

GOOGLE ประกาศใช้ TCP BBR ในระบบเครือข่ายของ GCP เพิ่ม THROUGHPUT สูงสุด 2,700 เท่า

July 21, 2017
Cloud and Systems, Cloud Services, Google, IT Knowledge, IT Researches, Networking, Products, Switch and Router

Google ออกมาประกาศถึงการนำ TCP BBR ซึ่งเป็น Congestion Control Algorithm ใหม่สำหรับระบบเครือข่ายมาใช้งานภายใน Google Cloud Platform (GCP) ซึ่งช่วยให้ประสิทธิภาพการทำงานของระบบในบางแง่มุมสูงขึ้นถึง 2,700 เท่าเลยทีเดียวเมื่อเทียบกับ Algorithm แบบก่อนๆ



https://cloudplatform.googleblog.com/2017/07/TCP-BBR-congestion-control-comes-to-GCP-your-Internet-just-got-faster.html

Summary

- Internet Protocol (IP) for (hierarchical) addressing and forwarding in the network layer.
- Supplementary protocols
  - DHCP for address allocatdion
  - ICMP for error reporting and query
- Network address translation
  - Share public IP address to many private hosts.
  - Often implemented with port forwarding and access control list
- Network congestion control using TCP
  - Prevent congestion collapse
  - Also result in fairness among flows.

Midterm Exam

- Closed-book, calculator NOT allowed
- Multipart exam
  - Questions for short answers.
  - T/F questions
  - Multiple-choice questions
  - Questions for detailed solutions.