COMP 3331/9331: Computer Networks and Applications

Week 7

Network Layer I: Data Plane

Reading Guide: Chapter 4: Sections 4.1-4.3

Network Layer: outline

Our goals:

- understand principles behind network layer services, focusing on data plane:
  - network layer service models
  - forwarding versus routing
  - how a router works
  - generalized forwarding
- instantiation, implementation in the Internet

Network Layer, data plane: outline

4.1 Overview of Network layer
- data plane
- control plane

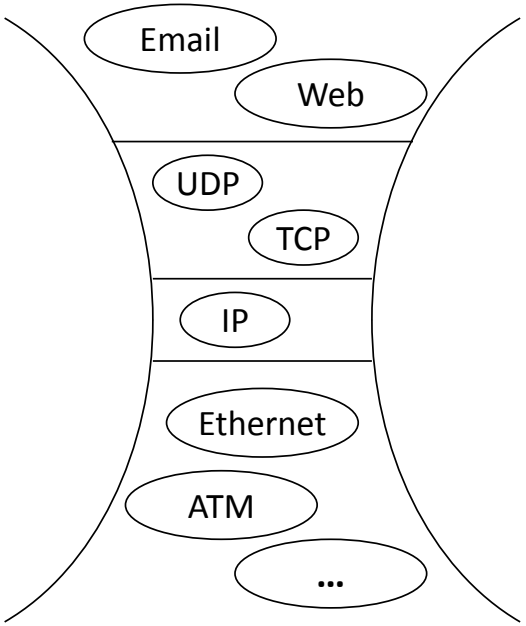
4.2 What's inside a router
-hardware design issues

4.3 IP: Internet Protocol
- datagram format
- fragmentation
- IPv4 addressing
- network address translation (NAT)

Some Background

- 1968: DARPAnet/ARPAnet (precursor to Internet)
  - (Defense) Advanced Research Projects Agency Network
- Mid 1970's: new networks emerge
  - SATNet, Packet Radio, Ethernet
  - All "islands" to themselves – didn't work together
- Big question: How to connect these networks?

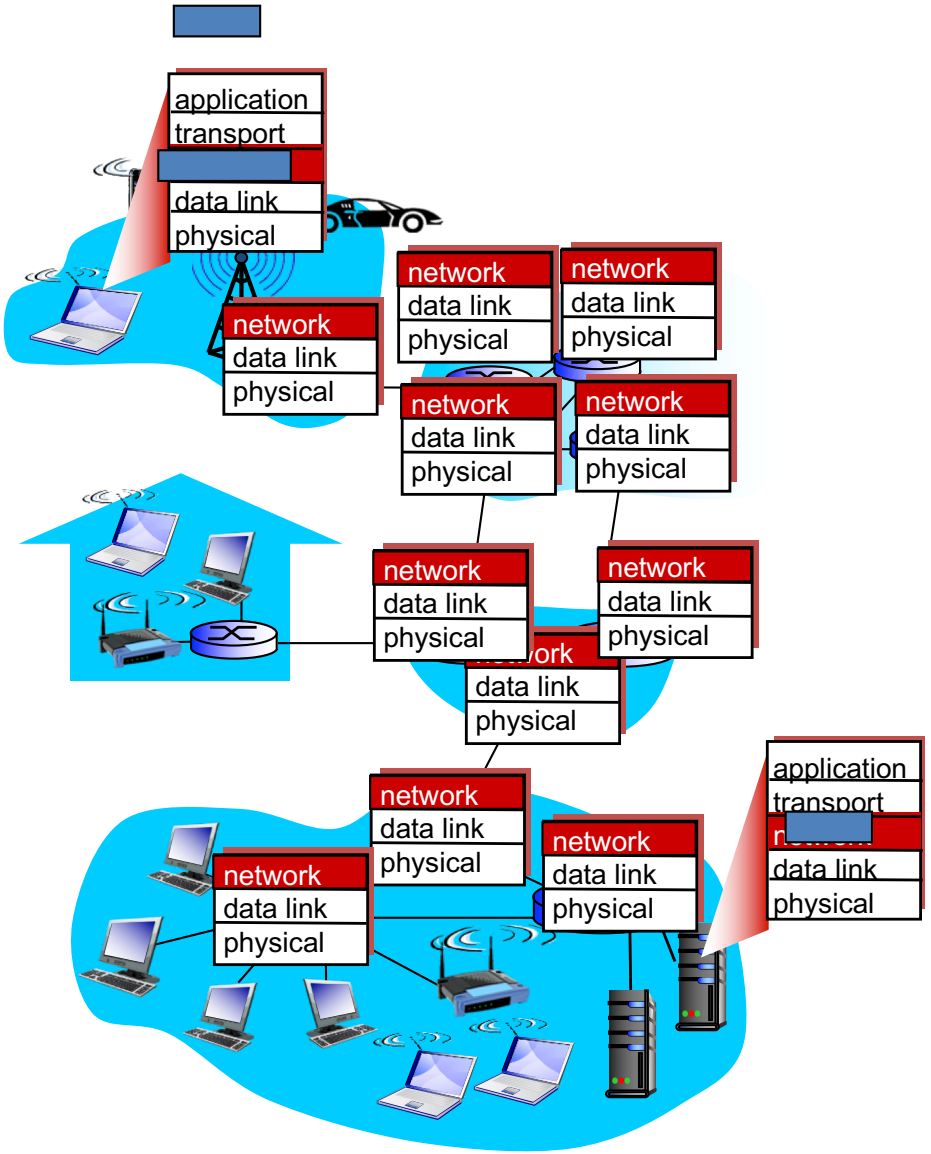
Internetworking



- Cerf & Kahn in 1974,
  - "A Protocol for Packet Network Intercommunication"
  - Foundation for the modern Internet
- **Routers** forward **packets** from source to destination
  - May cross many separate networks along the way
- All packets use a common **Internet Protocol**
  - Any underlying data link protocol
  - Any higher layer transport protocol

Network Layer

- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- on receiving side, delivers segments to transport layer
- network layer protocols in *every* host, router
- router examines header fields in all IP datagrams passing through it



Two key nework-layer functions

- *forwarding:* move packets from router's input to appropriate router output
- *routing:* determine route taken by packets from source to dest.
  - *routing algorithms*

analogy:

- *routing:* process of planning trip from source to dest
- *forwarding:* process of getting through single interchange

When should a router perform routing? And fowarding ?

A: Do both when a packet arrives

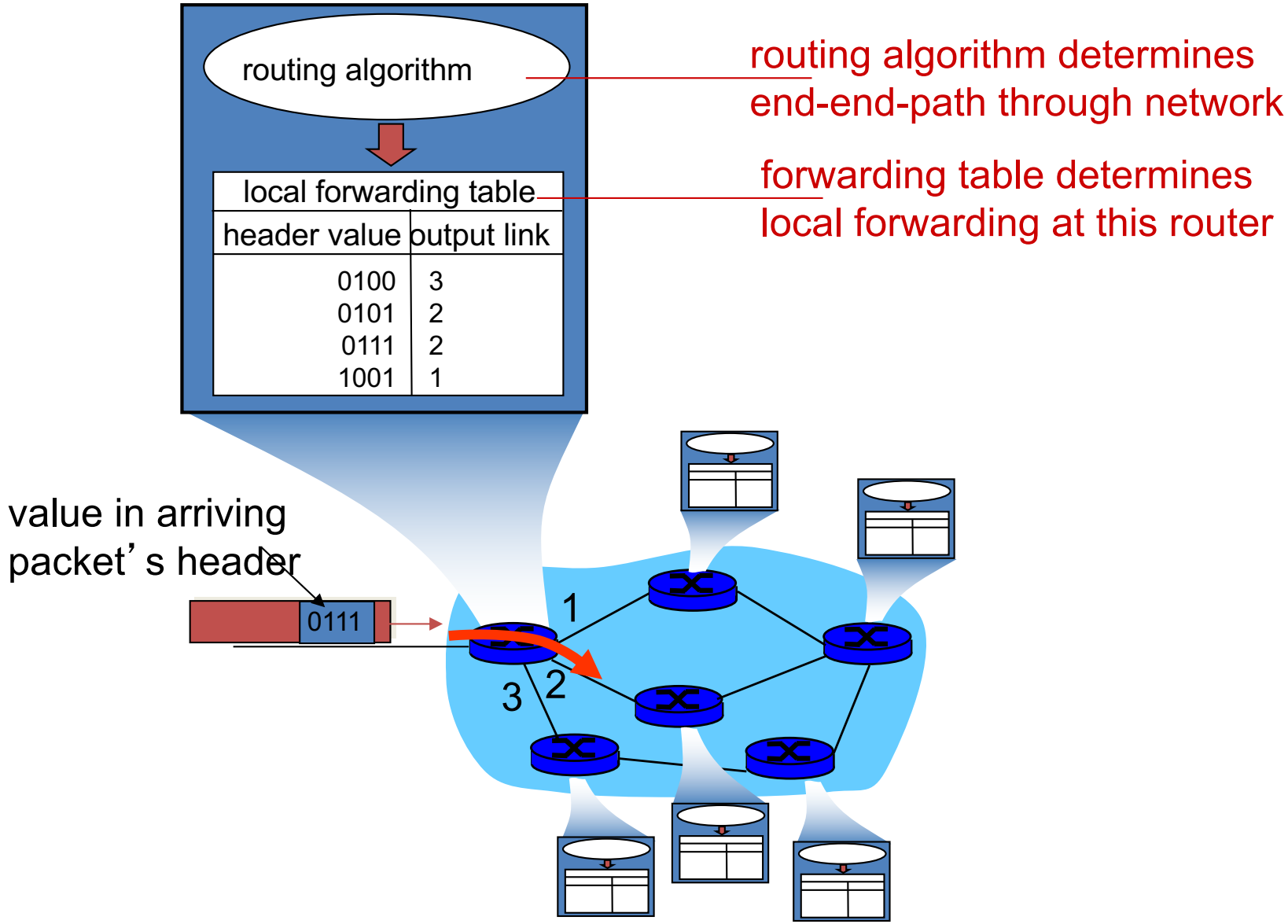
B: Route in advance, forward when a packet arrives

C: Forward in advance, route when a packet arrives

D: Do both in advance

E: Some other combination

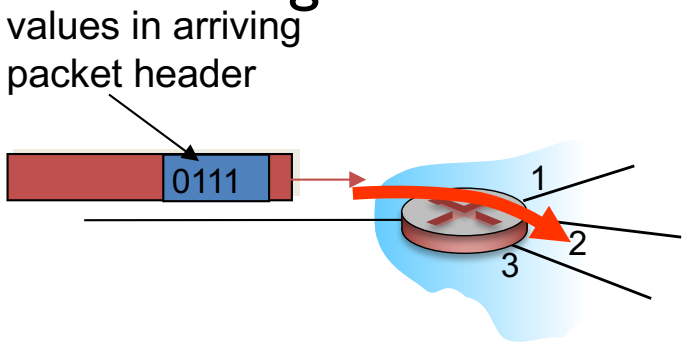
Interplay between routing and forwarding



Network Layer: data vs control plane

Data plane

- local, per-router function
- determines how datagram arriving on router input port is forwarded to router output port
- forwarding function

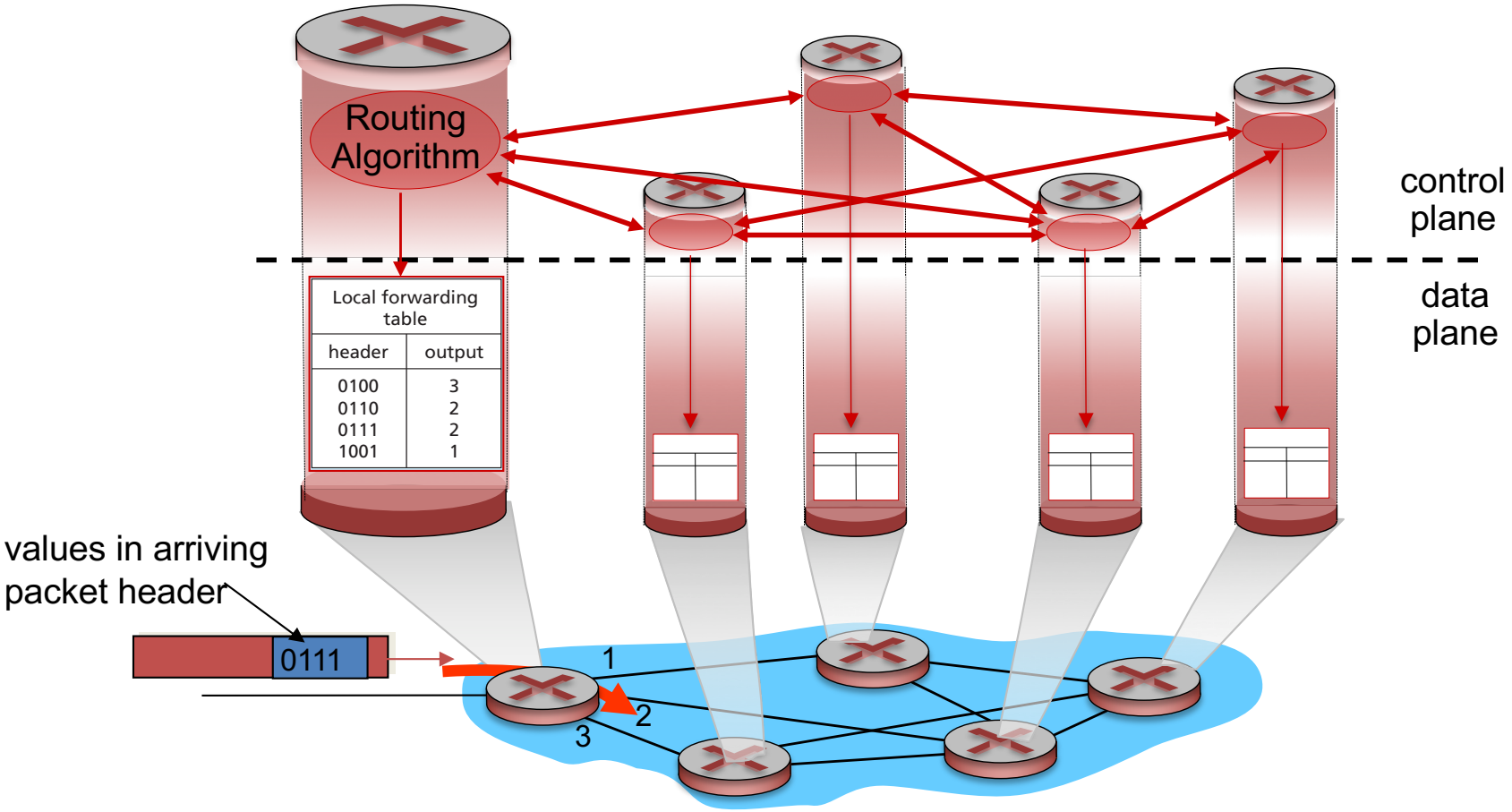


Control plane

- network-wide logic
- determines how datagram is routed among routers along end-end path from source host to destination host
- two control-plane approaches:
  - *traditional routing algorithms:* implemented in routers
  - *software-defined networking (SDN)*: centralised (remote) servers

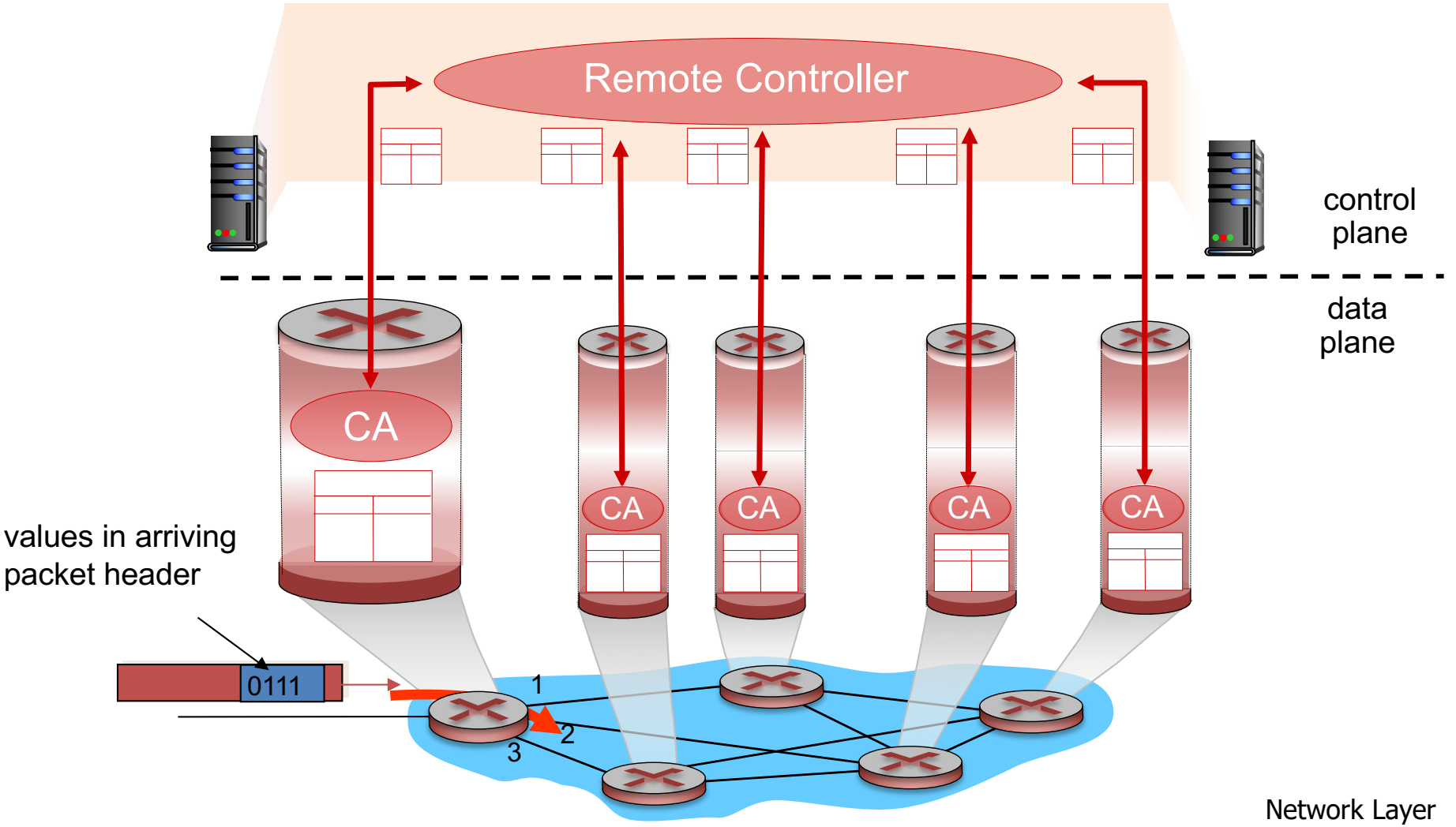
Per-router control plane

Individual routing algorithm components *in each and every router* interact in the control plane



Logically centralized control plane (SDN)

A distinct (typically remote) controller interacts with local control agents (CAs)



Network Layer: service model

Q: What *service model* for "channel" transporting datagrams from sender to receiver?

example services for individual datagrams:

- guaranteed delivery
- guaranteed delivery with less than 40 msec delay

example services for a flow of datagrams:

- in-order datagram delivery
- guaranteed minimum bandwidth to flow
- restrictions on changes in inter-packet spacing

Network Layer: service models

Network Architecture	Service Model	Guarantees ?				Congestion feedback
		Bandwidth	Loss	Order	Timing	
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

No need to memorise this table (ATM stands for asynchronous transfer mode, which is a backend technology used by some ISPs to implement high-speed backbone links)

Network Layer, data plane: outline

4.1 Overview of Network layer
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- control plane

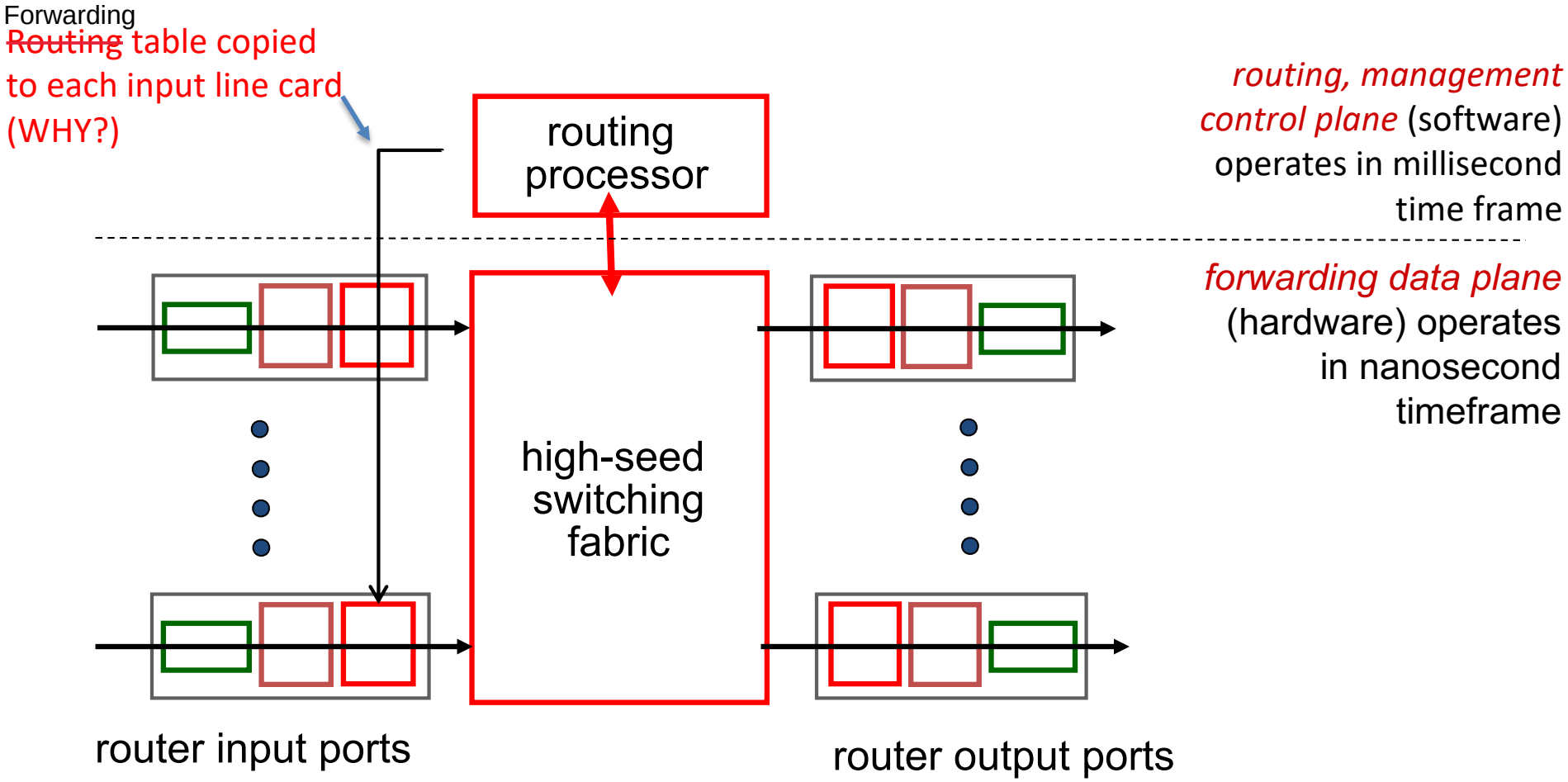
4.2 What's inside a router

4.3 IP: Internet Protocol
- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

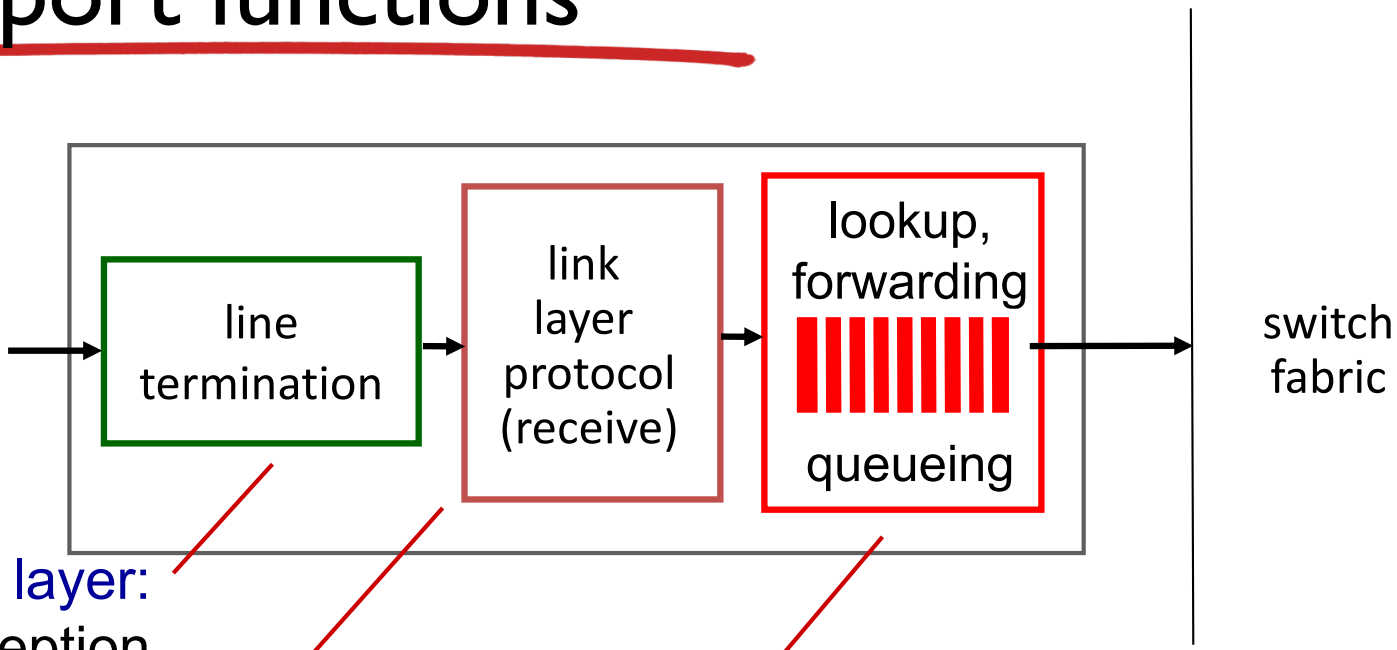
sometimes forwading table is also called routing table

Router architecture overview

- high-level view of generic router architecture:



Input port functions



physical layer:
bit-level reception

data link layer:
e.g., Ethernet

decentralized switching:

- using header field values, lookup output port using forwarding table in input port memory *("match plus action")*
- goal: complete input port processing at 'line speed'
- queuing: if datagrams arrive faster than forwarding rate into switch fabric

Destination-based forwarding

forwarding table

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Q: but what happens if ranges don't divide up so nicely?

Longest prefix matching

longest prefix matching

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Destination Address Range	Link interface
11001000 00010111 00010*** *********	0
11001000 00010111 00011000 *********	1
11001000 00010111 00011*** *********	2
otherwise	3

examples:

DA: 11001000 00010111 00010110 10100001 which interface?

DA: 11001000 00010111 00011000 10101010 which interface?

Quiz: Longest prefix matching

- On which outgoing interface will a packet destined to 11011001 be forwarded?

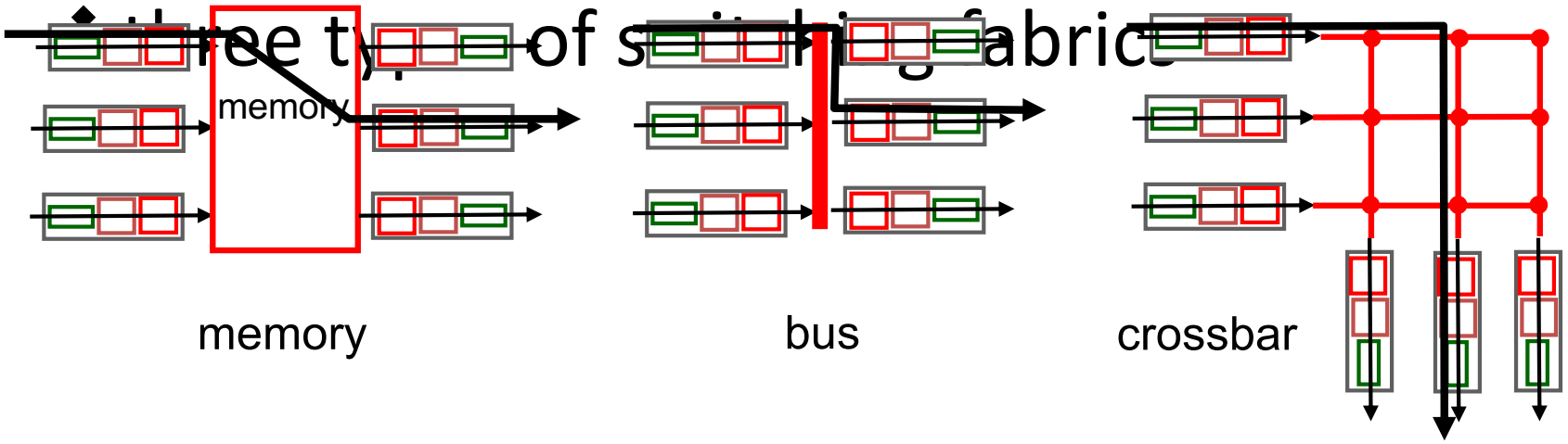
Prefix	Interface
1*	A
11*	B
111*	C
Default	D

Longest prefix matching

- we'll see *why* longest prefix matching is used shortly, when we study addressing
- longest prefix matching: often performed using ternary content addressable memories (TCAMs)
  - *content addressable:* present address to TCAM: retrieve address in one clock cycle, regardless of table size
  - Cisco Catalyst: up ~1M routing table entries in TCAM

Switching fabrics

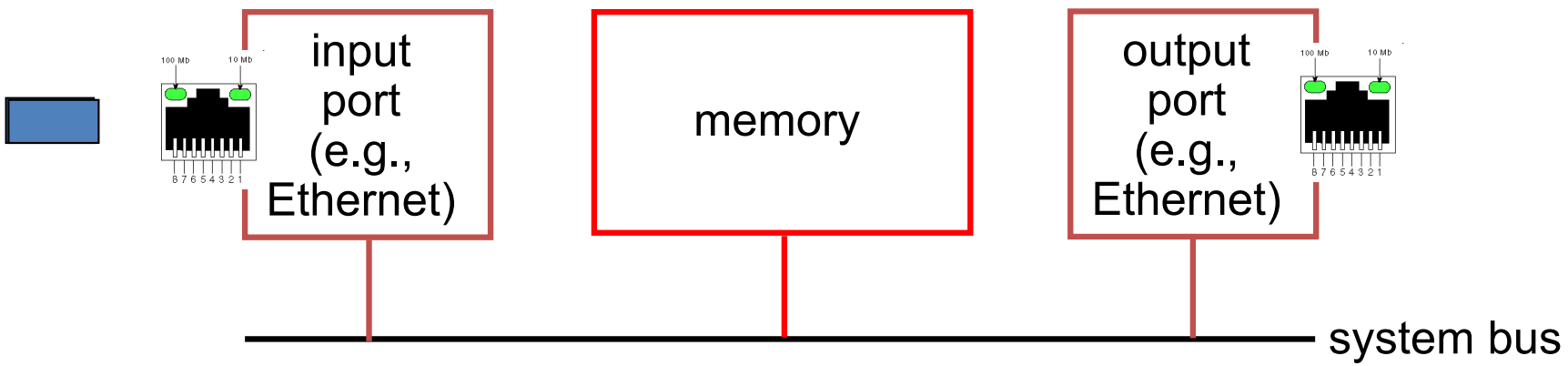
- transfer packet from input buffer to appropriate output buffer
- switching rate: rate at which packets can be transfer from inputs to outputs
  - often measured as multiple of input/output line rate
  - N inputs: switching rate N times line rate desirable
- three types of switching fabrics



Switching via memory

first generation routers:

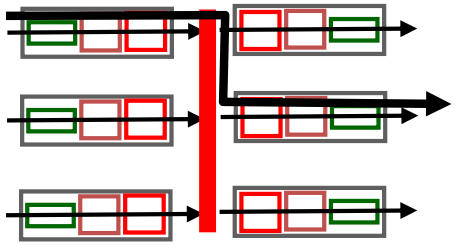
- traditional computers with switching under direct control of CPU
- packet copied to system's memory
- speed limited by memory bandwidth (2 bus crossings per datagram)



Switching via a bus

- datagram from input port memory

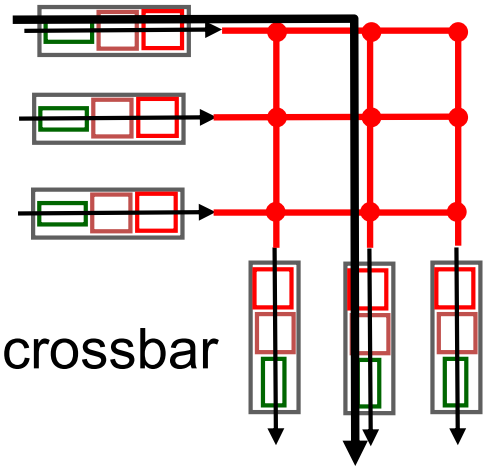
  to output port memory via a shared bus
- *bus contention:* switching speed limited by bus bandwidth
- 32 Gbps bus, Cisco 5600: sufficient speed for access and enterprise routers



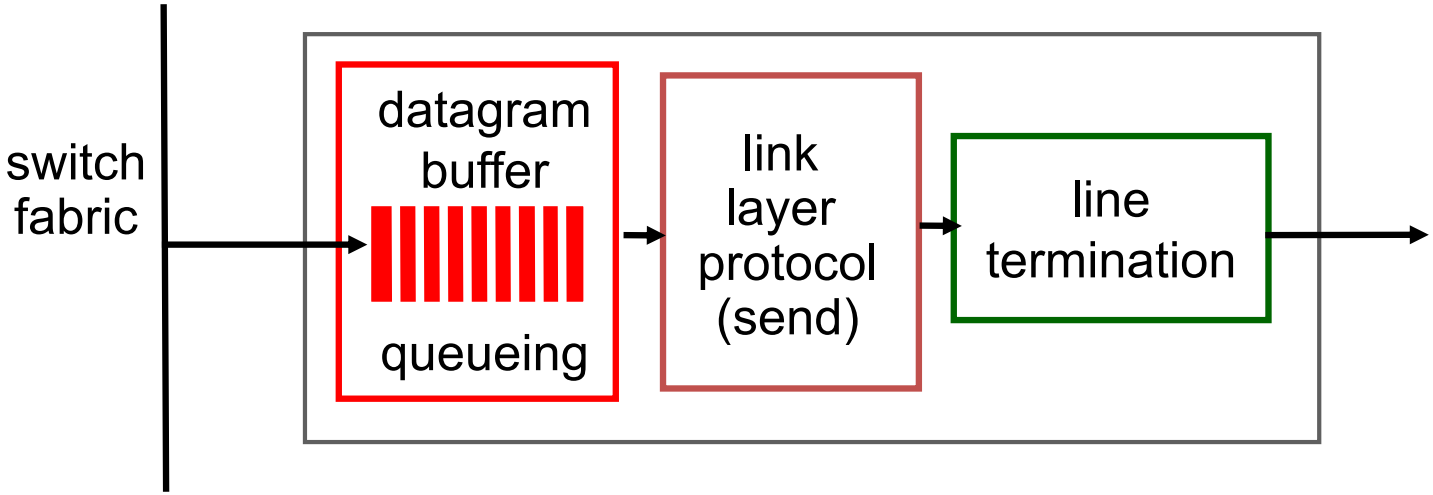
bus

Switching via interconnection network

- overcome bus bandwidth limitations
- banyan networks, crossbar, other interconnection nets initially developed to connect processors in multiprocessor
- advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.
- Cisco 12000: switches 60 Gbps through the interconnection network

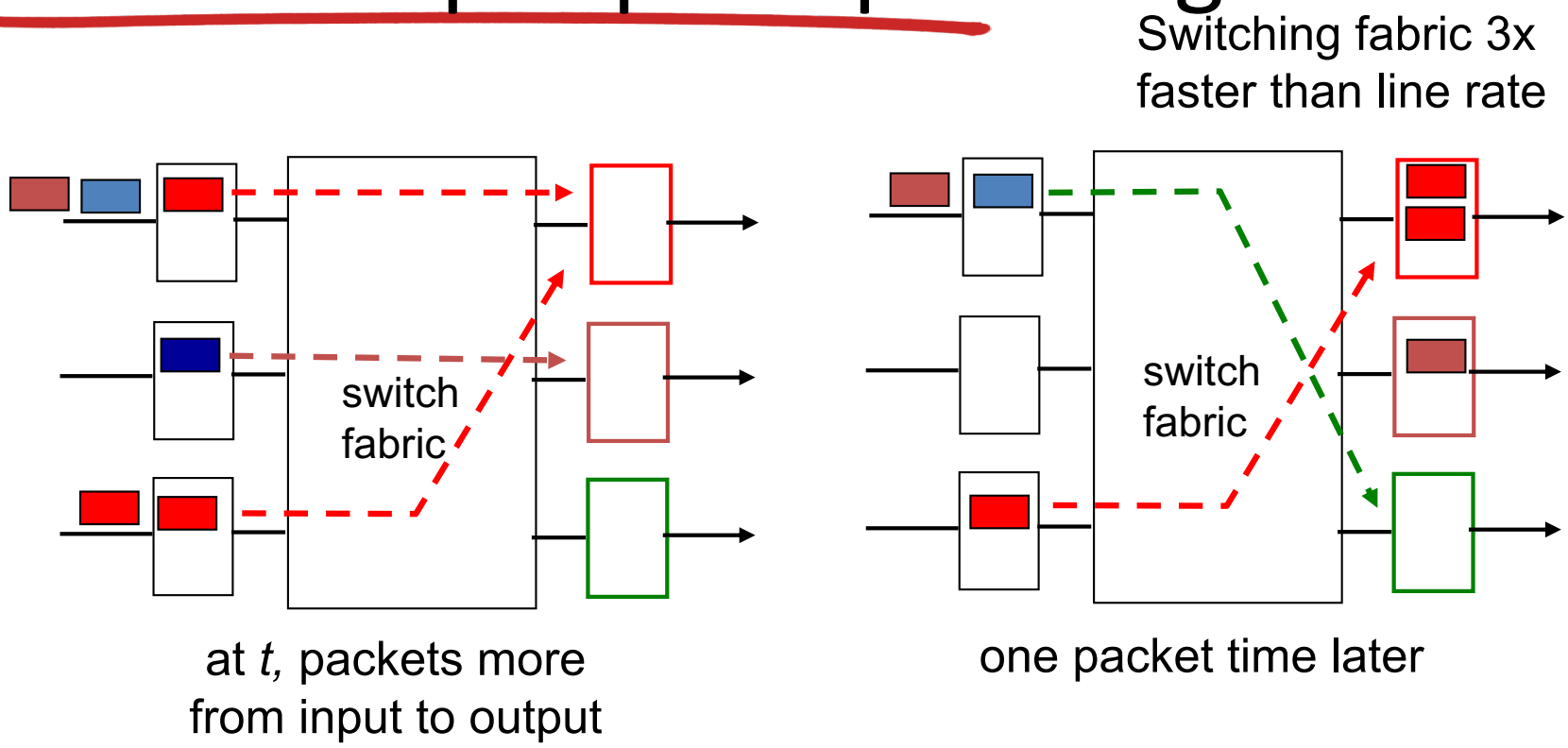


Output ports



- *buffering* required when datagrams arrive from fabric faster than the transmission rate
- *scheduling discipline* chooses among queued datagrams for transmission

Output port queueing



- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow!*

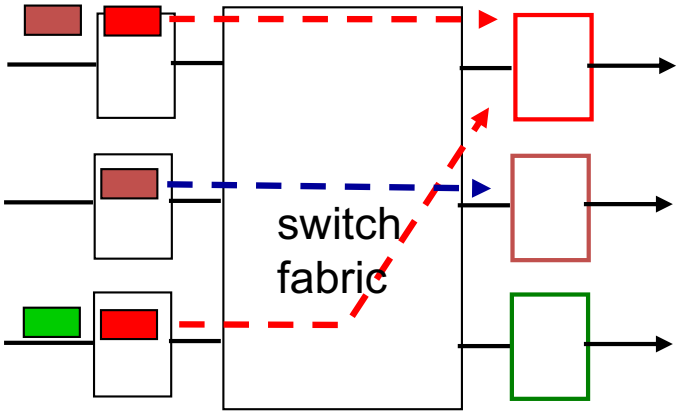
How much buffering?

- RFC 3439 rule of thumb: average buffering equal to “typical” RTT (say 250 msec) times link capacity C
  - e.g., C = 10 Gpbs link: 2.5 Gbit buffer
- recent recommendation: with *N* flows, buffering equal to $\frac{RTT \cdot C}{\sqrt{N}}$

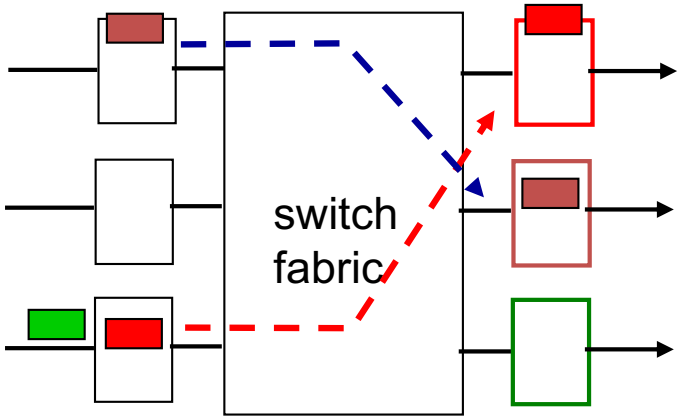
Input port queuing

Consider a basic crossbar fabric: only one packet can be transferred to a given outport at a time

- fabric slower than input ports combined -> queueing may occur at input queues
  - *queueing delay and loss due to input buffer overflow!*
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward



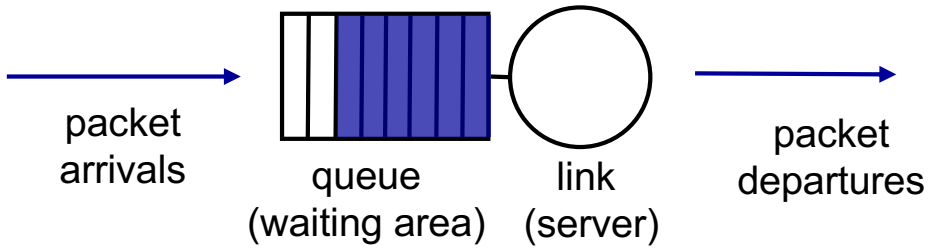
output port contention:
only one red datagram can be transferred.
lower red packet is blocked



one packet time later:
green packet
experiences HOL
blocking

Scheduling mechanisms

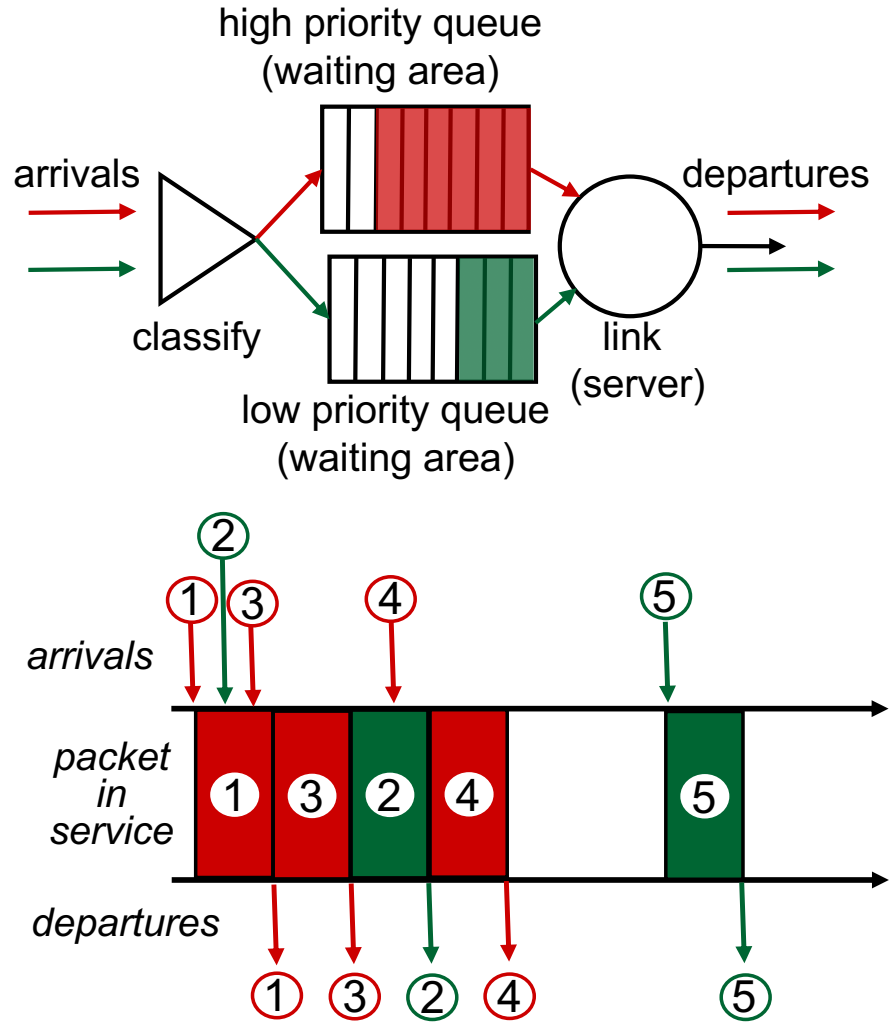
- *scheduling:* choose next packet to send on link
- *FIFO (first in first out) scheduling:* send in order of arrival to queue
  - real-world example?
  - *discard policy:* if packet arrives to full queue: who to discard?
    - *tail drop:* drop arriving packet
    - *priority:* drop/remove on priority basis
    - *random:* drop/remove randomly



Scheduling policies: priority

priority scheduling: send highest priority queued packet

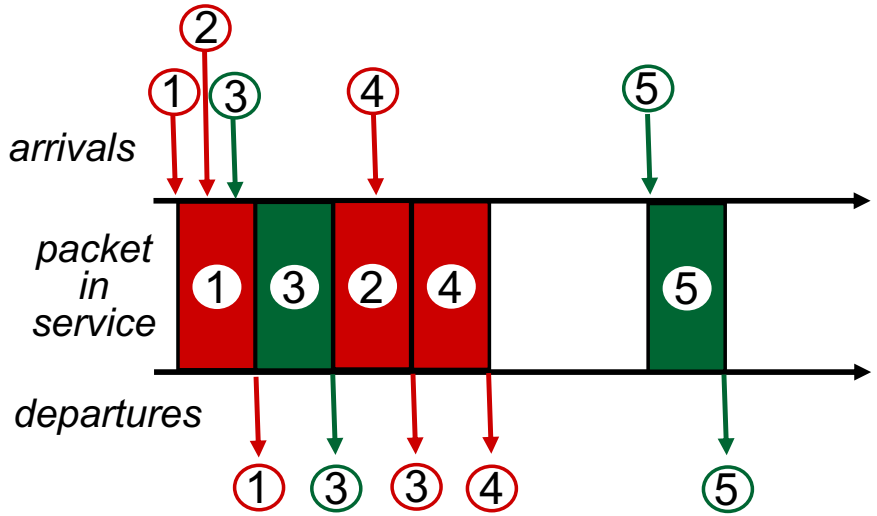
- multiple *classes*, with different priorities
  - class may depend on marking or other header info, e.g. IP source/dest, port numbers, etc.
  - real world example?



Scheduling policies: still more

Round Robin (RR) scheduling:

- multiple classes
- cyclically scan class queues, sending one complete packet from each class (if available)
- real world example?



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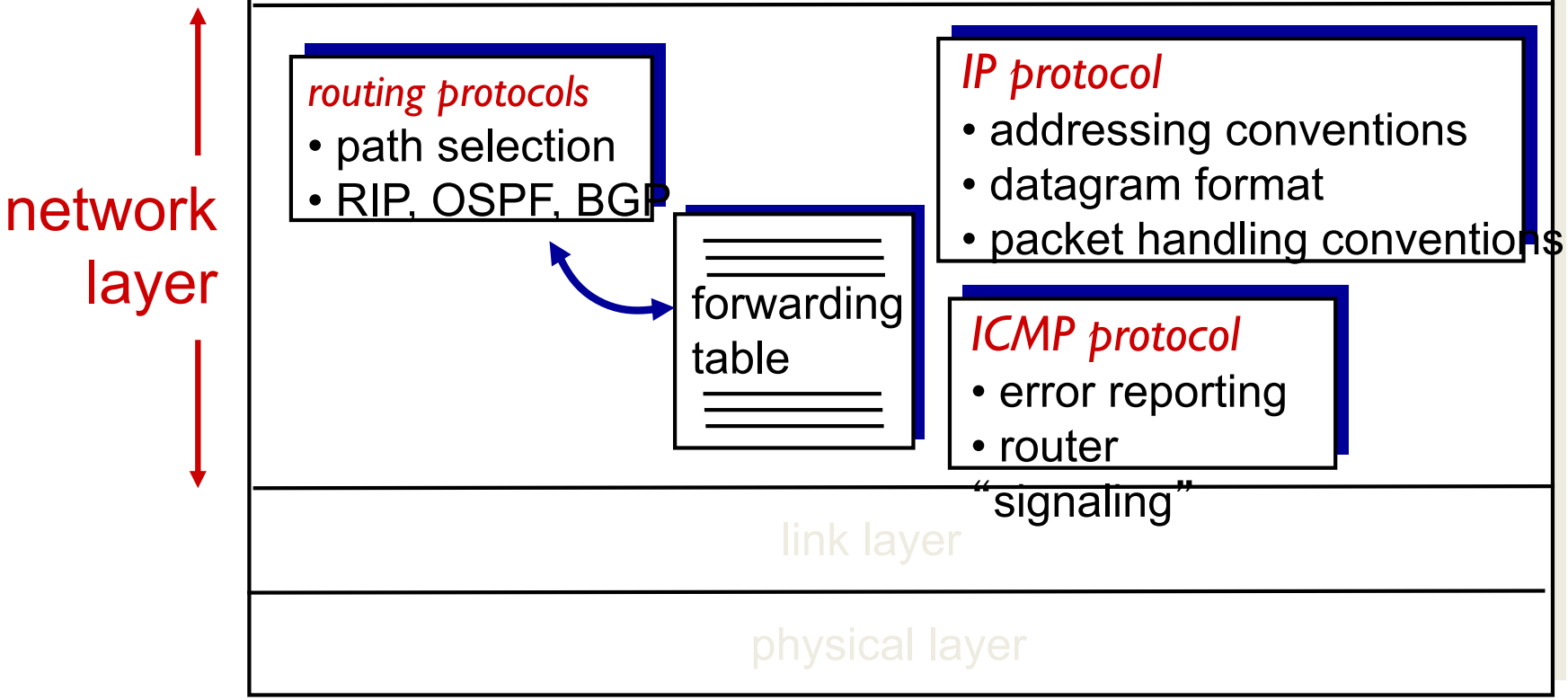
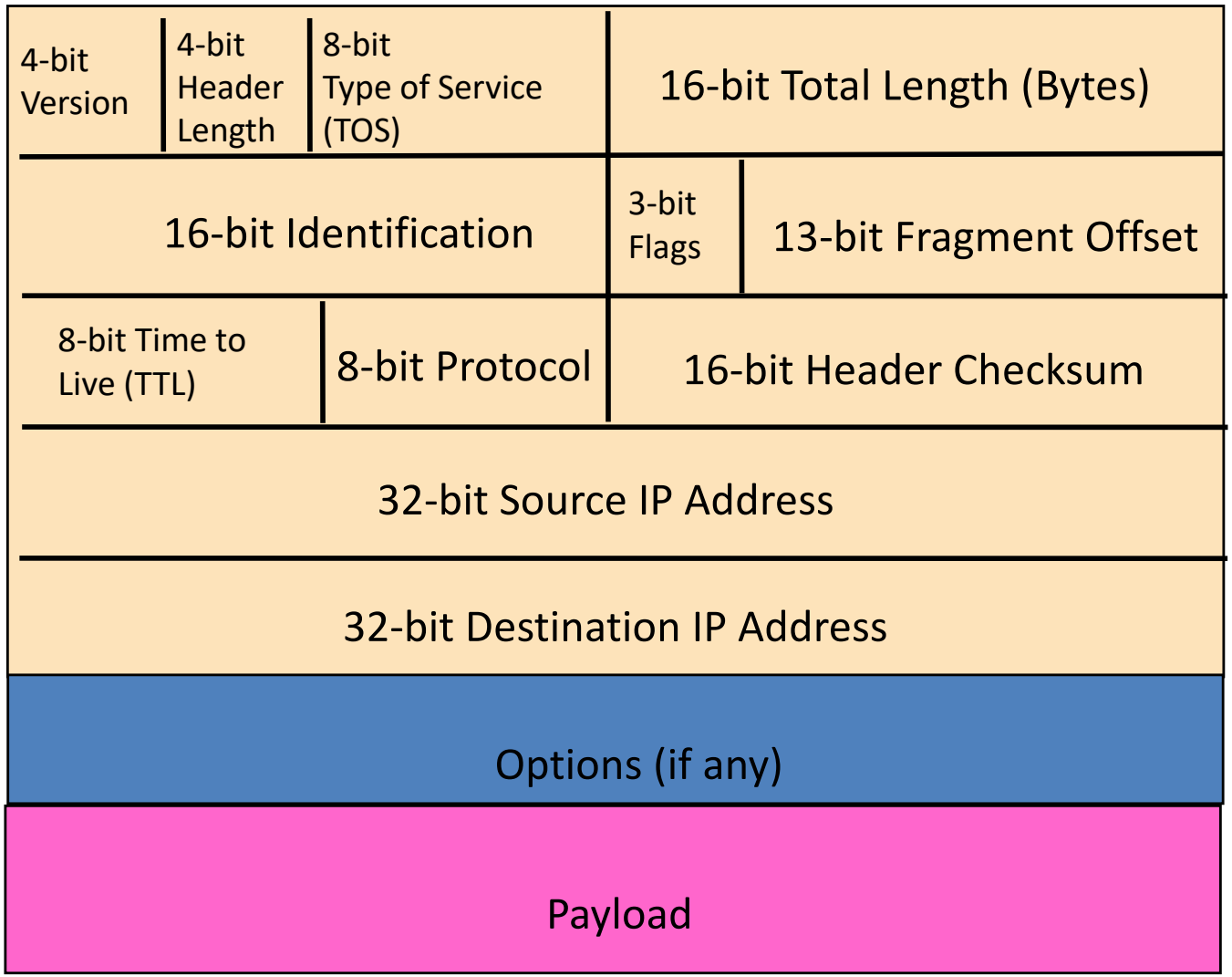
The Internet network layer

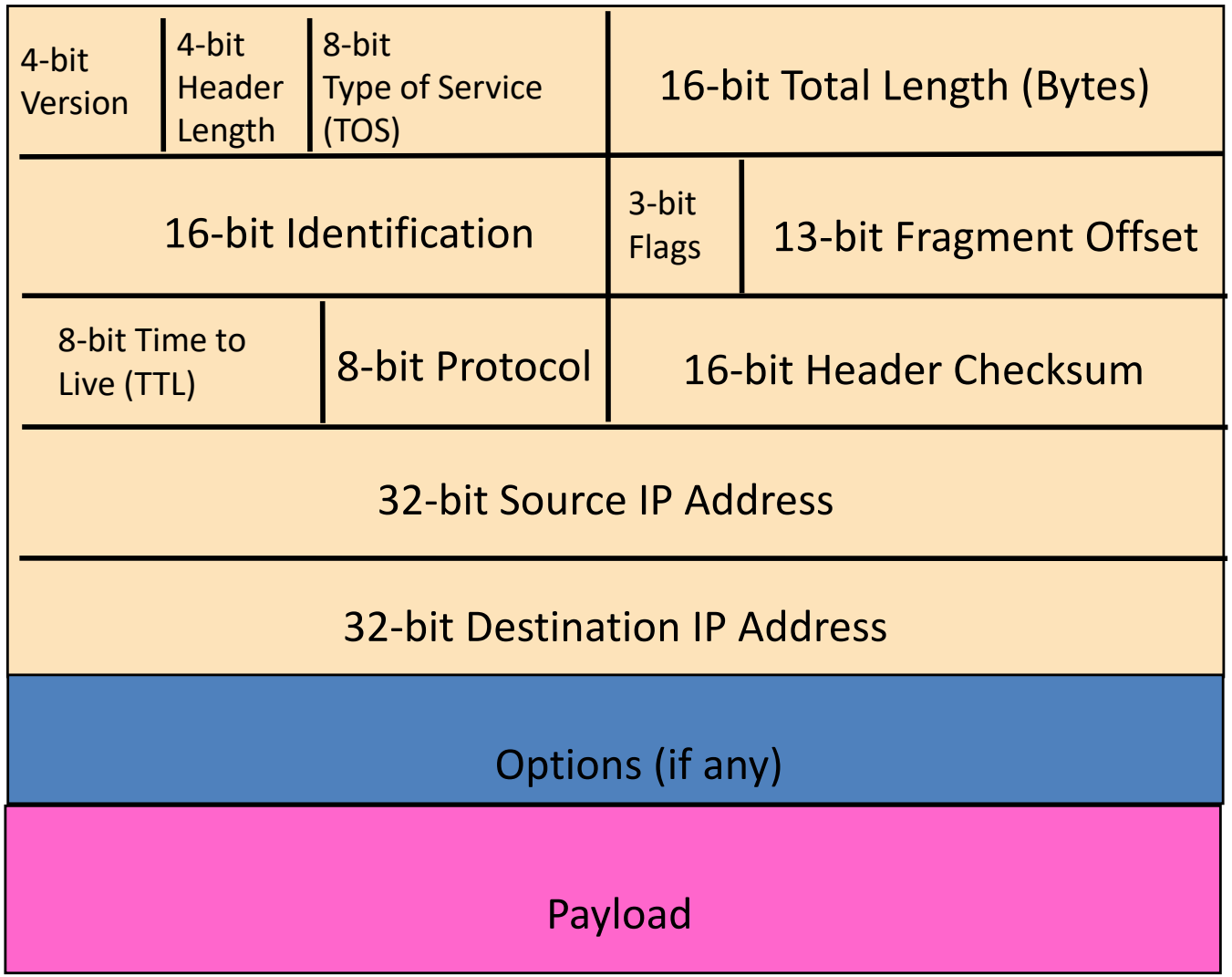
host, router network layer functions:



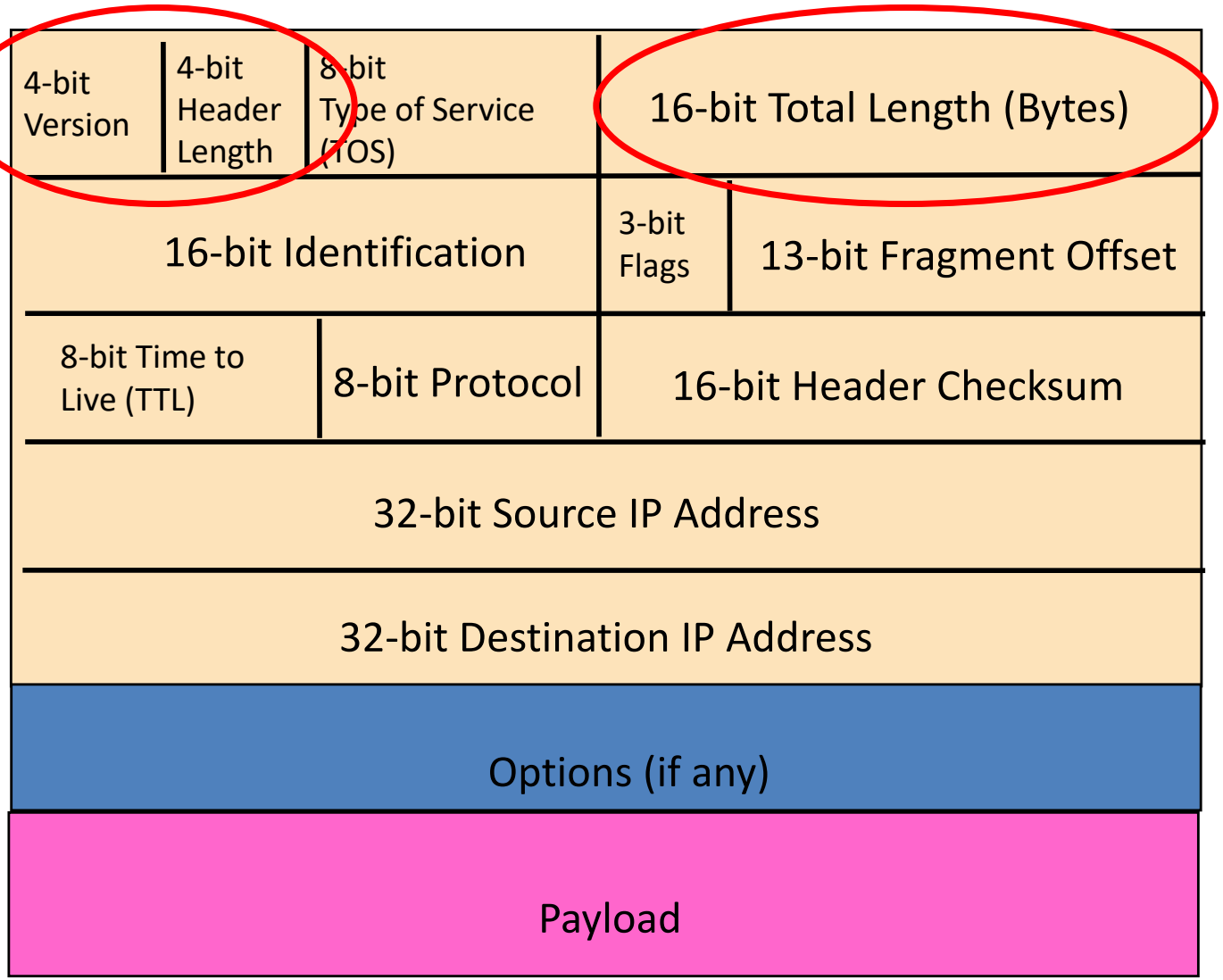
IP Packet Structure



20 Bytes of Standard Header, then Options



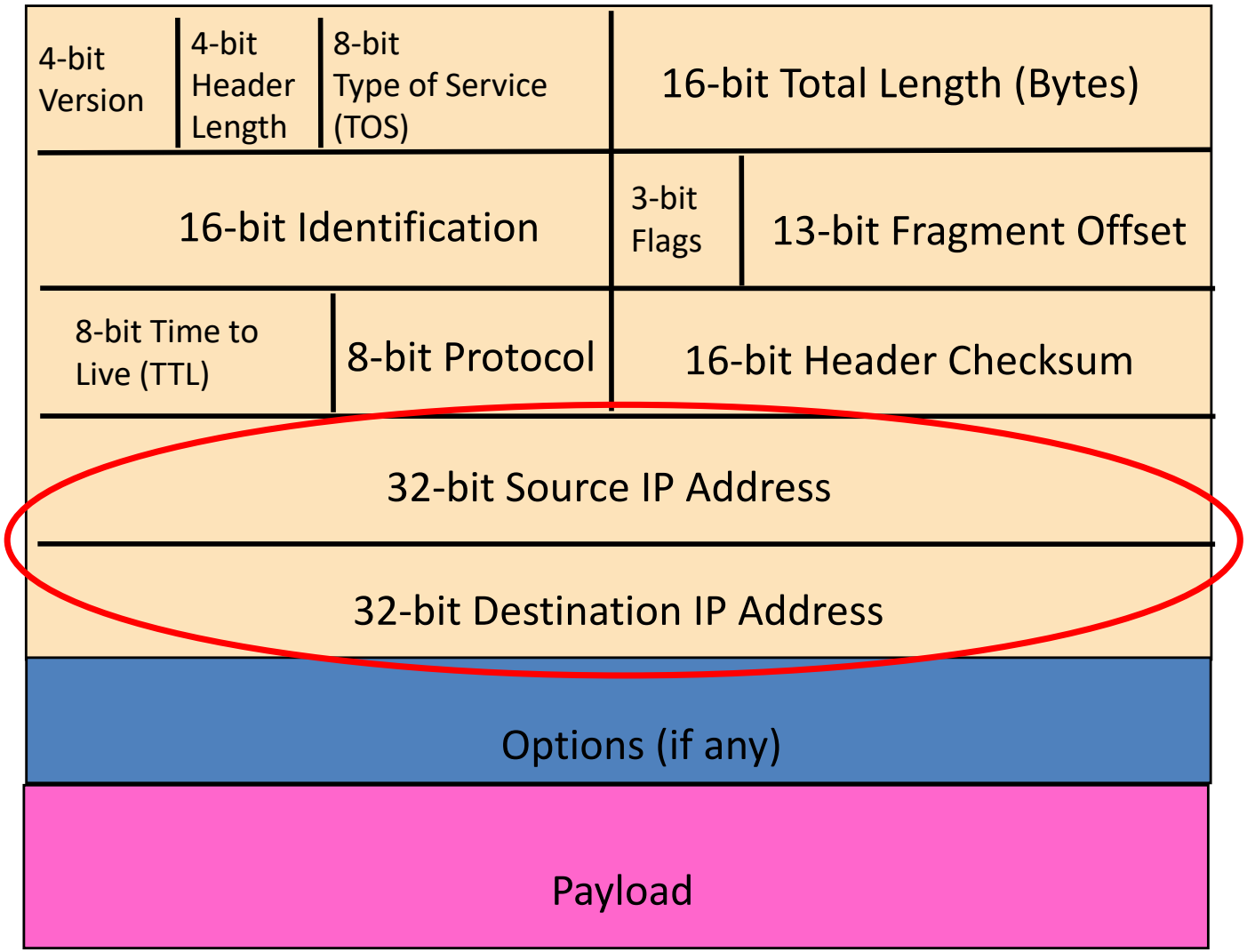
Fields for Reading Packet Correctly



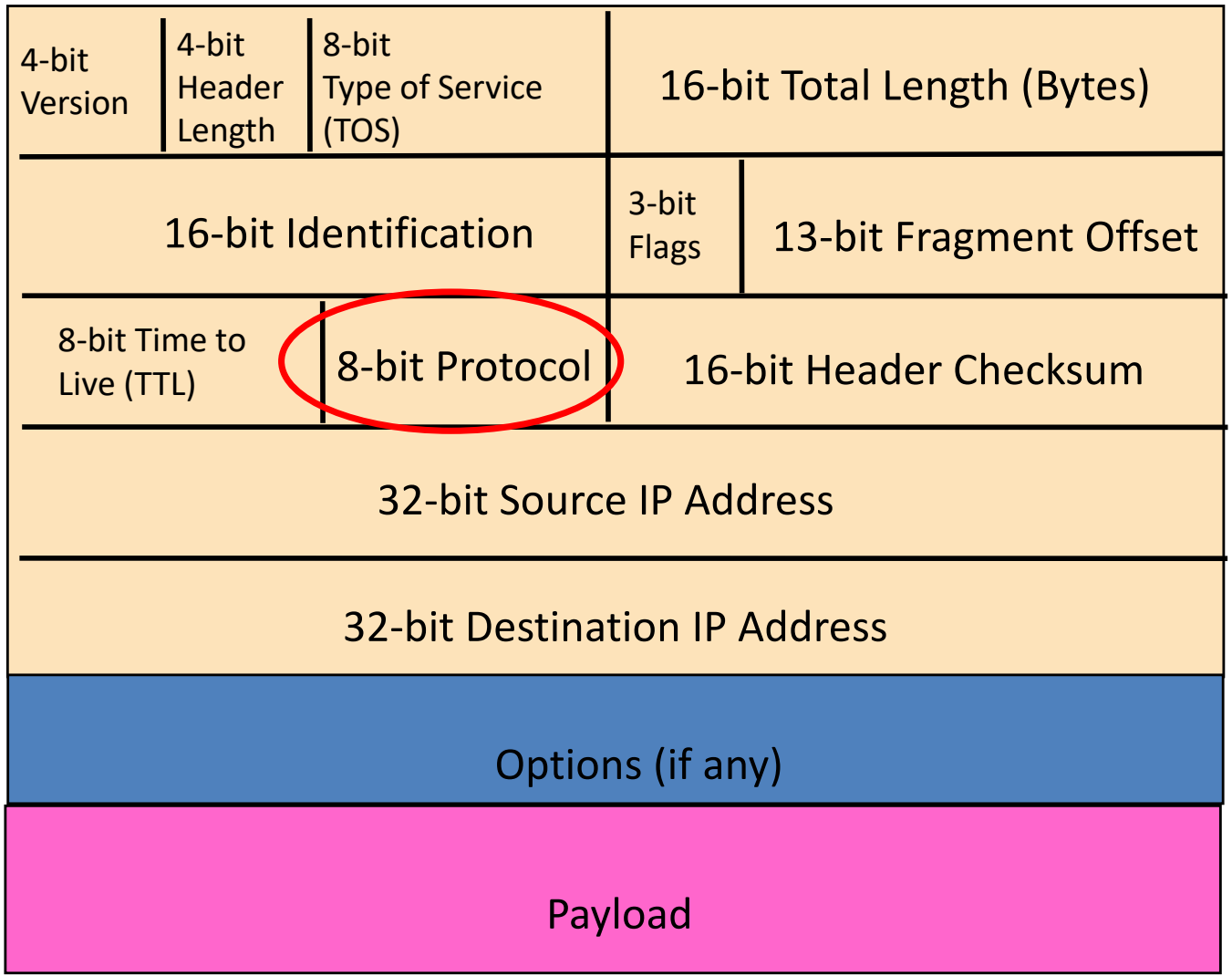
Reading Packet Correctly

- Version number (4 bits)
  - Indicates the version of the IP protocol
  - Necessary to know what other fields to expect
  - Typically “4” (for IPv4), and sometimes “6” (for IPv6)
- Header length (4 bits)
  - Number of 32-bit words in the header
  - Typically “5” (for a 20-byte IPv4 header)
  - Can be more when IP options are used
- Total length (16 bits)
  - Number of bytes in the packet
  - Maximum size is 65,535 bytes (2^{16} -1)
  - … though underlying links may impose smaller limits

Fields for Reaching Destination and Back

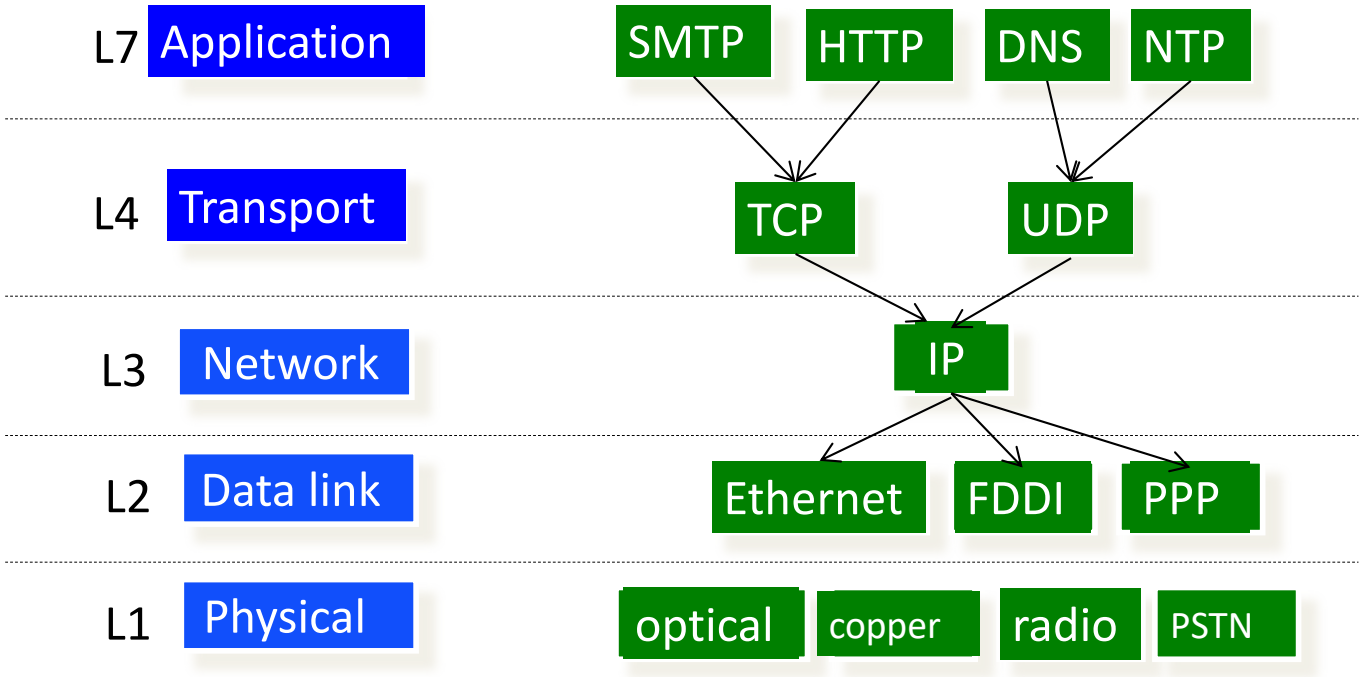


Telling End-Host How to Handle Packet



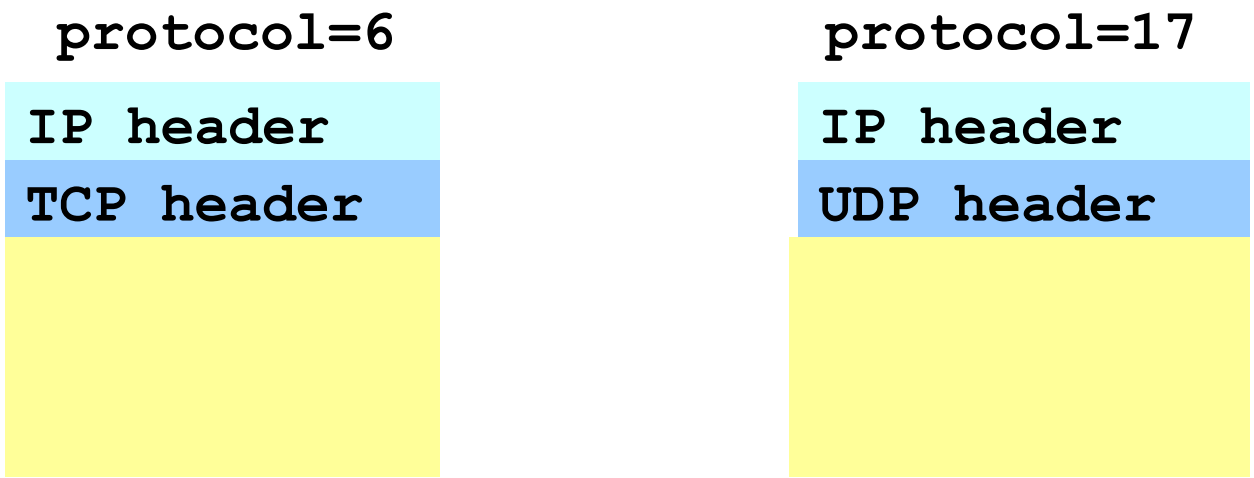
Telling End-Host How to Handle Packet

- Protocol (8 bits)
  - Identifies the higher-level protocol
  - Important for demultiplexing at receiving host



Telling End-Host How to Handle Packet

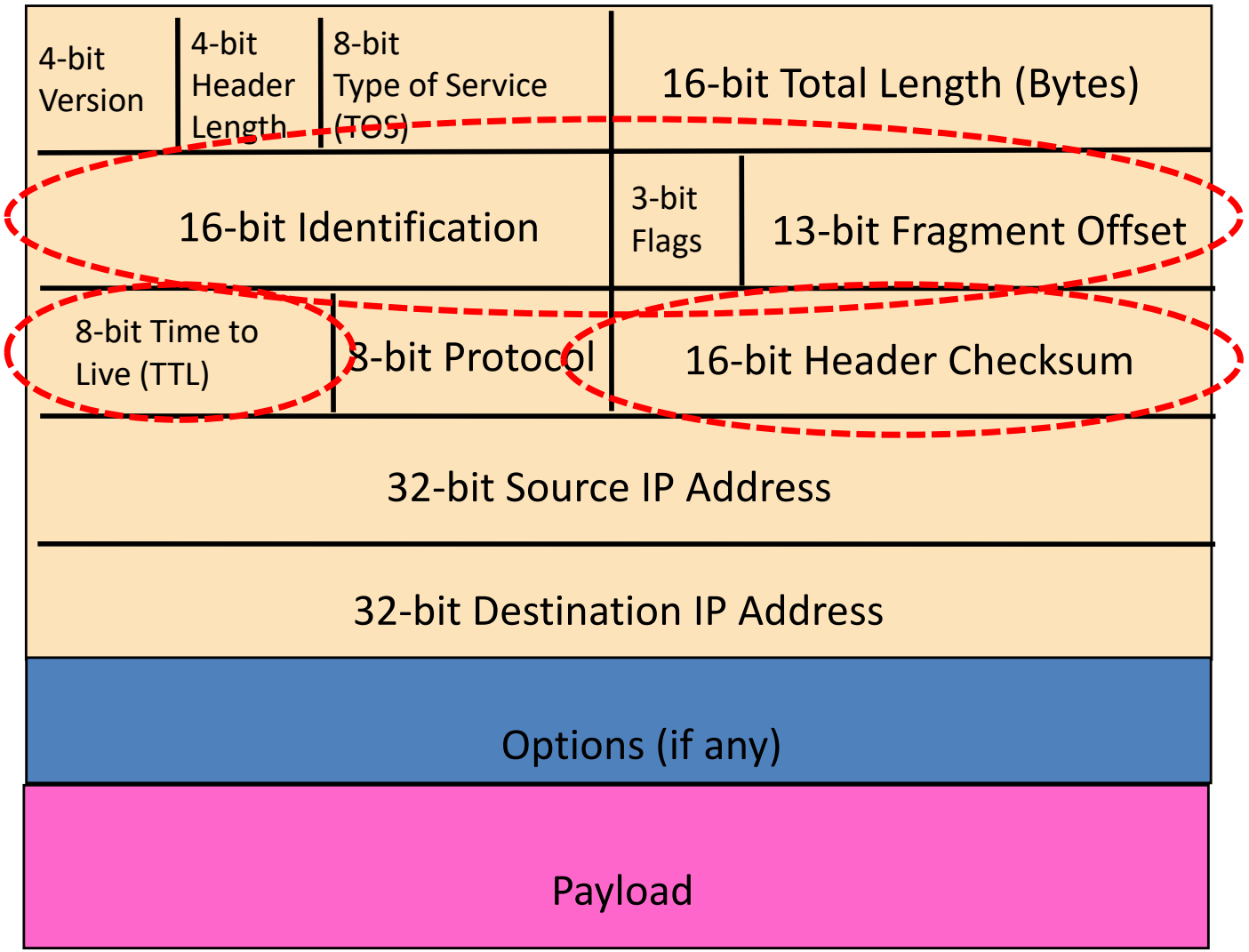
- Protocol (8 bits)
  - Identifies the higher-level protocol
  - Important for demultiplexing at receiving host
- Most common examples
  - E.g., “6” for the Transmission Control Protocol (TCP)
  - E.g., “17” for the User Datagram Protocol (UDP)



Potential Problems

- Header Corrupted: **Checksum**
- Loop: **TTL**
- Packet too large: **Fragmentation**

Checksum, TTL and Fragmentation Fields

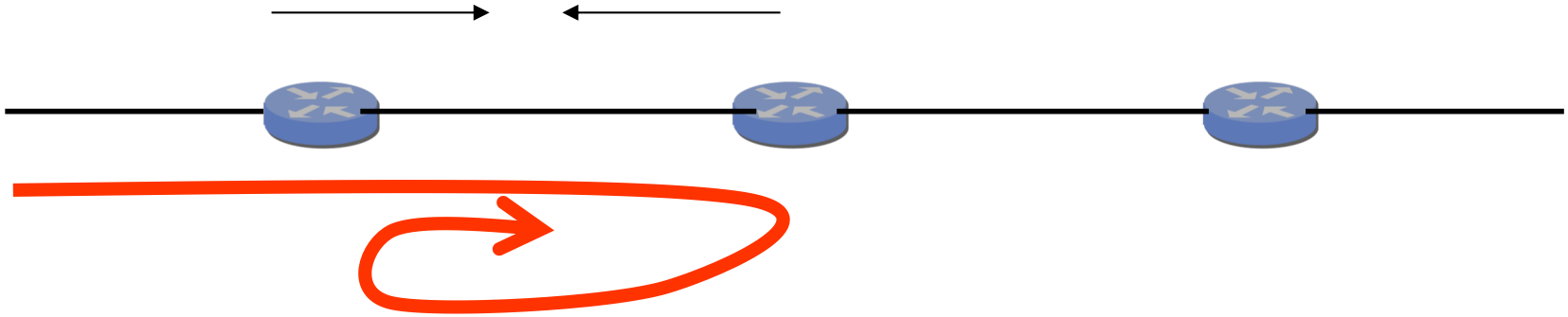


Header Corruption (Checksum)

- Checksum (16 bits)
  - Particular form of checksum over packet header
- If not correct, router discards packets
  - So it doesn't act on bogus information
- Checksum recalculated at every router
  - **Why?**
  - **Why include TTL?**
  - **Why only header?**

Preventing Loops (TTL)

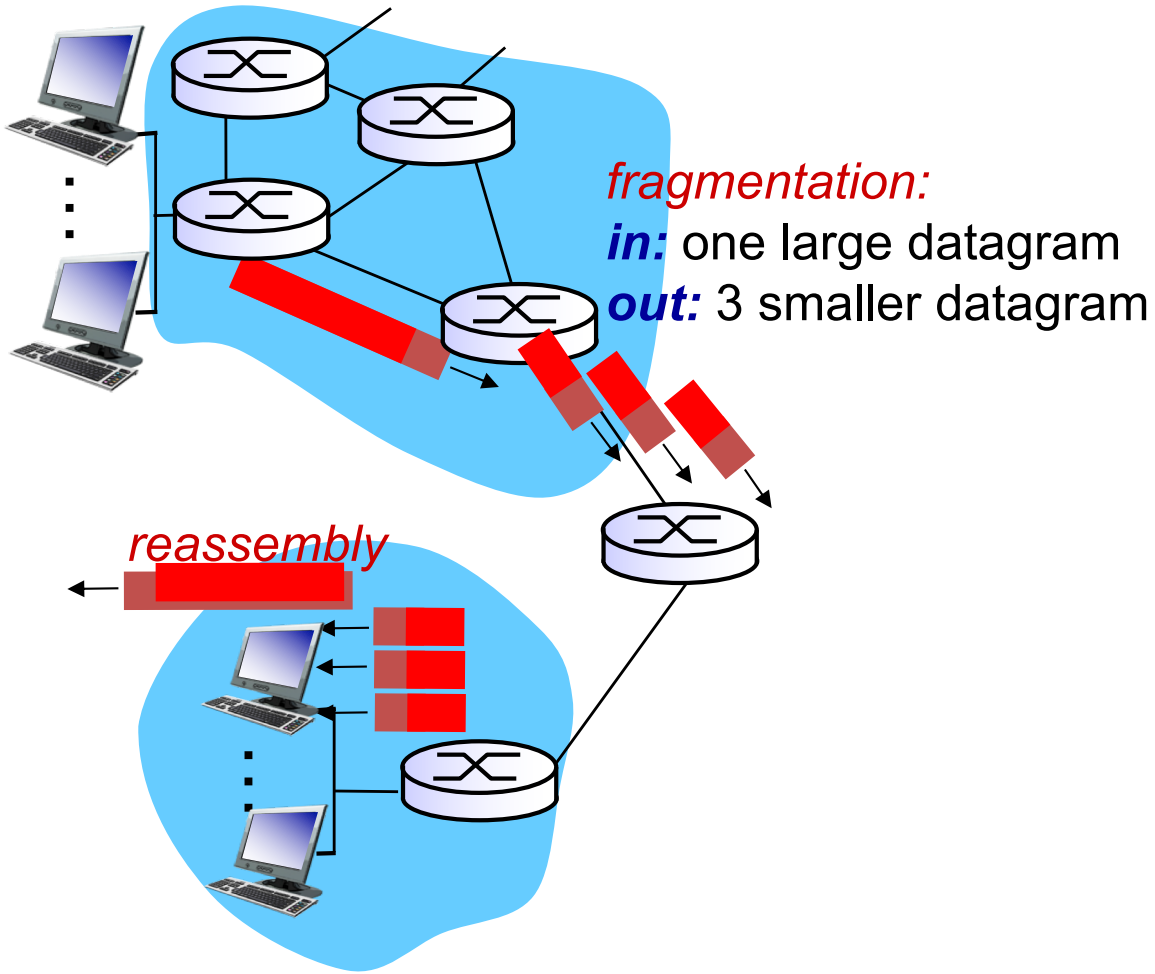
- Forwarding loops cause packets to cycle for a looong time
  - As these accumulate, eventually consume **all** capacity



- Time-to-Live (TTL) Field (8 bits)
  - Decremented at each hop, packet discarded if reaches 0
  - …and "time exceeded" message is sent to the source

IP fragmentation, reassembly

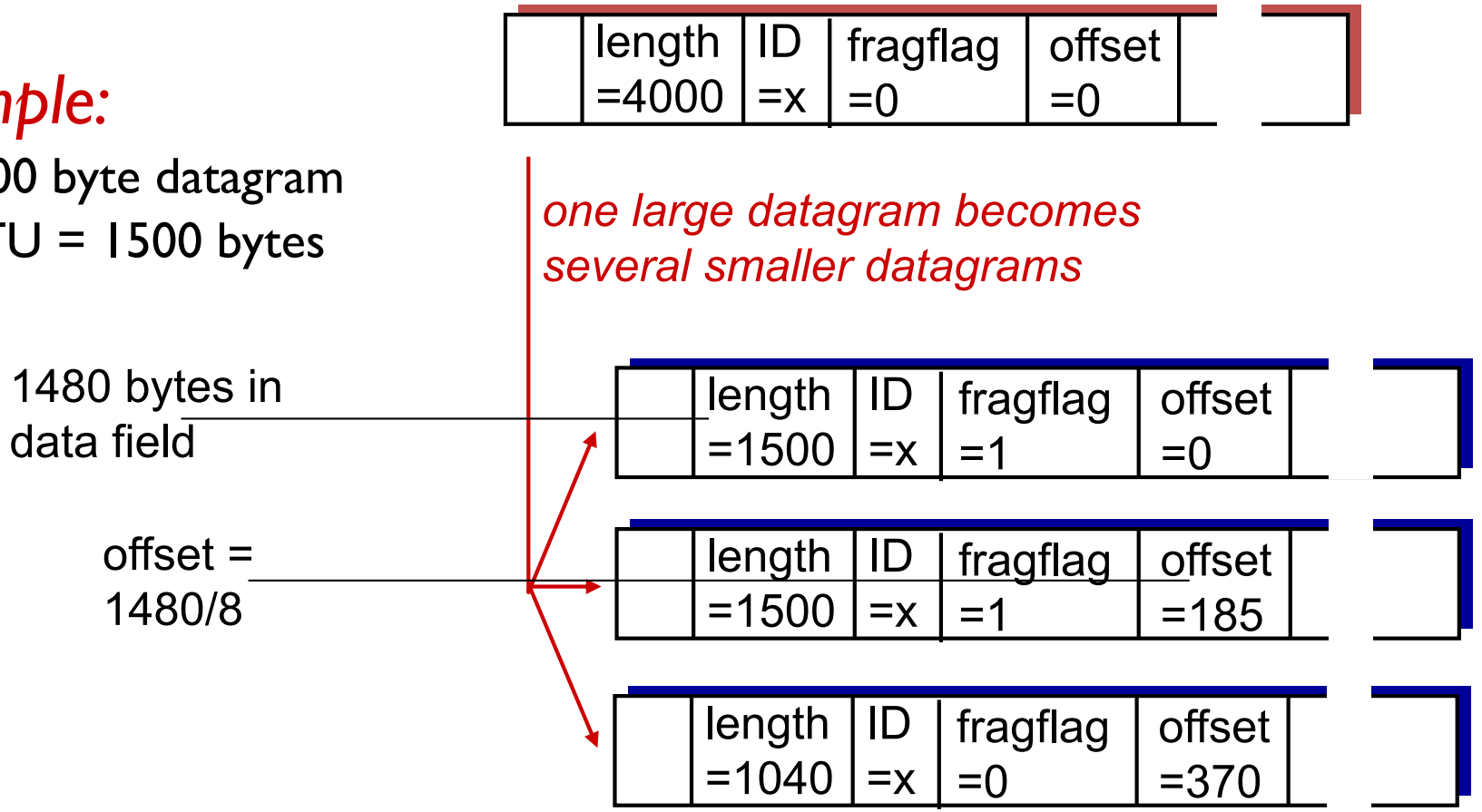
- network links have MTU (max.transfer size) - largest possible link-level frame
  - different link types, different MTUs
- large IP datagram divided ("fragmented") within net
  - one datagram becomes several datagrams
  - "reassembled" only at final destination
  - IP header bits used to identify, order related fragments



IP fragmentation, reassembly

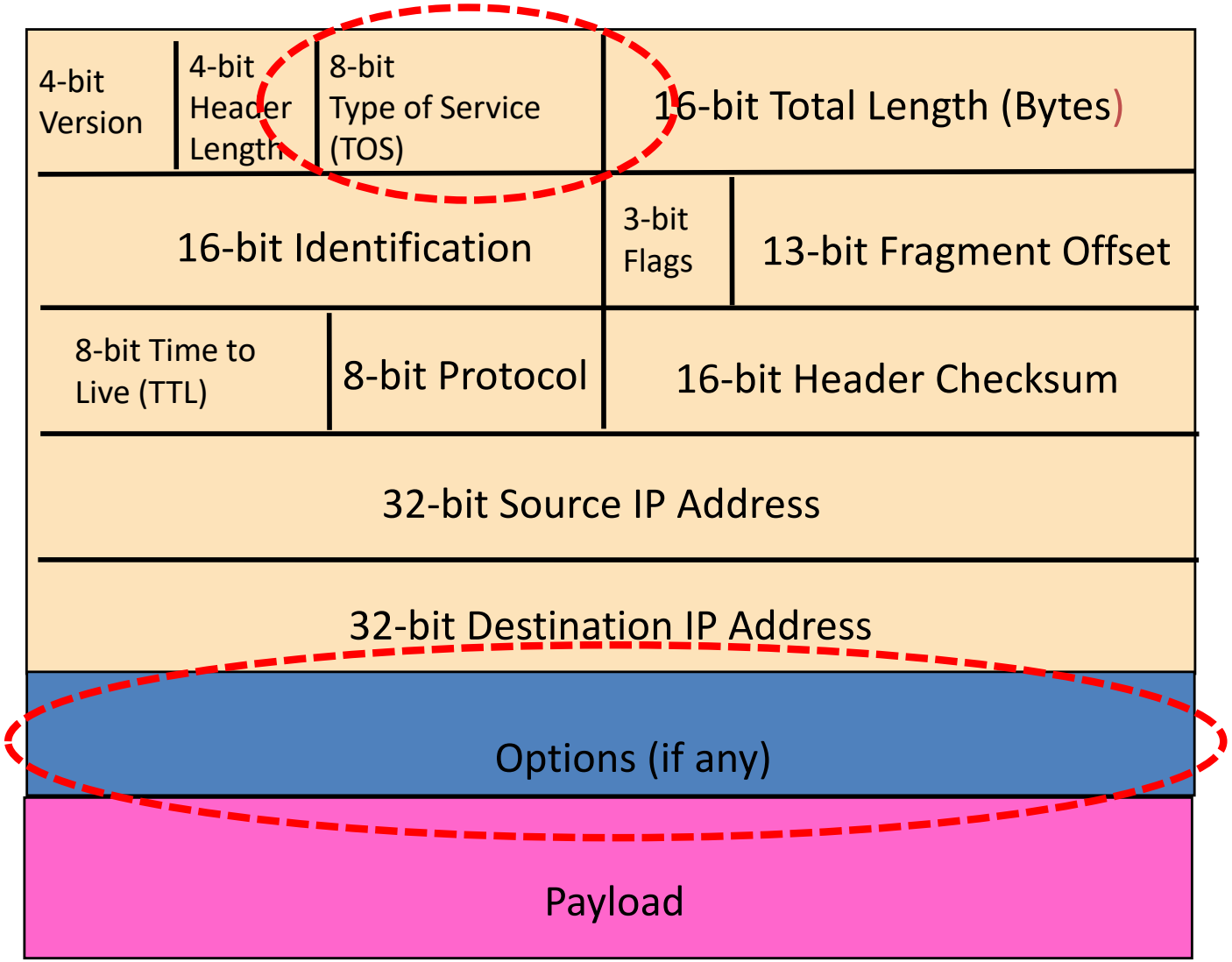
example:

- 4000 byte datagram
- MTU = 1500 bytes



Applet:
http://media.pearsoncmg.com/aw/aw_kurose_network_2/applets/ip/ipfragmentation.html

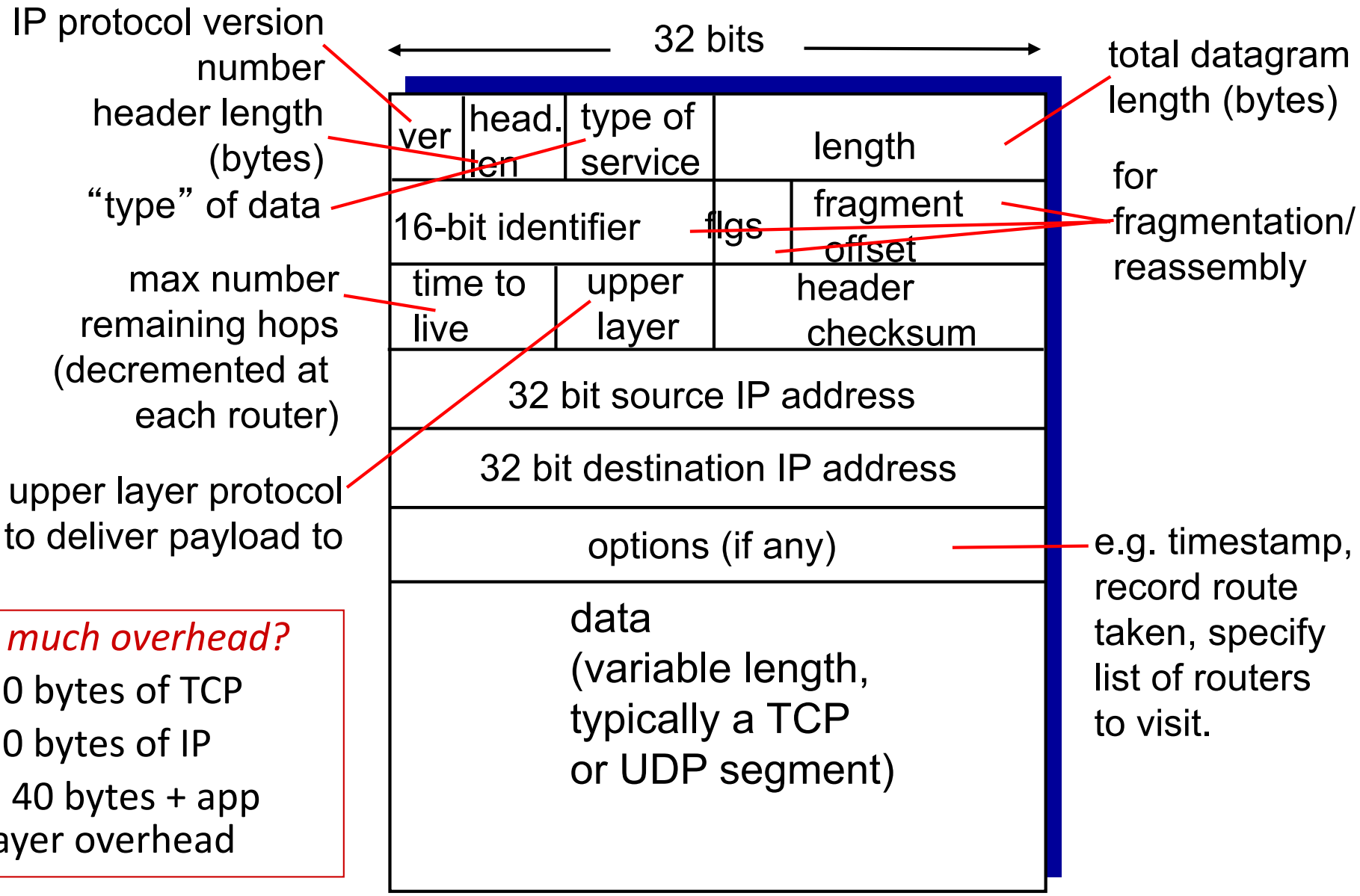
Fields for Special Handling



Special Handling

- "Type of Service", or "Differentiated Services Code Point (DSCP)" (8 bits)
  - Allow packets to be treated differently based on needs
  - E.g., low delay for audio, high bandwidth for bulk transfer
  - Has been redefined several times, will cover later in class
- Options (not often used)

RECAP: IP datagram format



how much overhead?

- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes + app layer overhead

Network Layer, data plane: outline

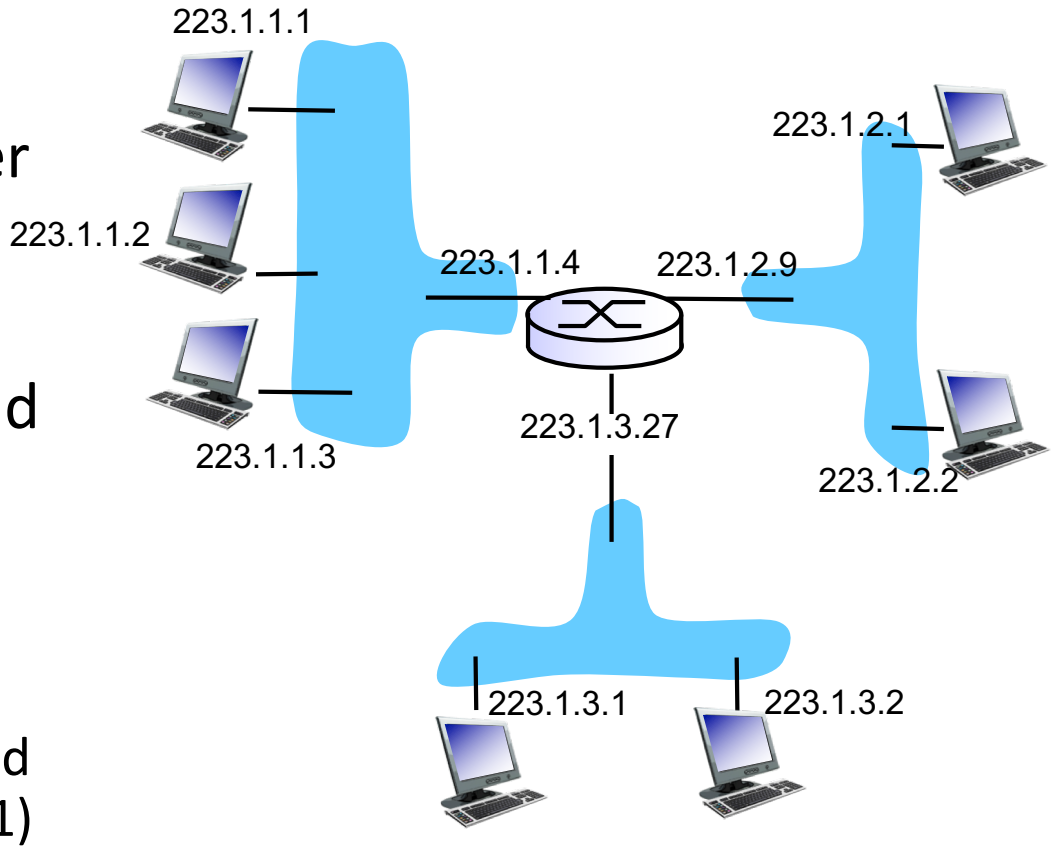
4.1 Overview of Network layer
- data plane
- control plane

4.2 What's inside a router

4.3 IP: Internet Protocol
- datagram format
- fragmentation
- IPv4 addressing
- network address translation

IP addressing: introduction

- *IP address:* 32-bit identifier for host, router *interface*
- *interface:* connection between host/router and physical link
  - router's typically have multiple interfaces
  - host typically has one or two interfaces (e.g., wired Ethernet, wireless 802.11)
- *IP addresses associated with each interface*



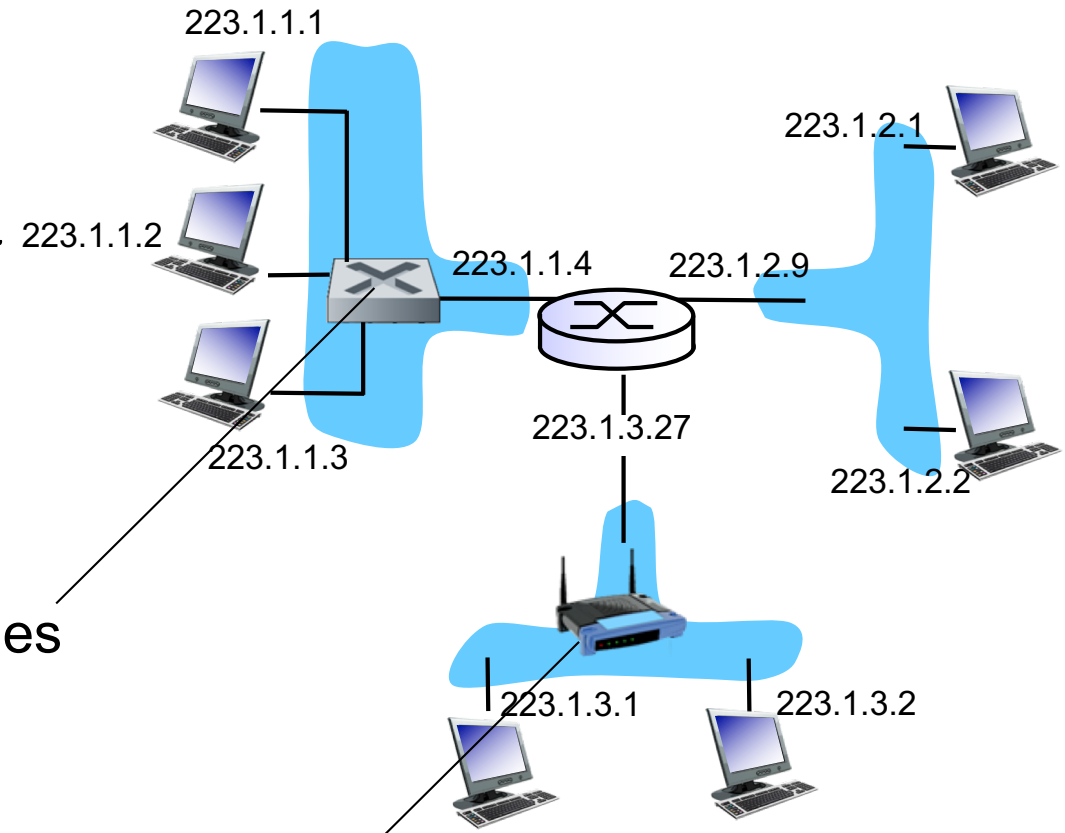
223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

IP addressing: introduction

Q: how are interfaces actually connected?

A: we'll learn about that in the link layer



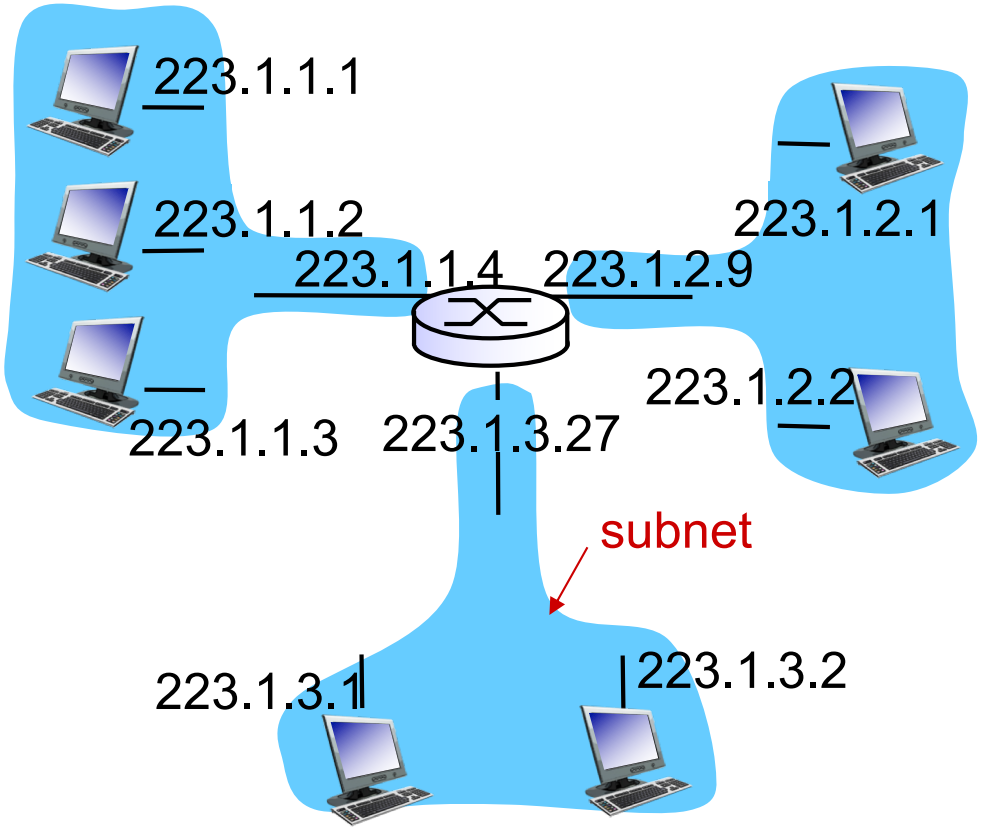
A: wired Ethernet interfaces connected by Ethernet switches

For now: don't need to worry about how one interface is connected to another (with no intervening router)

A: wireless WiFi interfaces connected by WiFi base station

Subnets

- IP address:
  - –subnet part - high order bits
  - –host part - low order bits
- *what's a subnet ?*
  - –device interfaces with same subnet part of IP address
  - –can physically reach each other *without intervening router*

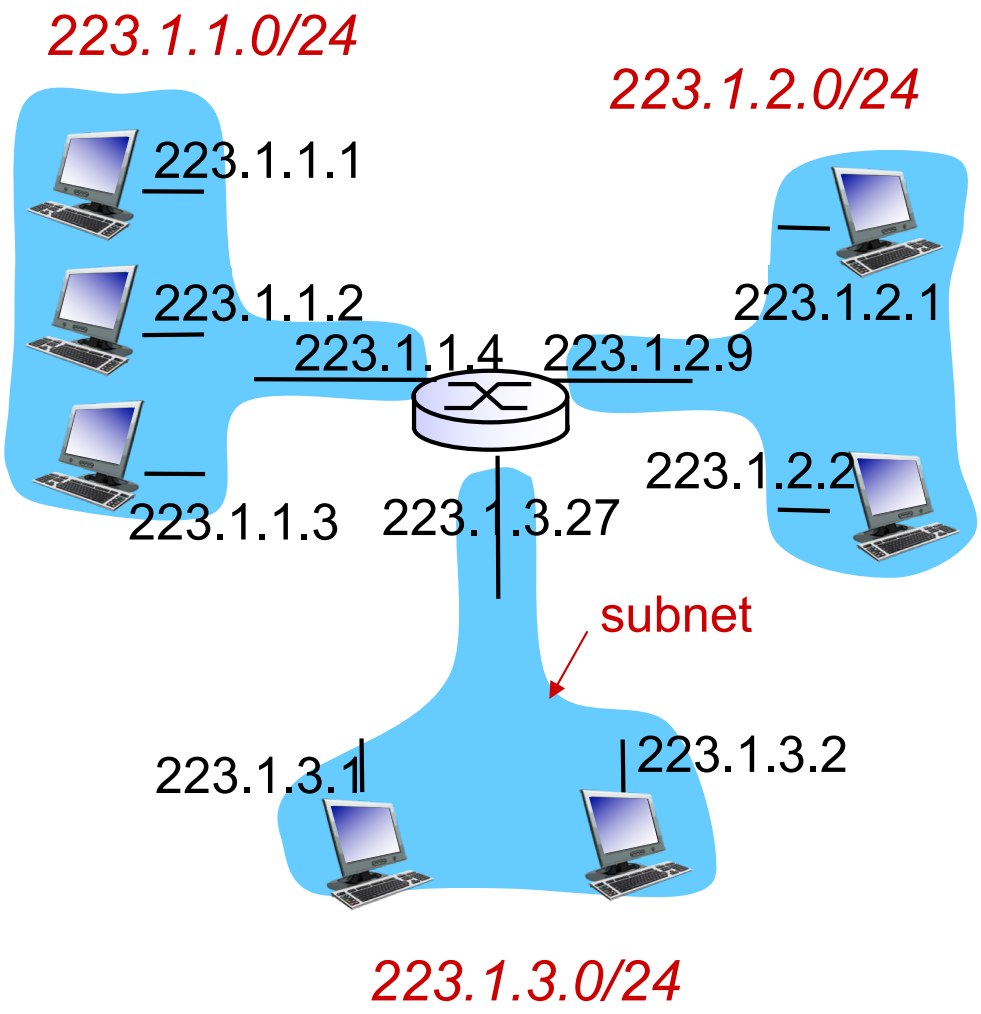


network consisting of 3 subnets

Subnets

recipe

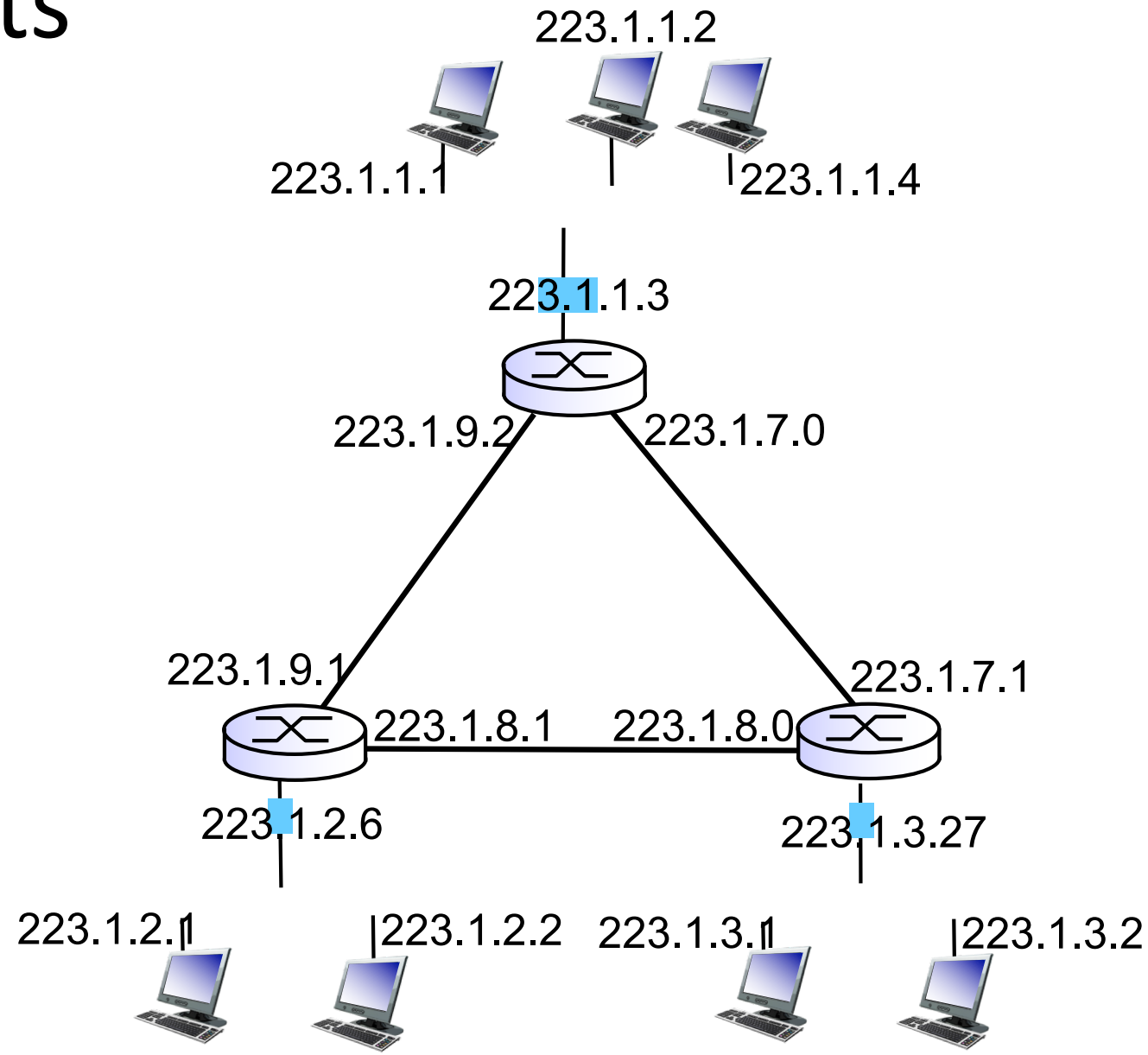
- to determine the subnets, detach each interface from its host or router, creating islands of isolated networks
- each isolated network is called a *subnet*



subnet mask: /24

Subnets

how many?



Original Internet Addresses

- First eight bits: network address (/8)
- Last 24 bits: host address

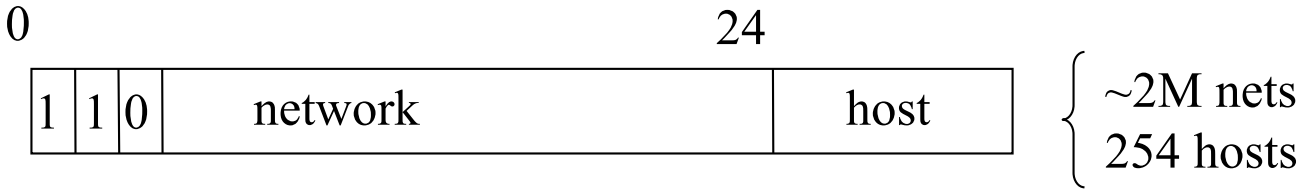
Assumed 256 networks were more than enough!

Next Design: "Classful" Addressing

- Three main classes
  - Class A

  - Class B

  - Class C

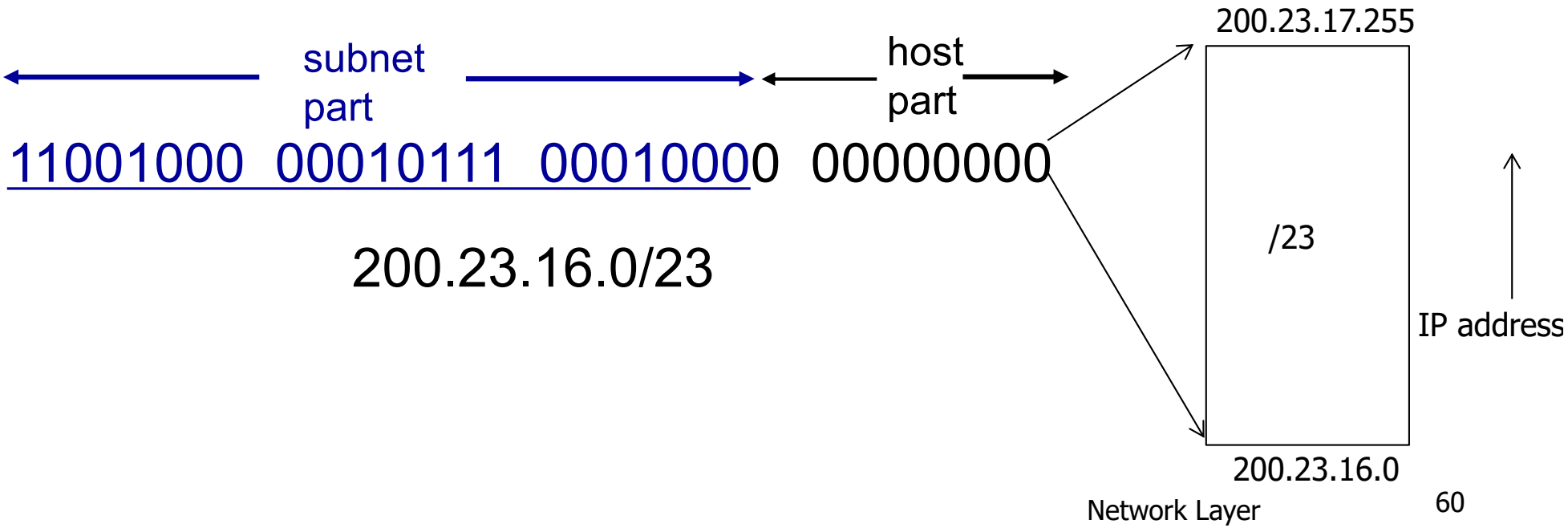


Problem: Networks only come in three sizes!

Today's addressing: CIDR

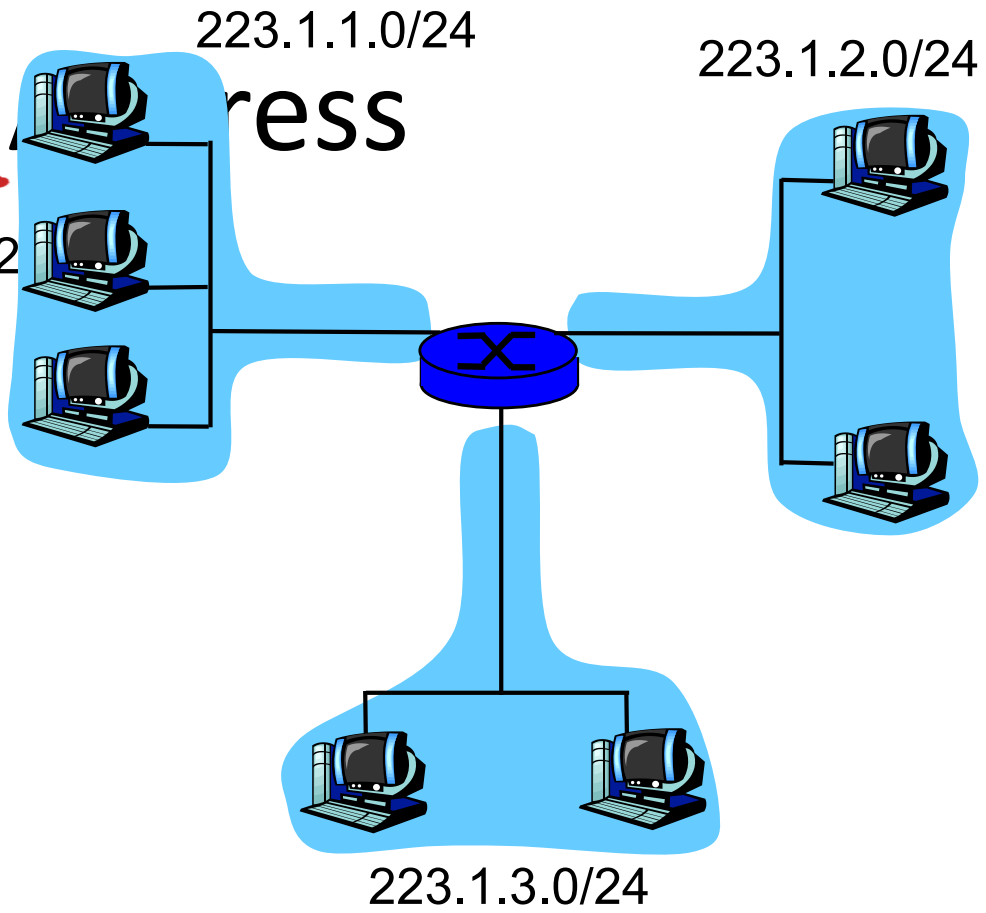
CIDR: Classless InterDomain Routing

- subnet portion of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in subnet portion of address



Subnet Address

- Subnet Mask
  - Used in conjunction with the network address to indicate how many higher order bits are used for the network part of the address (i.e. network prefix)
    - Bit-wise AND
  - 223.1.1.0/24 is equivalent to 223.1.1.0 with subnet mask 255.255.255.0
- Broadcast Address
  - host part is all 111's
  - E.g. 223.1.1.255
- Subnet Address
  - Host part is all 0000's
  - E.g. 223.1.1.0
- Both of these are not assigned



Host B	Dot-decimal address	Binary
IP address	223.1.1.2	11111101.00000001.00000001.00000010
Subnet Mask	255.255.255.0	11111111.11111111.11111111.00000000
Network Part	223.1.1.0	11111101.00000001.00000001.00000000
Host Part	0.0.0.2	00000000.00000000.00000000.00000010

Q&A: Subnet

- The IP address assigned to my computer when I use Ethernet is 10.248.10.68 and the subnet mask is 255.255.240.0. What is

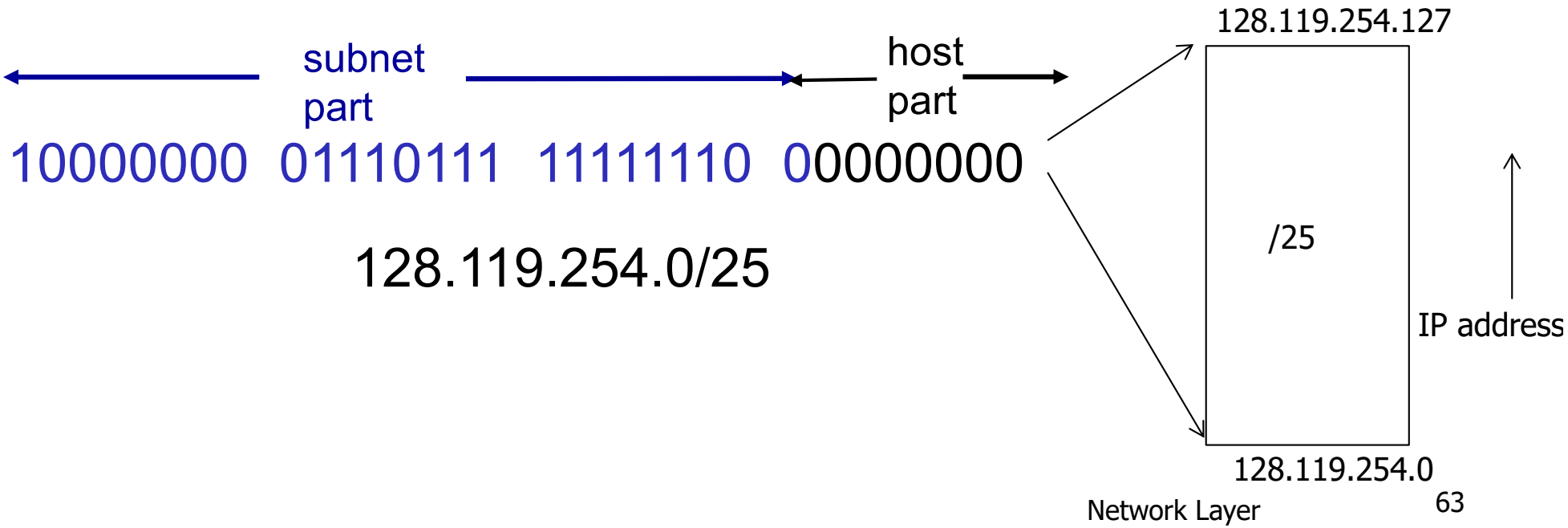
Solil's IP	Dot-decimal	Binary
IP address	10.248.10.68	00001010.11111000.00001010.01000100
Subnet Mask	255.255.240.0	11111111.11111111.11110000.00000000
Network Part	10.248.0.0.	00001010.11111000.00000000.00000000
Host Part	0.0.10.68.	00000000.00000000.00001010.01000100.

Subnet is 10.248.0.0/20

Q&A: IP Addressing

- How many IP addresses belong to the subnet 128.119.254.0/25 ? What are the IP addresses at the two end-points of this range ?

Answer: 2^7 = 128 addresses (126 are usable)



IP addresses: how to get one?

Q: How does a *host* get IP address?

- hard-coded by system admin in a file
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
  - "plug-and-play"

DHCP: Dynamic Host Configuration Protocol

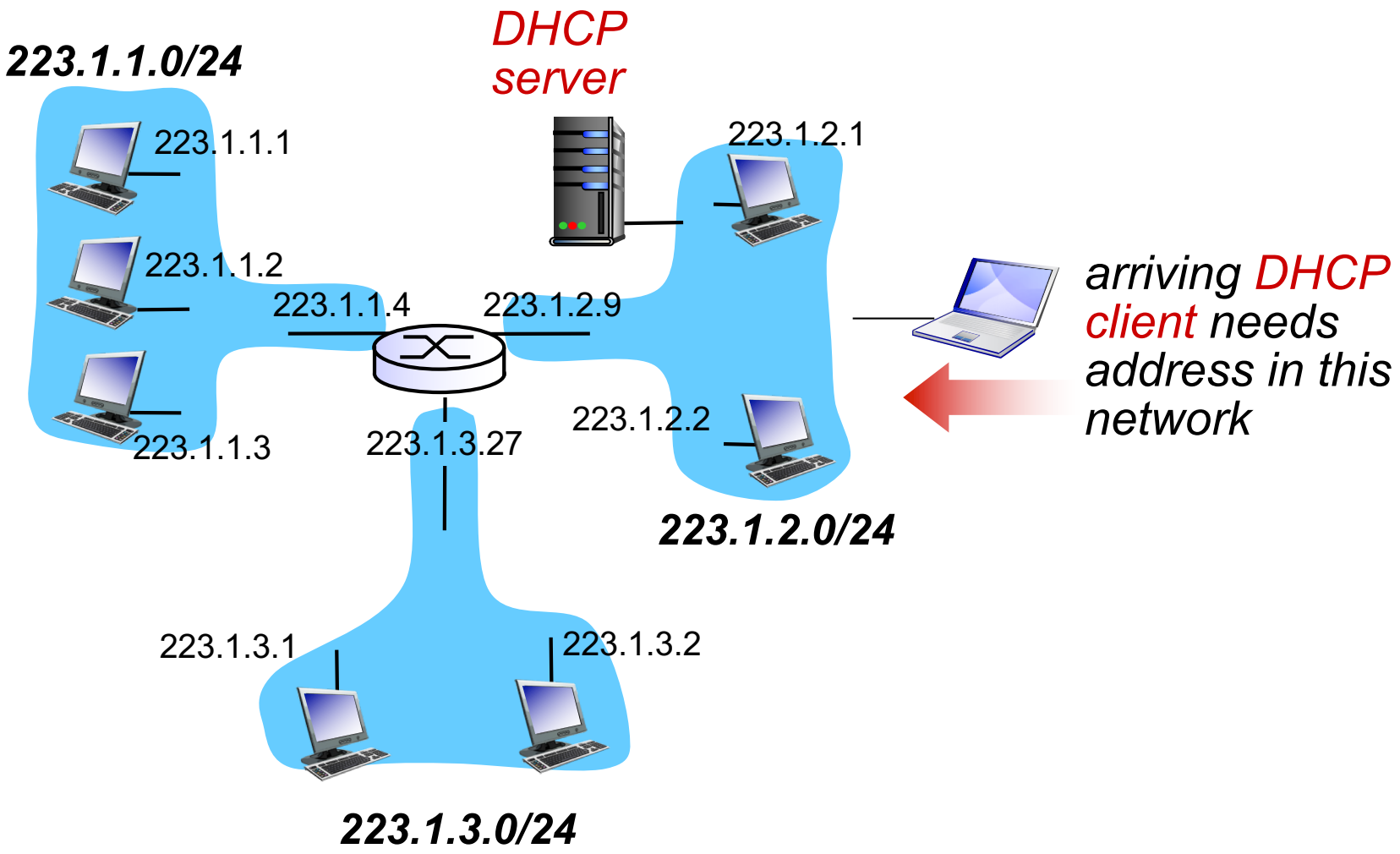
goal: allow host to *dynamically* obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/"on")
- support for mobile users who want to join network (more shortly)

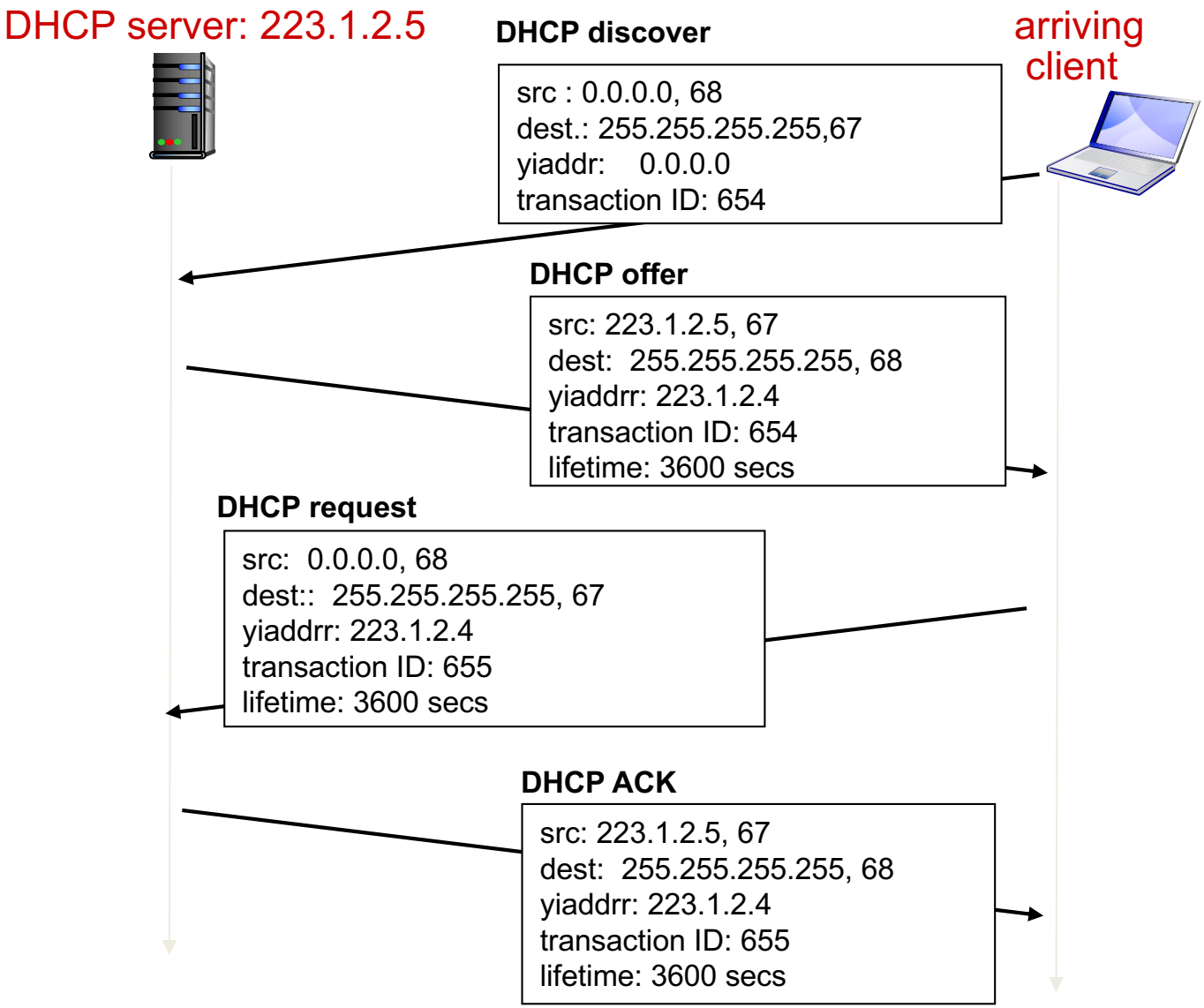
DHCP overview:

- host broadcasts "DHCP discover" msg
- DHCP server responds with "DHCP offer" msg
- host requests IP address: "DHCP request" msg
- DHCP server sends address: "DHCP ack" msg

DHCP client-server scenario



DHCP client-server scenario

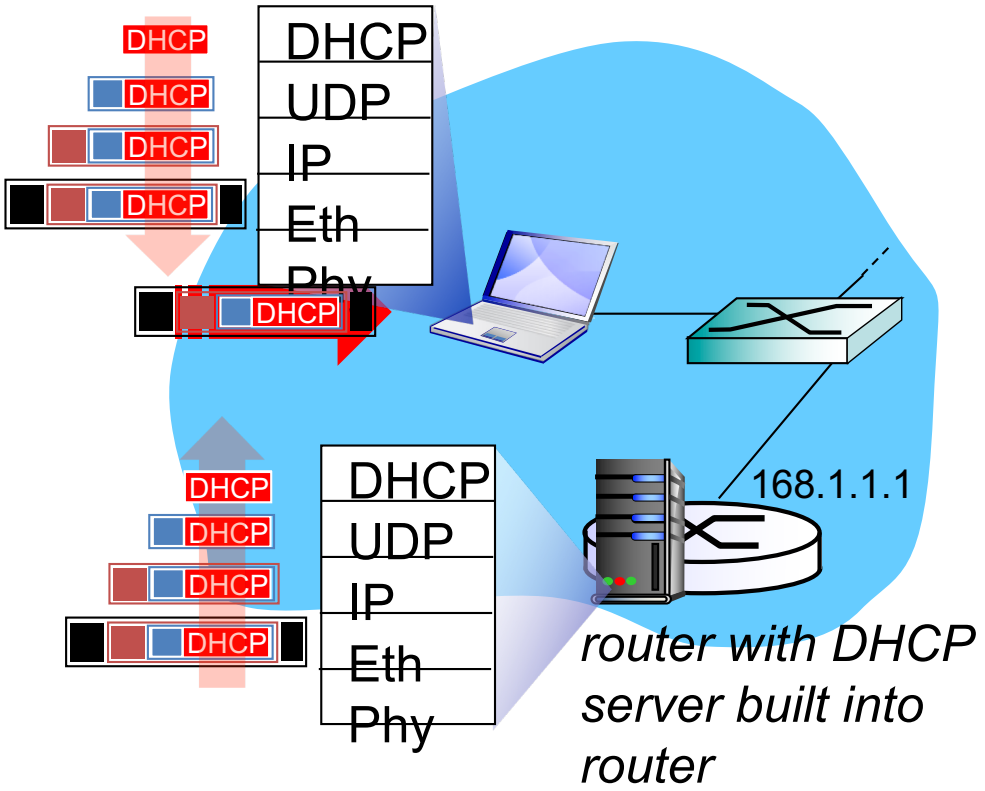


DHCP: more than IP addresses

DHCP can return more than just allocated IP address on subnet:

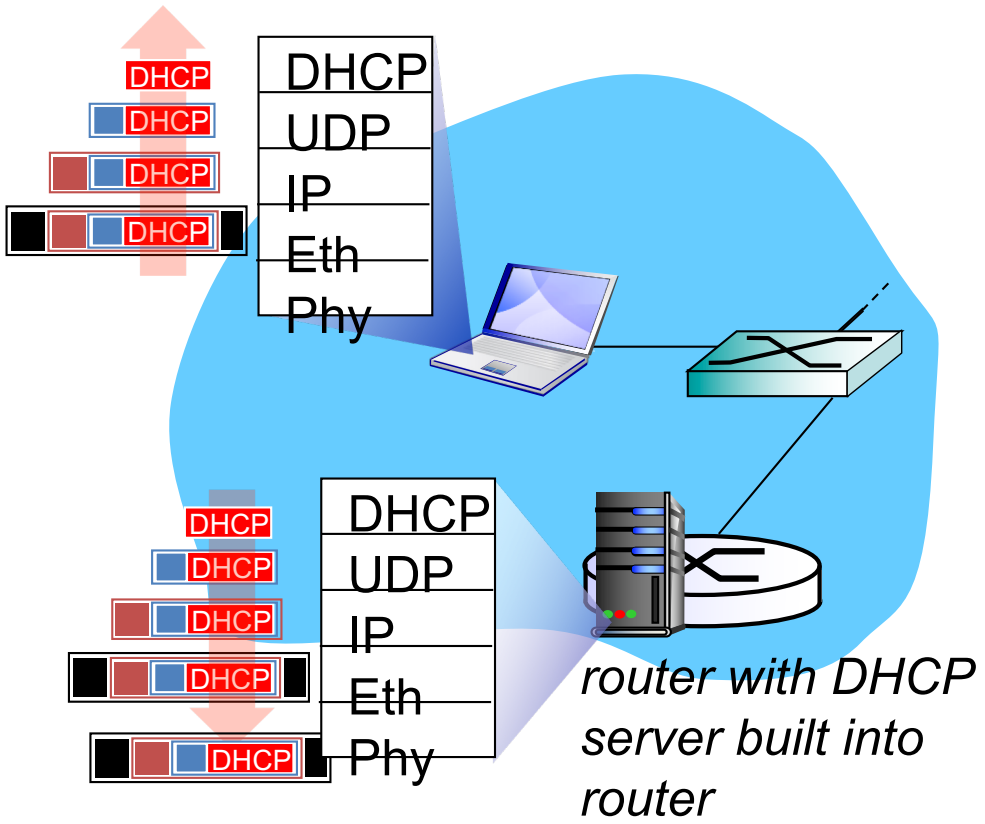
- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

DHCP: example



- connecting laptop needs its IP address, addr of first-hop router, addr of DNS server: use DHCP
- DHCP request encapsulated in UDP, encapsulated in IP, encapsulated in 802.1 Ethernet
- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running DHCP server
- Ethernet demuxed to IP demuxed, UDP demuxed to DHCP

DHCP: example



- DCP server formulates DHCP ACK containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server

- encapsulation of DHCP server, frame forwarded to client, demuxing up to DHCP at client

- client now knows its IP address, name and IP address of DSN server, IP address of its first-hop router

DHCP: Wireshark output (home LAN)

request

Message type: **Boot Request (1)**
Hardware type: Ethernet
Hardware address length: 6
Hops: 0
Transaction ID: 0x6b3a11b7
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: Wistron_23:68:8a (00:16:d3:23:68:8a)
Server host name not given
Boot file name not given
Magic cookie: (OK)
Option: (t=53,l=1) **DHCP Message Type = DHCP Request**
Option: (61) Client identifier
    Length: 7; Value: 010016D323688A;
    Hardware type: Ethernet
    Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)
Option: (t=50,l=4) Requested IP Address = 192.168.1.101
Option: (t=12,l=5) Host Name = "nomad"
Option: (55) Parameter Request List
    Length: 11; Value: 010F03062C2E2F1F21F92B
    1 = Subnet Mask; 15 = Domain Name
    3 = Router; 6 = Domain Name Server
    44 = NetBIOS over TCP/IP Name Server
    ……

reply

Message type: **Boot Reply (2)**
Hardware type: Ethernet
Hardware address length: 6
Hops: 0
Transaction ID: 0x6b3a11b7
Seconds elapsed: 0
Bootp flags: 0x0000 (Unicast)
Client IP address: 192.168.1.101 (192.168.1.101)
Your (client) IP address: 0.0.0.0 (0.0.0.0)
Next server IP address: 192.168.1.1 (192.168.1.1)
Relay agent IP address: 0.0.0.0 (0.0.0.0)
Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)
Server host name not given
Boot file name not given
Magic cookie: (OK)
Option: (t=53,l=1) DHCP Message Type = DHCP ACK
Option: (t=54,l=4) Server Identifier = 192.168.1.1
Option: (t=1,l=4) Subnet Mask = 255.255.255.0
Option: (t=3,l=4) Router = 192.168.1.1
Option: (6) Domain Name Server
    Length: 12; Value: 445747E2445749F244574092;
    IP Address: 68.87.71.226;
    IP Address: 68.87.73.242;
    IP Address: 68.87.64.146
Option: (t=15,l=20) Domain Name = "hsd1.ma.comcast.net."

DHCP: further details

- DHCP uses UDP and port numbers 67 (server side) and 68 (client side)
- Usually the MAC address is used to identify clients
  - DHCP server can be configured with a "registered list" of acceptable MAC addresses
- DHCP offer message includes ip address, length of lease, subnet mask, DNS servers, default gateway
- DHCP security holes
  - DoS attack by exhausting pool of IP addresses
  - Masquerading as a DHCP server
  - Authentication for DHCP - RFC 3118

IP addresses: how to get one?

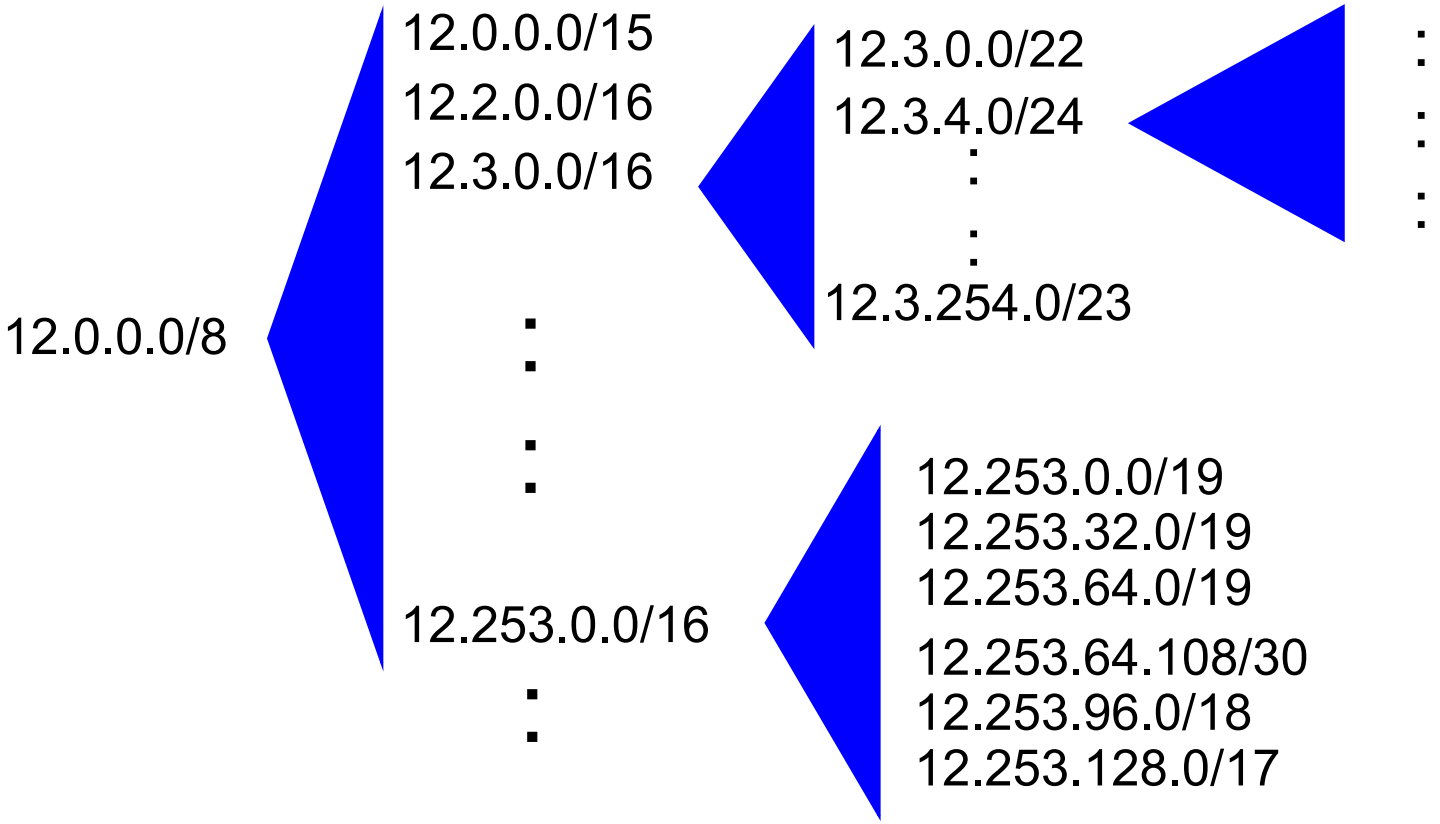
Q: how does *network* get subnet part of IP addr?

A: gets allocated portion of its provider ISP's address space

ISP's block	11001000 00010111 00010000	00000000	200.23.16.0/20
Organization 0	11001000 00010111 00010000	00000000	200.23.16.0/23
Organization 1	11001000 00010111 00010010	00000000	200.23.18.0/23
Organization 2	11001000 00010111 00010100	00000000	200.23.20.0/23
...	.....	....	....
Organization 7	11001000 00010111 00011110	00000000	200.23.30.0/23

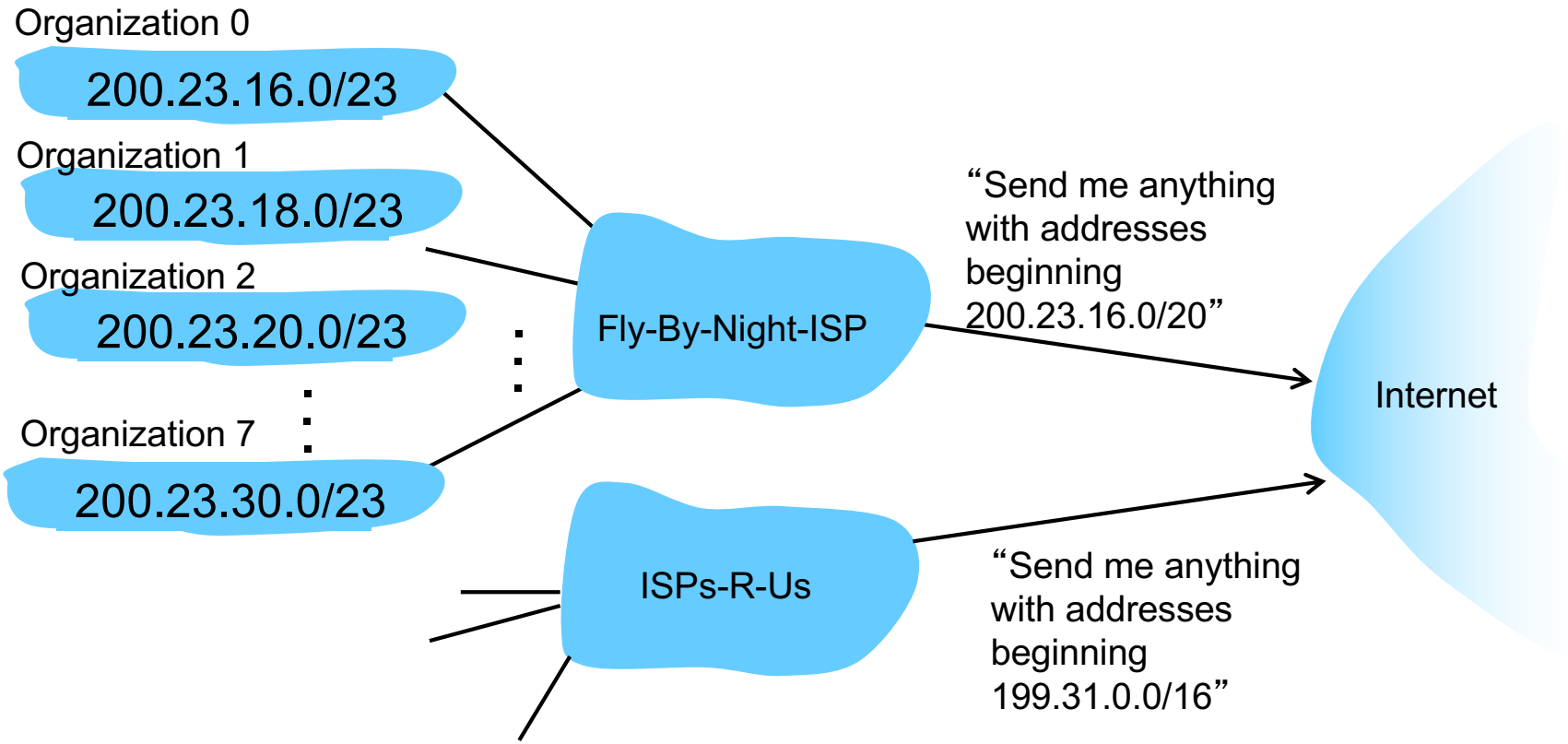
CIDR: Addresses allocated in contiguous prefix chunks

Recursively break down chunks as get closer to host

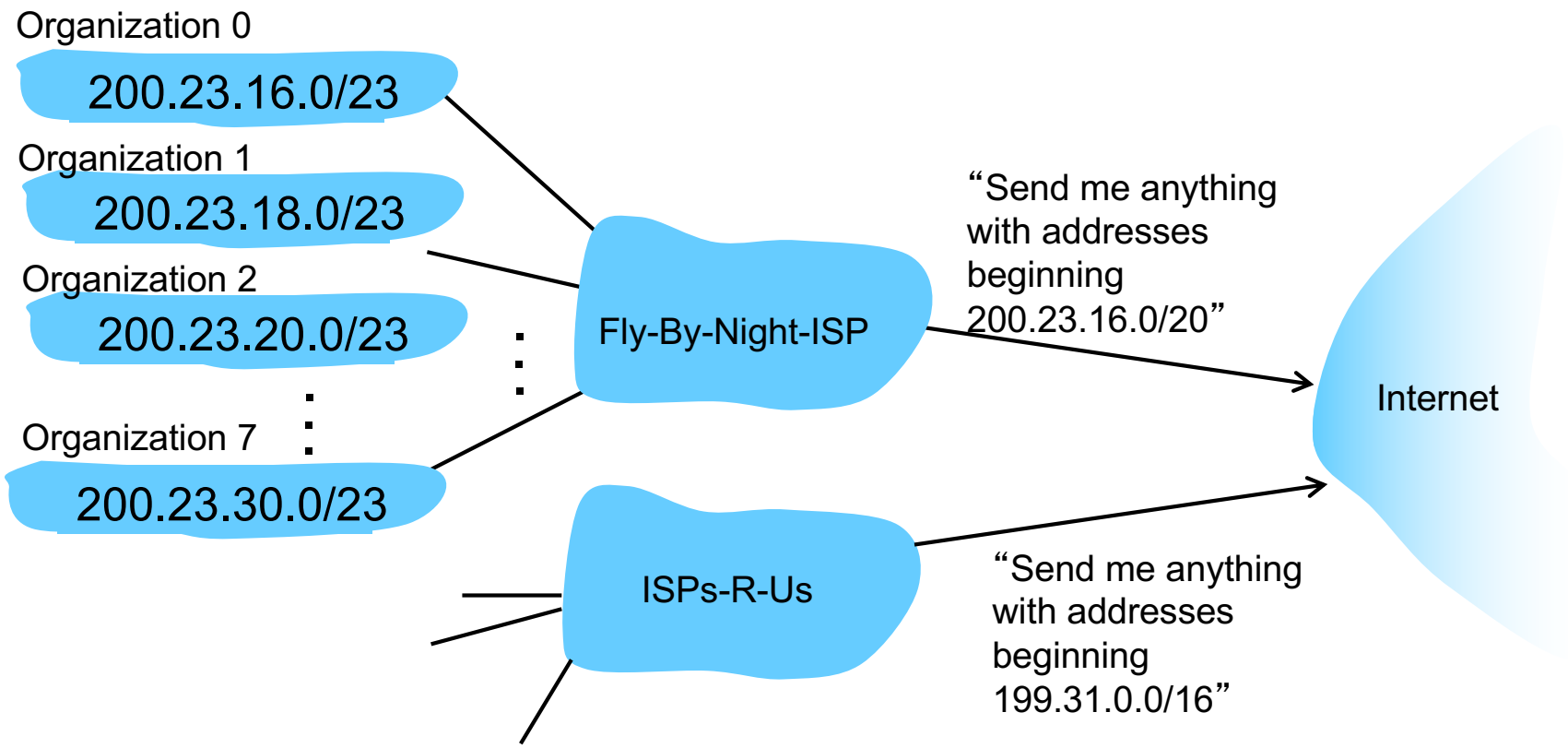


Hierarchical addressing: route aggregation

hierarchical addressing allows efficient advertisement of routing information:



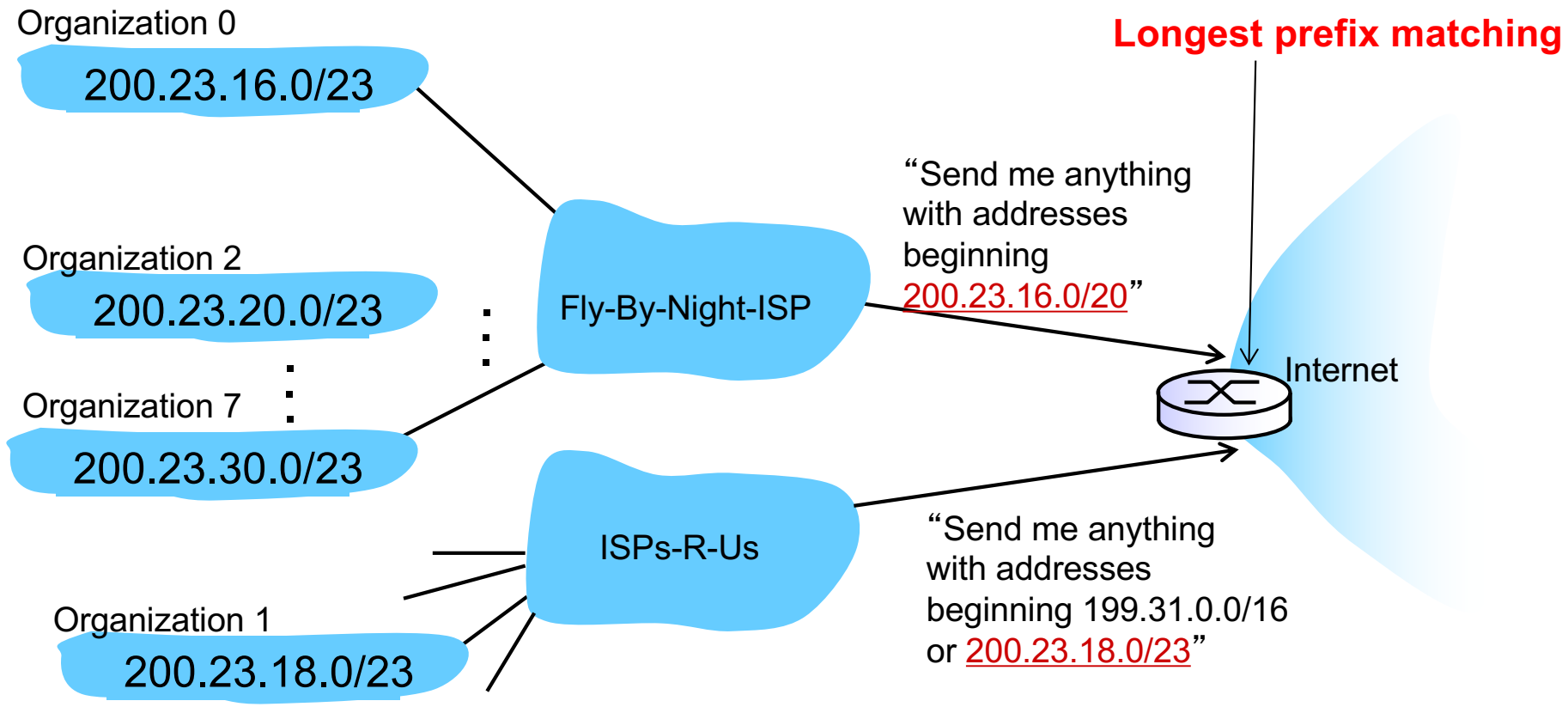
Quiz: What should we do if organization 1 deci to switch to ISPs-R-Us



A: Move 200.23.18.0/23 to ISPs-R-Us (and break up Fly-By-Night's/20 block).
B: Give new addresses to Organization 1 (and force them to change all their addresses)
C: Some other solution

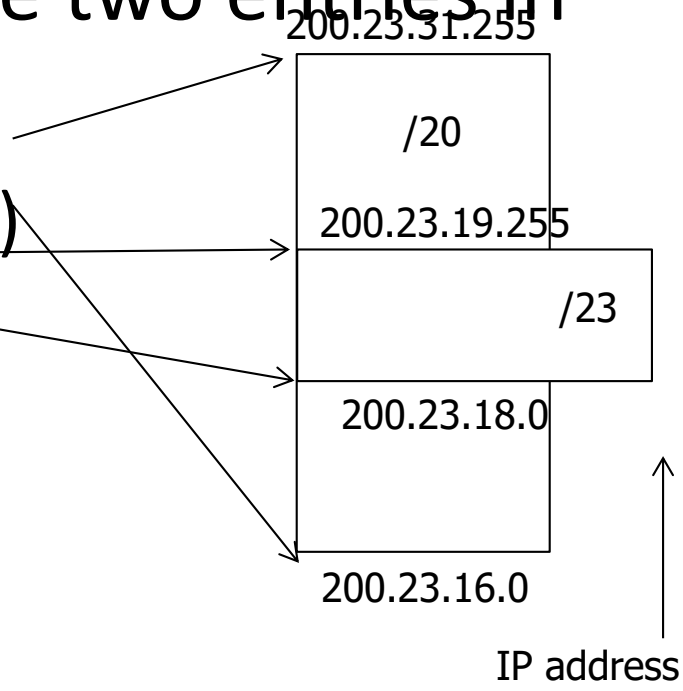
Hierarchical addressing: more specific routes

ISPs-R-Us has a more specific route to Organization 1



Example: continued

- But how will this work?
- Routers in the Internet will have two entries in their tables
  - 200.23.16.0/20 (Fly-by-Night-ISP)
  - 200.23.18.0/23 (ISPs-R-Us)
- Longest prefix match

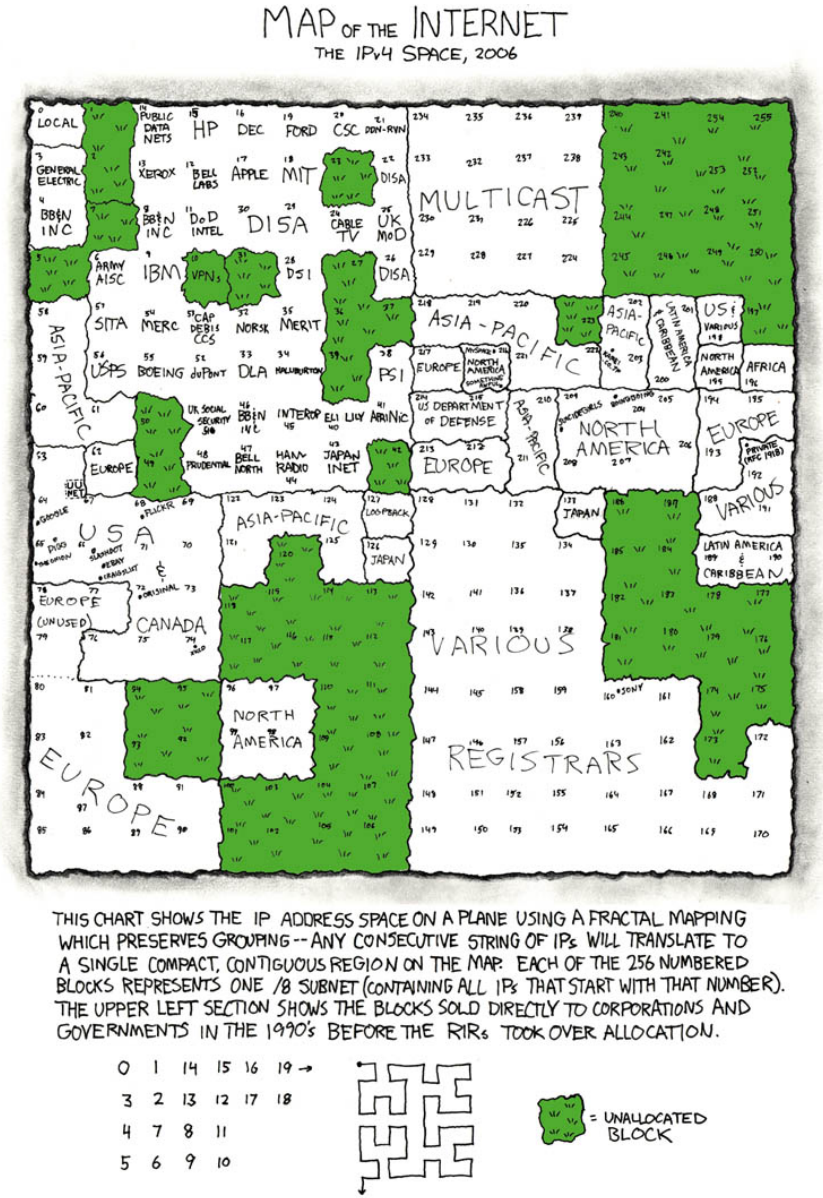


More on IP addresses

- IP addresses are allocated as blocks and have geographical significance
- It is possible to determine the geographical location of an IP address

http://www.geobytes.com/IpLocator.htm

Source: www.xkcd.com



IP addressing: the last word...

Q: how does an ISP get block of addresses?

A: ICANN: Internet Corporation for Assigned Names and Numbers http://www.icann.org/

- allocates addresses
- manages DNS
- assigns domain names, resolves disputes

- Regional Internet Registries (RIR) act as intermediaries
  - RIPE NCC (Riseaux IP Europiens Network Coordination Center) for Europe, Middle East, Africa
  - APNIC (Asia Pacific Network Information Center) for Asia and Pacific
  - ARIN (American Registry for Interent Numbers) for the Americas, Caribbean, sub-Saharan Africa
  - LACNIC (Latin America and Caribbean)

Made-up Example in More Detail

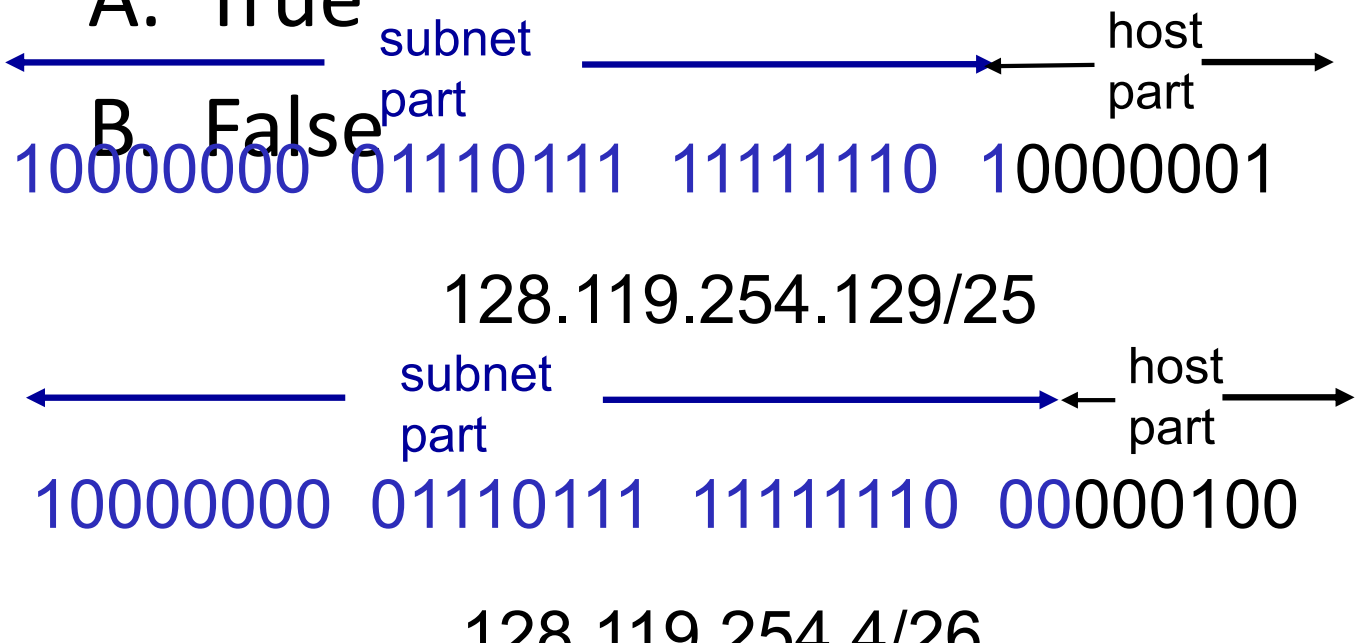
- ICANN gives APNIC several /8s
- APNIC gives Telstra one /8, **129.0/8**
  - Network Prefix**: 10000001**
- Telstra gives UNSW a /16, **129.94/16**
  - Network Prefix**: 1000000101011110**
- UNSW gives CSE a /24, **129.197.242/24**
  - Network Prefix**: 100000010101111011110010**
- CSE gives me a specific address **129.94.242.51**
  - Address: **10000001010111101111001000110011**

Quiz: Subnets

- The two subnets 128.119.245.129/25 and 128.119.245.4/26 have overlapping IP addresses.

A. True

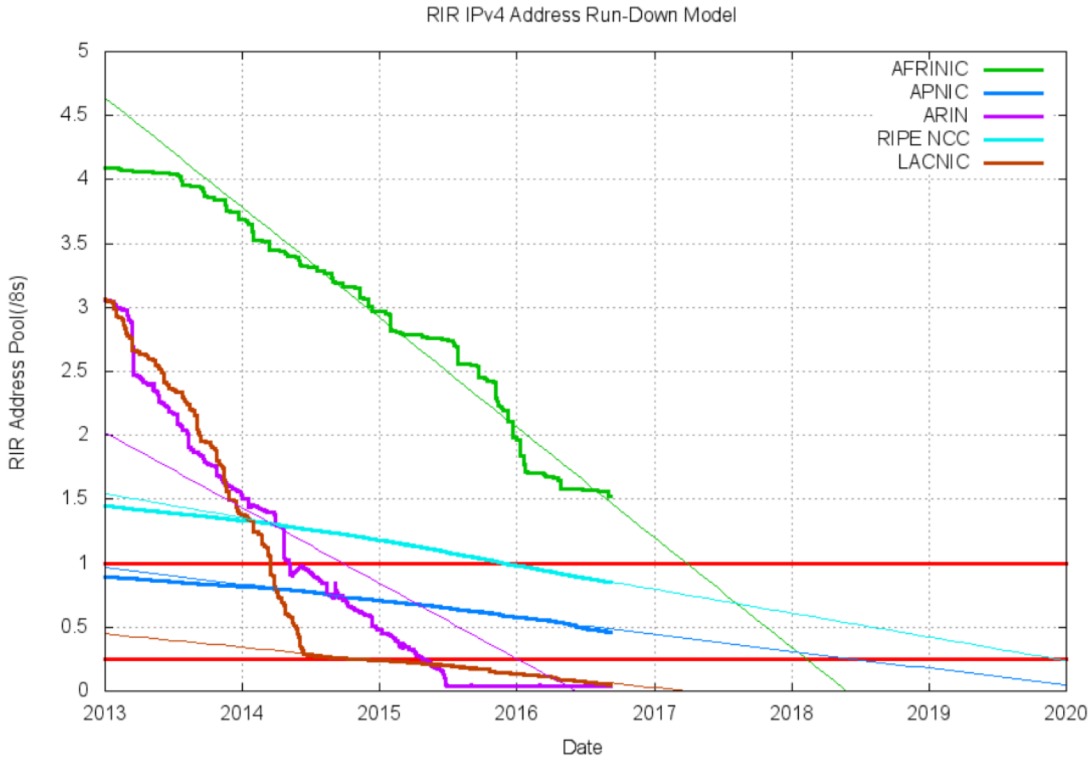
B. False



IANA Unallocated Address Pool Exhaustion:
03-Feb-2011

Projected RIR Address Pool Exhaustion Dates:

RIR	Projected Exhaustion Date	Remaining Addresses in RIR Pool (/8s)
APNIC:	**19-Apr-2011** (actual)	0.4599
RIPE NCC:	**14-Sep-2012** (actual)	0.8493
LACNIC:	**10-Jun-2014** (actual)	0.0508
ARIN:	**24 Sep-2015** (actual)	
AFRINIC:	**20-Jun-2018**	1.5233



Projection of consumption of Remaining RIR Address Pools

Network Layer, data plane: outline

4.1 Overview of Network layer
- data plane
- control plane

4.2 What's inside a router

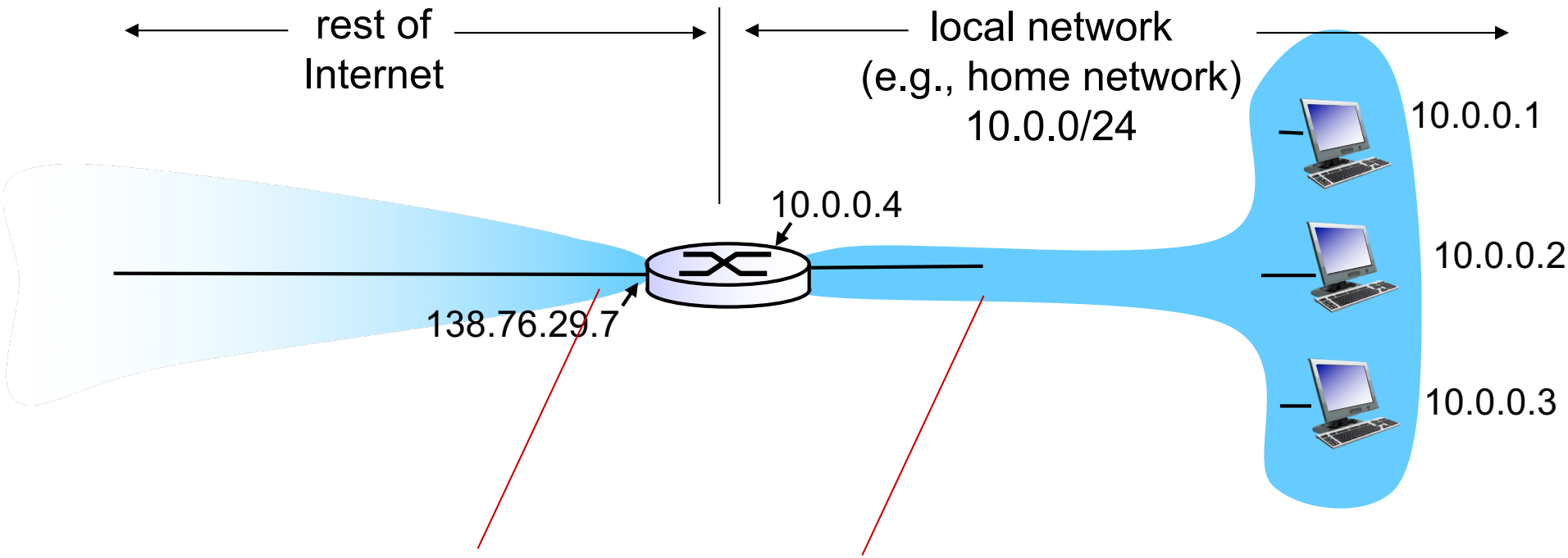
4.3 IP: Internet Protocol
- datagram format
- fragmentation
- IPv4 addressing
- network address translation

Private Addresses

- Defined in RFC 1918:
  - 10.0.0.0/8 (16,777,216 hosts)
  -172.16.0.0/12 (1,048,576 hosts)
  -192.168.0.0/16 (65536 hosts)

- These addresses cannot be routed
  - Anyone can use them
  -Typically used for NAT

NAT: network address translation



all datagrams *leaving* local network have *same* single source NAT IP address: 138.76.29.7,different source port numbers

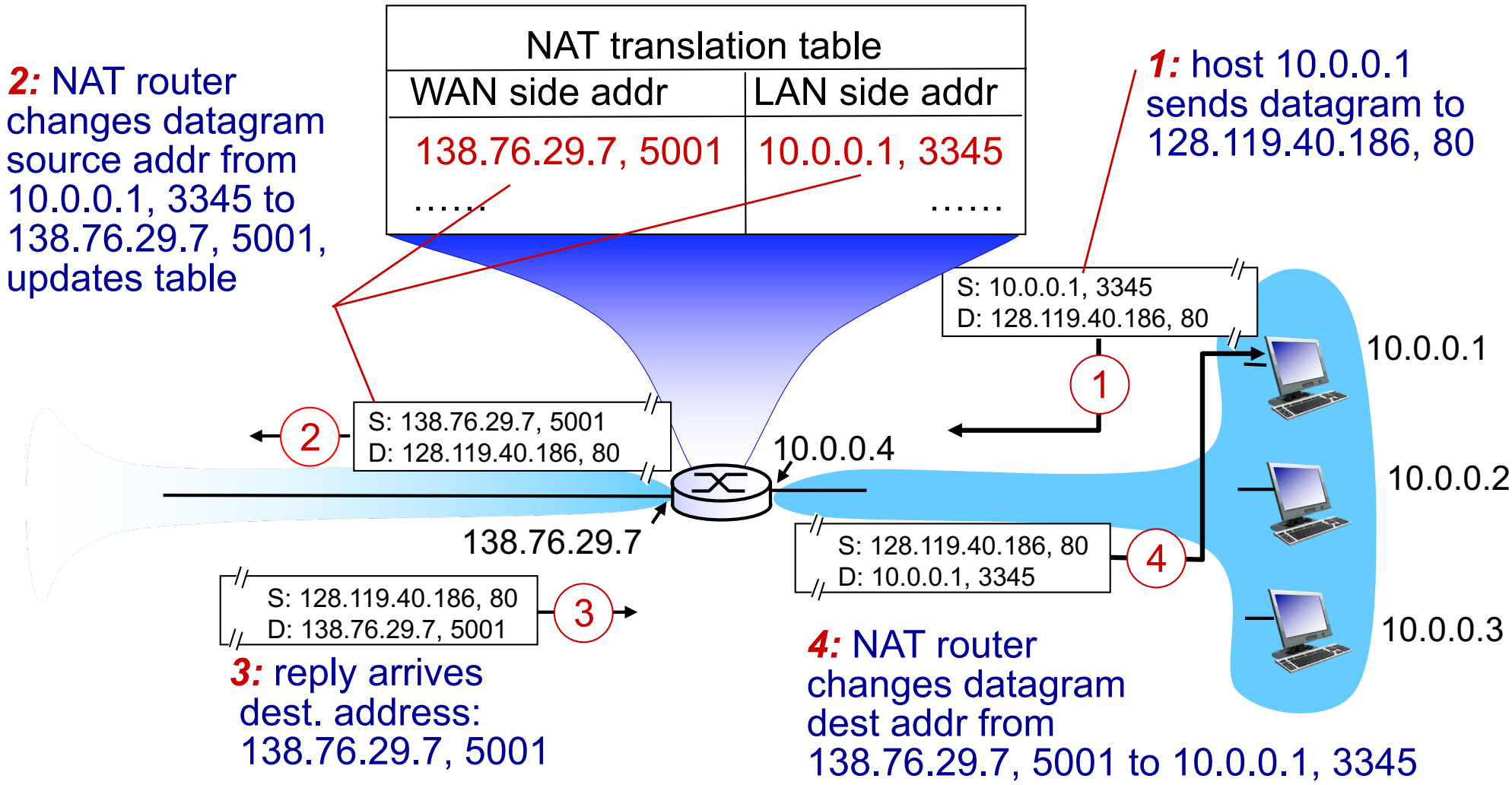
datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: network address translation

implementation: NAT router must:

- *outgoing datagrams: replace* (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)
  - . . . remote clients/servers will respond using (NAT IP address, new port #) as destination addr
- *remember (in NAT translation table)* every (source IP address, port #) to (NAT IP address, new port #) translation pair
- *incoming datagrams: replace* (NAT IP address, new port #) in dest fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

NAT: network address translation



NAT Advantages

Local network uses just one IP address as far as outside world is concerned:

- range of addresses not needed from ISP: just one IP address for all devices
- can change addresses of devices in local network without notifying outside world
- can change ISP without changing addresses of devices in local network

Discussion: NAT

- Devices inside the local network are not explicitly addressable or visible by outside world.

  A: This is an advantage

  B: This is a disadvantage

NAT: network address translation

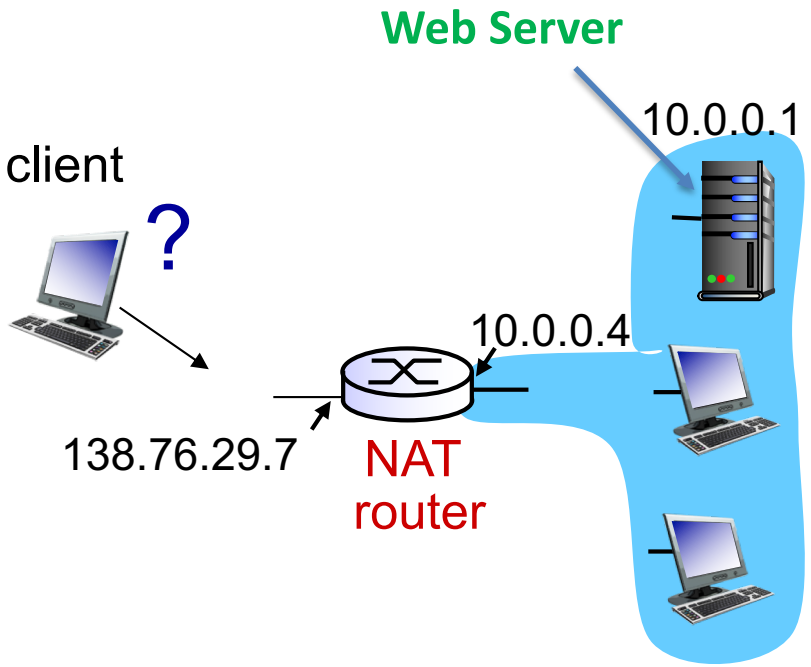
- 16-bit port-number field:
  - 60,000 simultaneous connections with a single LAN-side address!
- NAT is controversial:
  - routers should only process up to layer 3
  - violates end-to-end argument
    - NAT possibility must be taken into account by app designers, e.g., P2P applications
  - address shortage should instead be solved by IPv6

NAT: Practical Issues

- NAT modifies port # and IP address
  - *Requires recalculation of TCP and IP checksum*
- Some applications embed IP address or port numbers in their message payloads
  - DNS, FTP (PORT command), SIP, H.323
  - For legacy protocols, NAT must look into these packets and translate the embedded IP addresses/port numbers
  - Duh, What if these fields are encrypted ?? (SSL/TLS, IPSEC, etc)
  - **Q: In some cases why may NAT need to change TCP sequence number??**
- If applications change port numbers periodically, the NAT must be aware of this
- NAT Traversal Problems
  - E.g: How to setup a server behind a NAT router?
  - How to talk to a Skype user behind a NAT router?
  - Possible workarounds in next few slides

NAT traversal problem

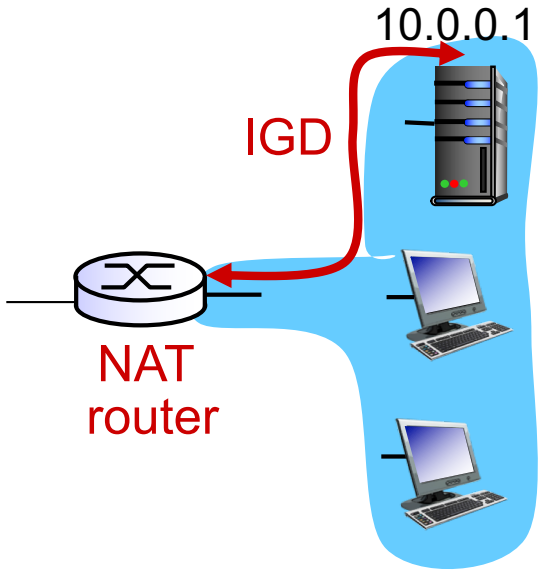
- client wants to connect to server with address 10.0.0.1
  - server address 10.0.0.1 local to LAN (client can't use it as destination addr)
  - only one externally visible NATed address: 138.76.29.7
- *solution1:* statically configure NAT to forward incoming connection requests at given port to server
  - e.g., (138.76.29.7, port 80) always forwarded to 10.0.0.1 port 80



NAT traversal problem

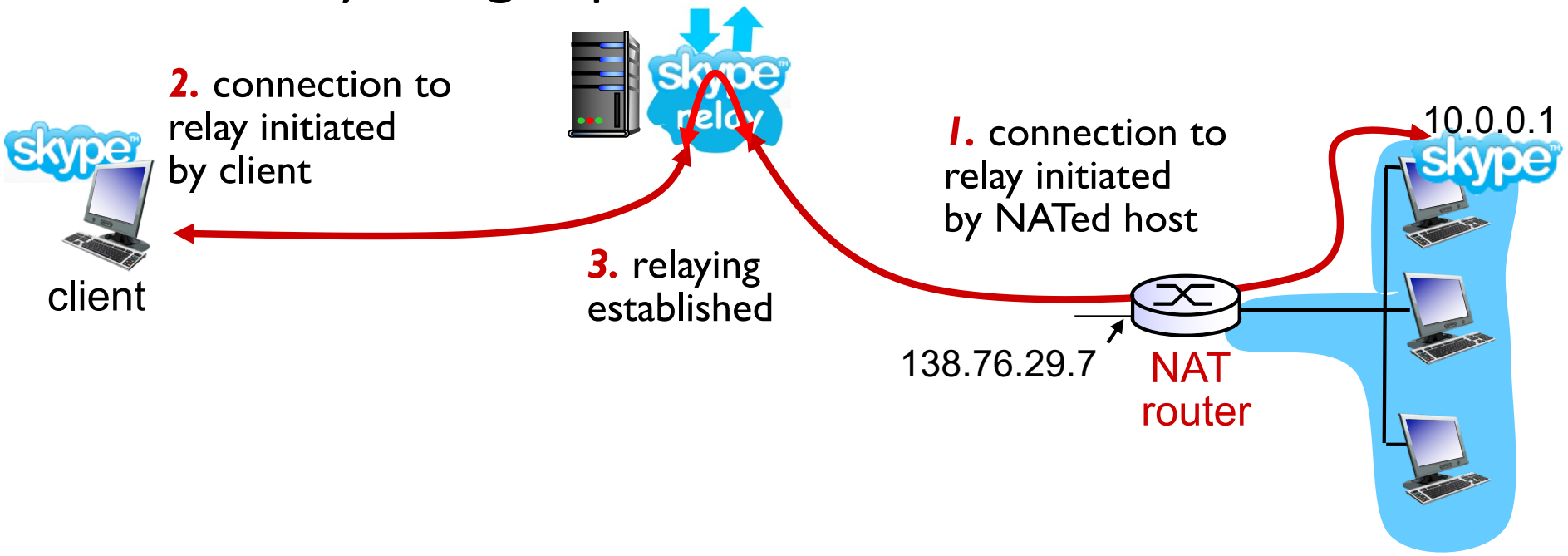
- *solution 2:* Universal Plug and Play (UPnP) Internet Gateway Device (IGD) Protocol. Allows NATed host to:
  - learn public IP address (138.76.29.7)
  - add/remove port mappings (with lease times)

i.e., automate static NAT port map configuration



NAT traversal problem

- *solution 3:* relaying (used in Skype)
  - NATed client establishes connection to relay
  - external client connects to relay
  - relay bridges packets between to connections

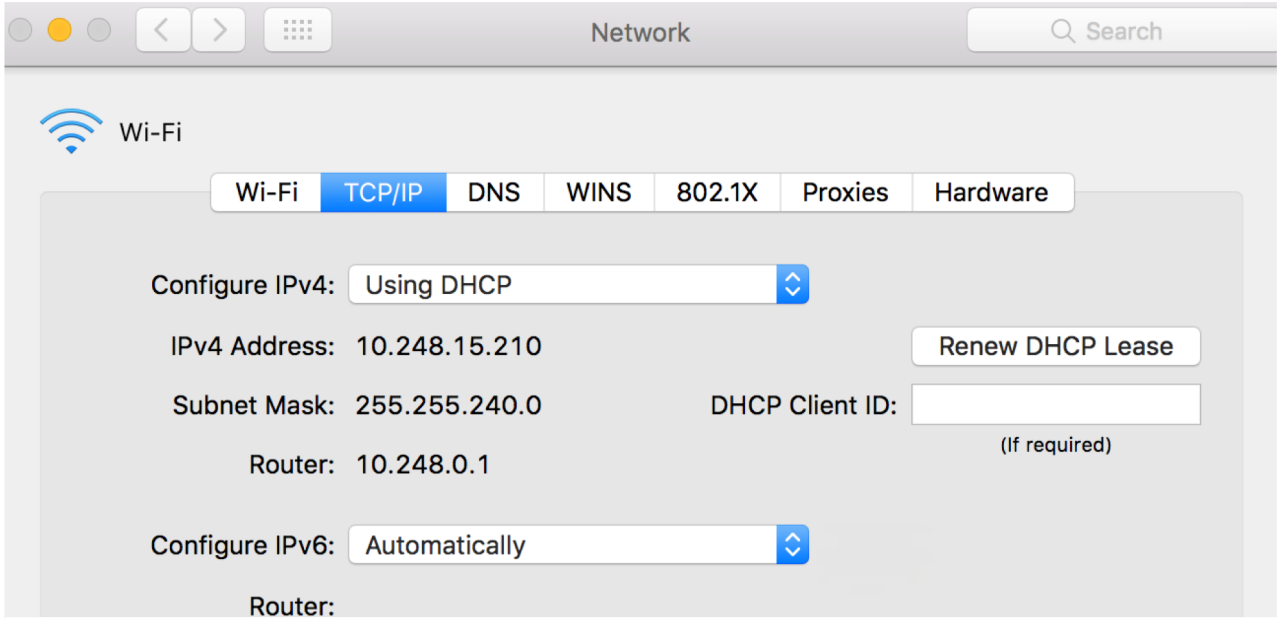


NAT: Devil in the details

- Despite the problems, NAT has been widely deployed
- Most protocols can be successfully passed through a NAT, including VPN
- Modern hardware can easily perform NAT functions at > 100 Mbps
- IPv6 is still not widely deployed commercially, so the need for NAT is real
- After years of refusing to work on NAT, the IETF has been developing "NAT control protocols" for hosts
- Lot of practical variations
  - Full-cone NAT, Restricted Cone NAT, Port Restricted Cone NAT, Symmetric NAT, …..
    - The devil is in the detail

Discussion

- The picture below shows you the IP address of my machine connected to the uniwide wireless network.



- However when I ask Google it says my IP address is as noted below. Can you explain the discrepancy?