CSCE 463/612
Networks and Distributed Processing
Fall 2025

Network Layer II

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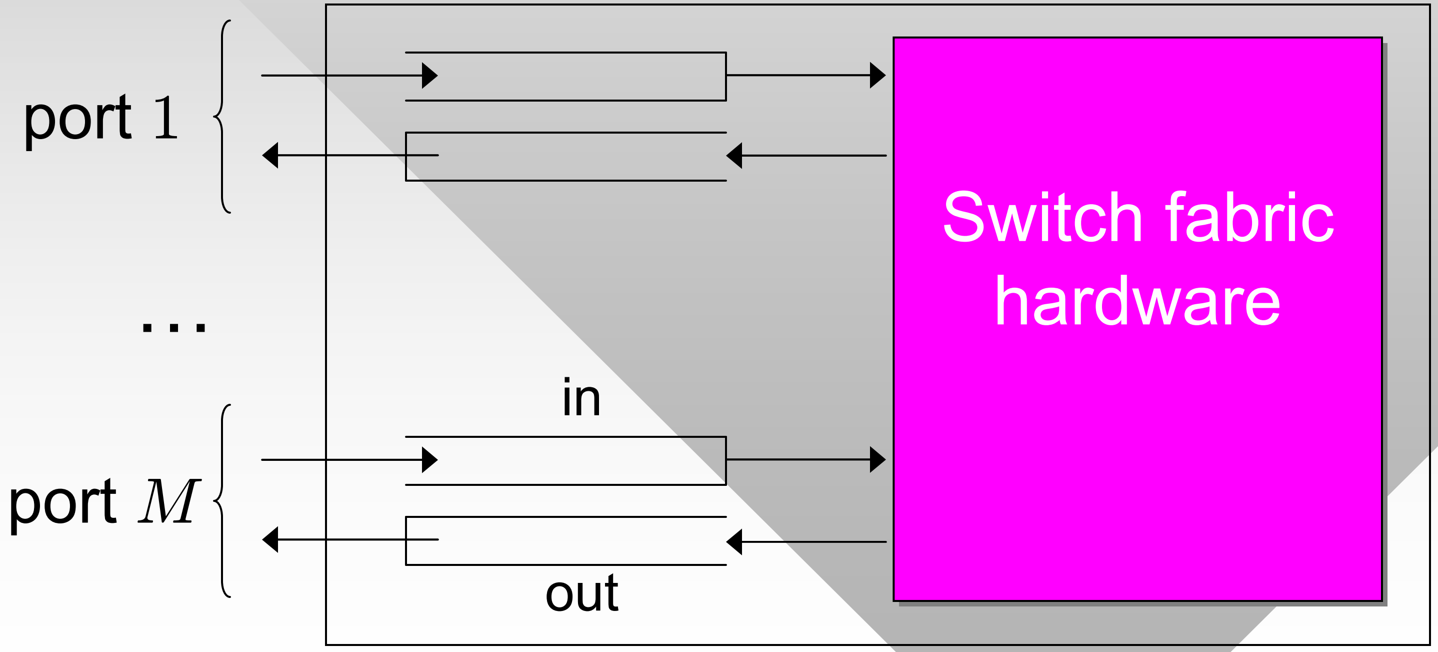
Chapter 4: Roadmap

4.1 Introduction
4.2 Virtual circuit and datagram networks
4.3 What’s inside a router
4.4 IP: Internet Protocol
4.5 Routing algorithms
4.6 Routing in the Internet
4.7 Broadcast and multicast routing

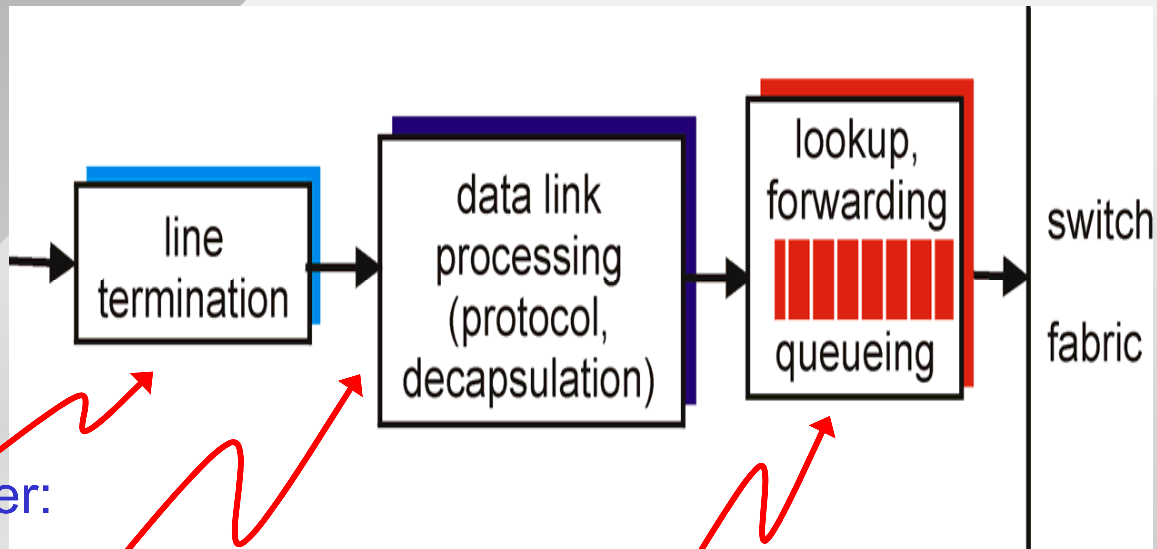
Router Architecture Overview

Two key router functions:

- Run routing algorithms/protocols (RIP, OSPF, BGP)
- Forward datagrams from incoming to outgoing link
  - Terminology: port = interface capable of sending/receiving



Input Port (Queue) Functions



Physical layer:
bit-level reception

Data link layer
(e.g., Ethernet, ATM, Token Ring, 802.11b): see ch. 5

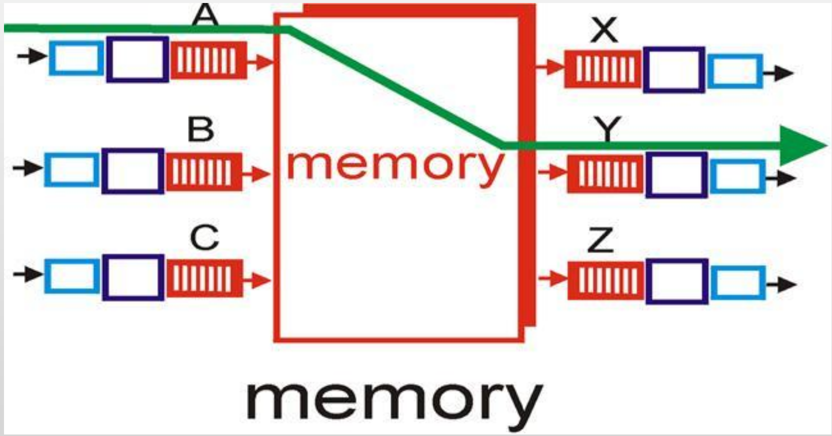
Decentralized switching*:*

- Given datagram destination, look up output port using forwarding table in input port memory
- Goal: complete input port processing at “line speed”
- Queuing: if datagrams arrive faster than forwarding rate into switch fabric

Switching Via Memory

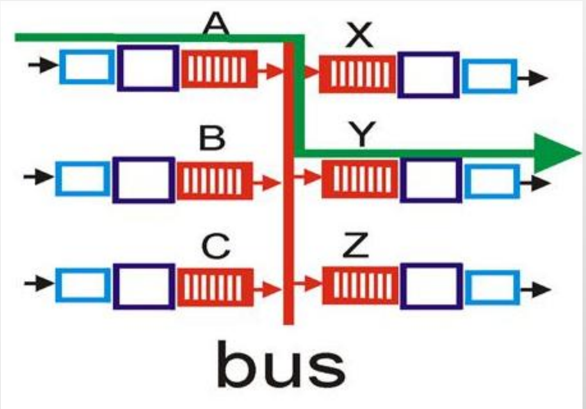
First generation routers (1960s-mid 1980s):

- Traditional computers with switching under direct control of CPU
- Packet copied to system memory
- Speed limited by CPU, memory latency/bandwidth, and bus bandwidth (two bus crossings per datagram)
- Honeywell 316 (1969) →



Switching Via a Bus

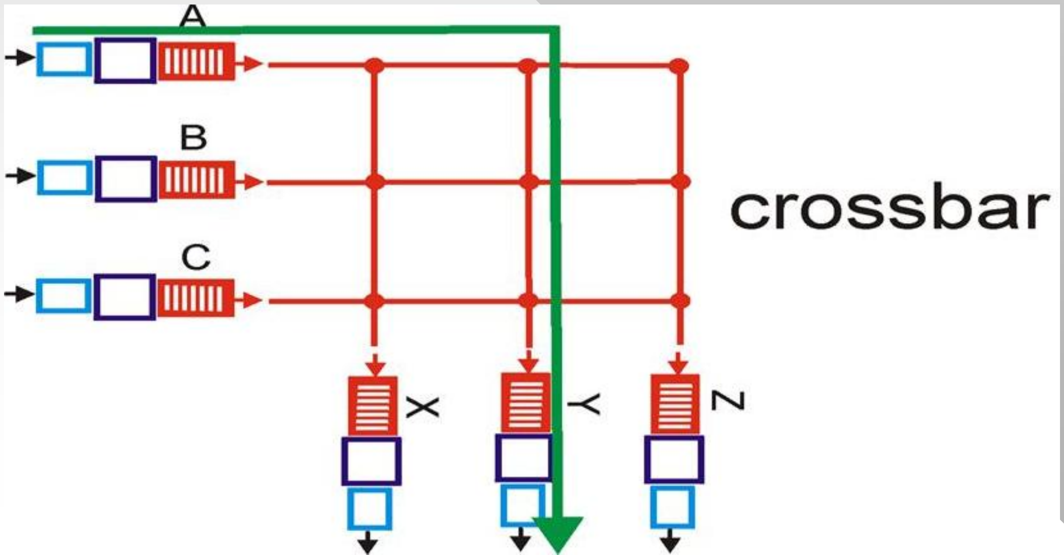
- Datagram from input port memory to output port memory via a shared bus
- Bus contention: switching speed limited by bus bandwidth



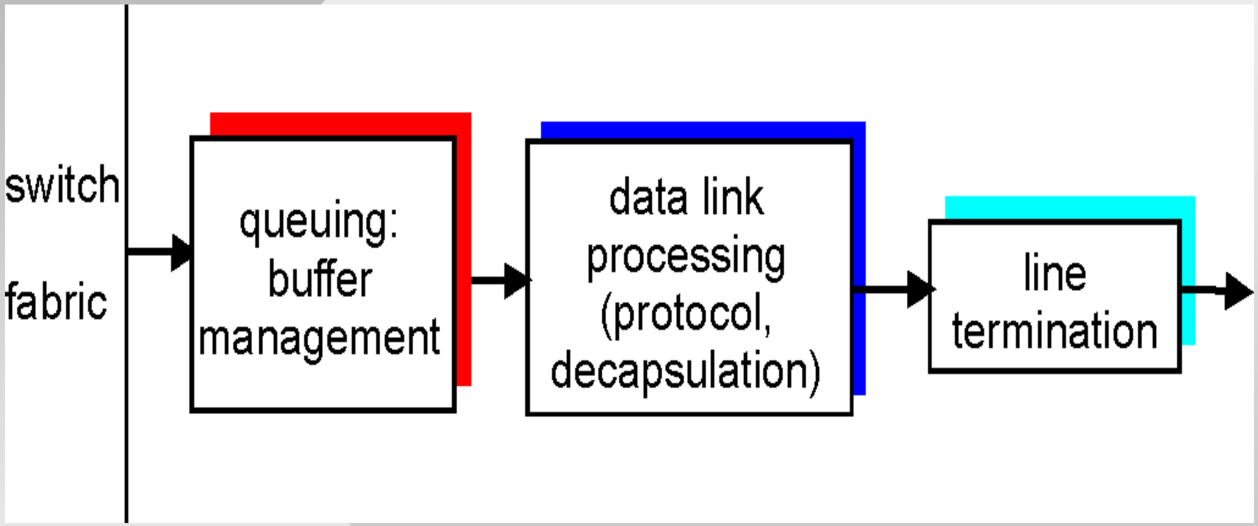
- 1 Gbps bus in Cisco 1900: sufficient speed for access and small enterprise networks (not ISPs)

Switching Via An Interconnection Network

- Overcomes bus bandwidth limitations
  - Crossbar: packets transmitted in parallel as long as they do not occupy the same horizontal or vertical bus
- Cisco 12000 (1996): uses an interconnection network
  - CRS-X (2013): 1600 lbs, 84” rack, 7.6 KWatt, 800 Gbps/slot
  - 16 slots/rack = 12.8 Tbps
  - Up to 72 racks (922 Tbps)

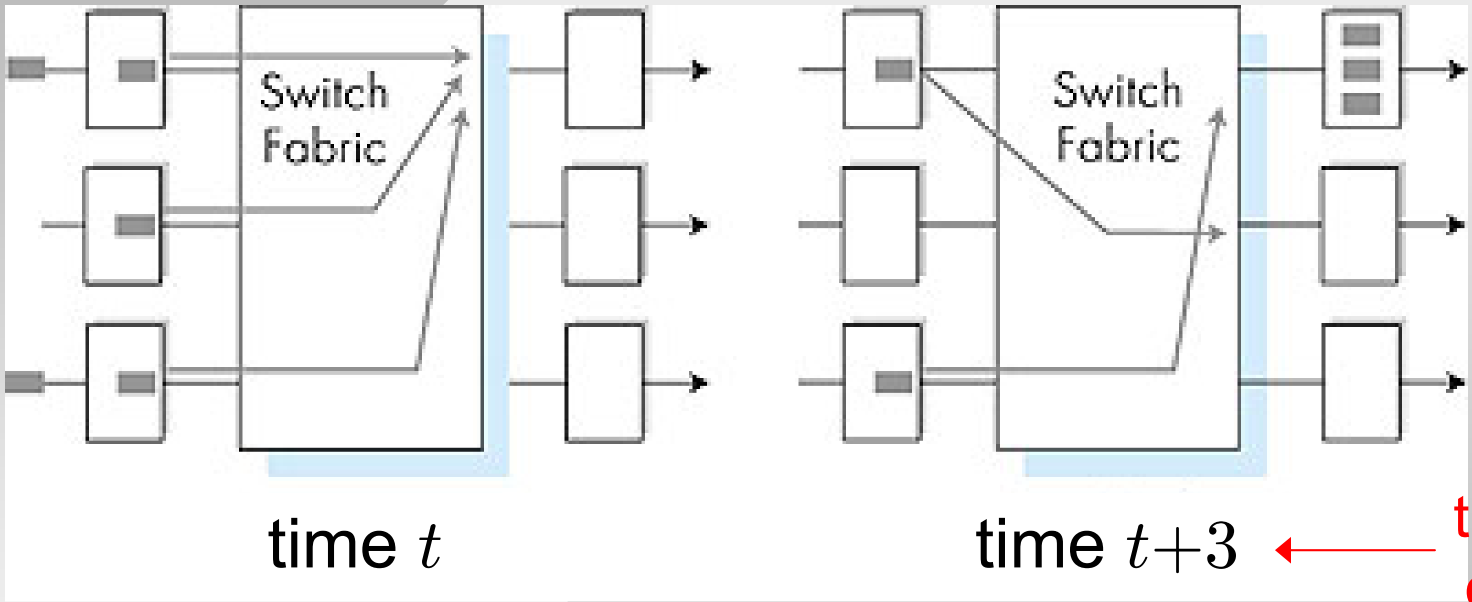


Output Ports



- *Buffering/queuing* required when datagrams arrive from fabric faster than the transmission rate
- *Scheduling discipline* chooses among queued datagrams for transmission
  - Customer traffic: single FIFO drop-tail queue
  - ISP traffic: multiple queues with WRR or priority queuing

Output Port Queuing

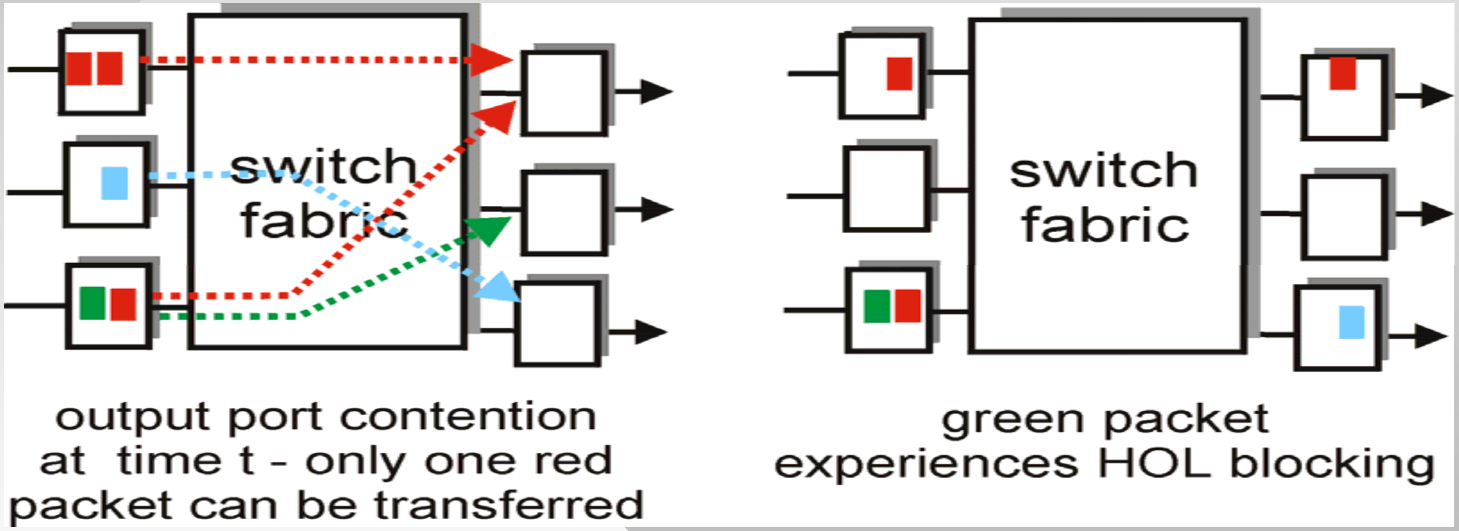


time units of switch fabric

- Buffering when arrival rate via switch fabric exceeds output line speed
  - Queuing delay and loss due to output buffer overflow
- Switch fabric often faster than individual ports
  - Produces large bursts of arrivals into output queues

Input Port Queuing

- Reasons for input-port queuing:
  - Head-of-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward



time t time $t+1$

- Queuing delay and loss due to input buffer overflow!
  - How likely is this compared to output port queuing/loss?

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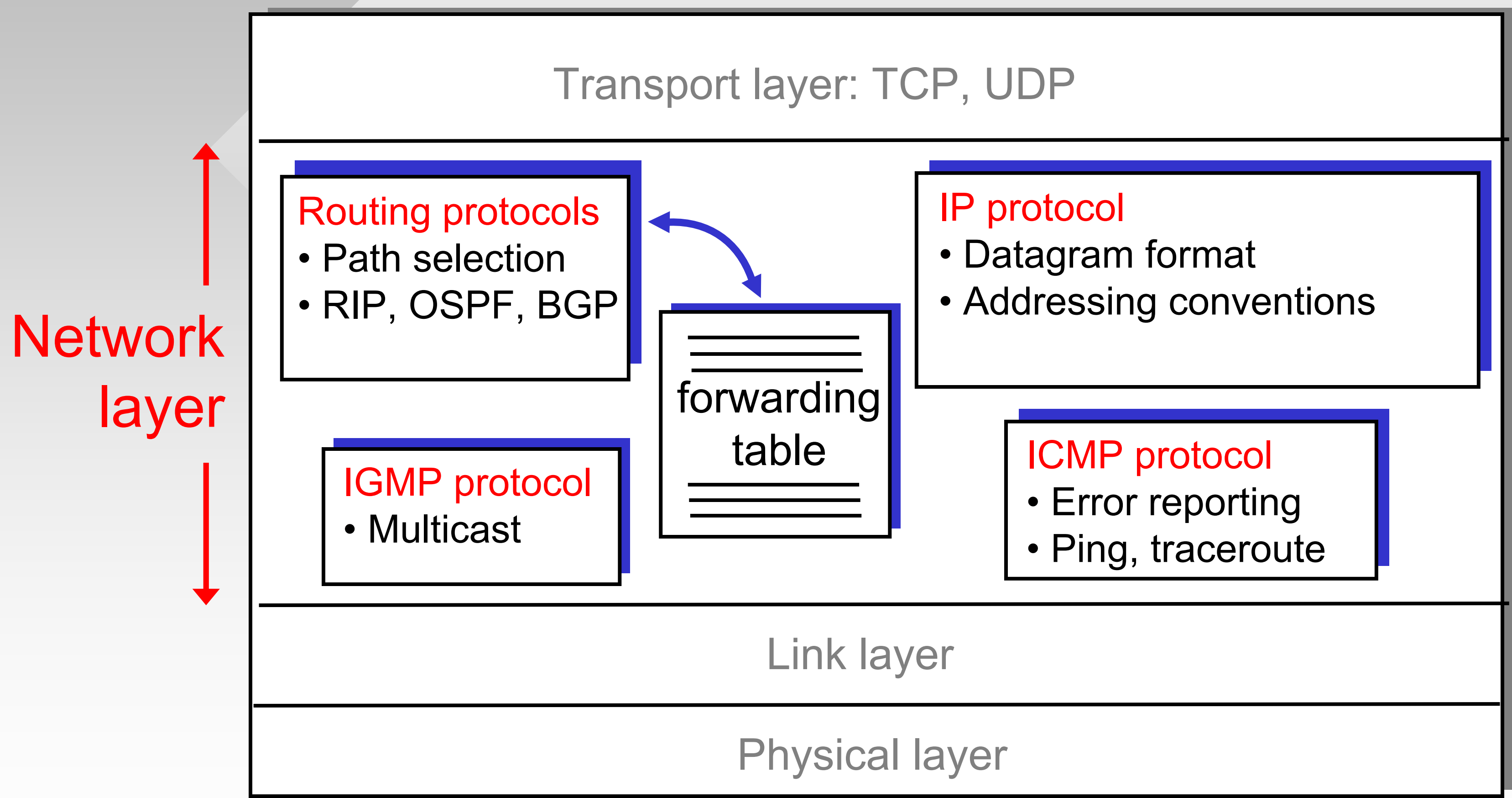
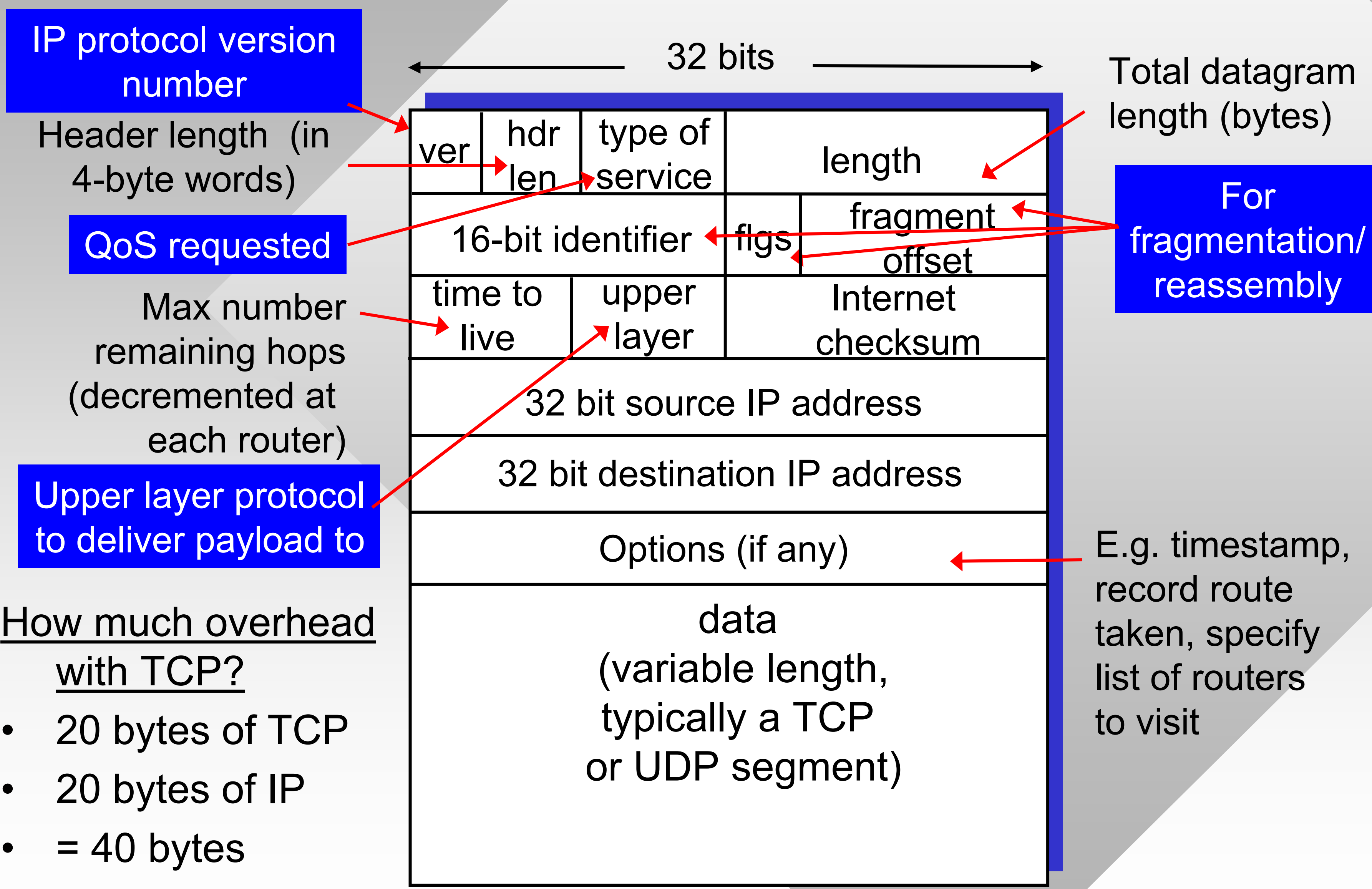
The Internet Network Layer

Host and router network layer functions:



Chapter 4: Roadmap

IPv4 Datagram Format

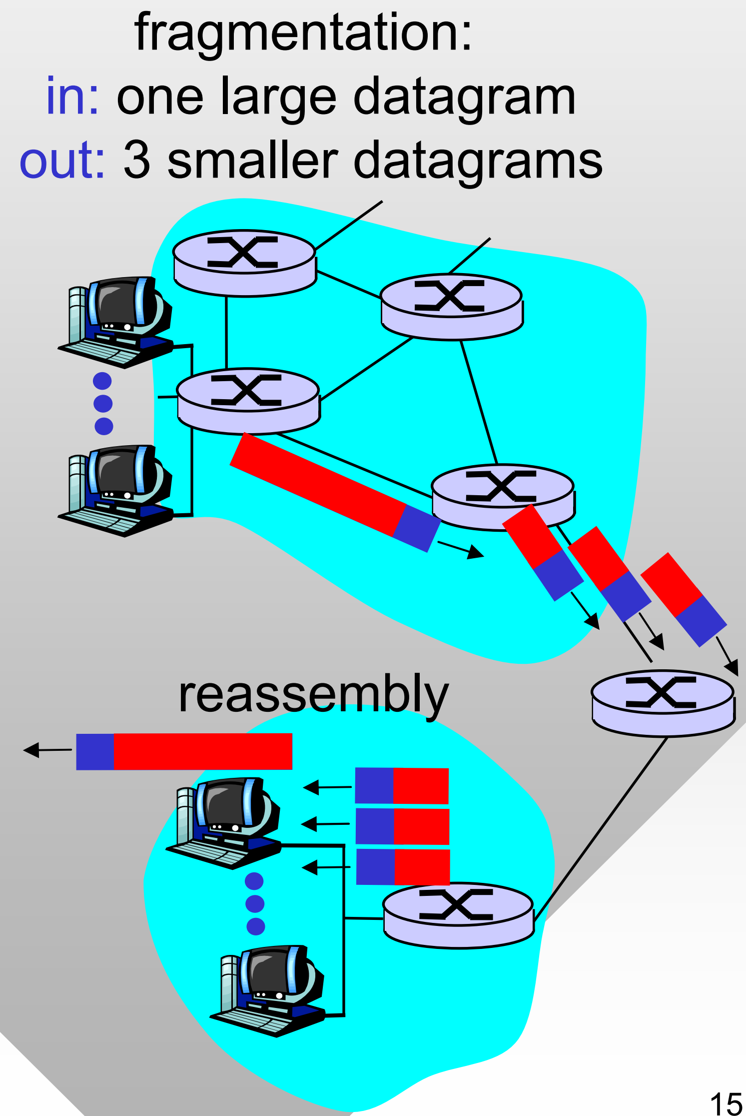


How much overhead with TCP?

- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes

IP Fragmentation & Reassembly

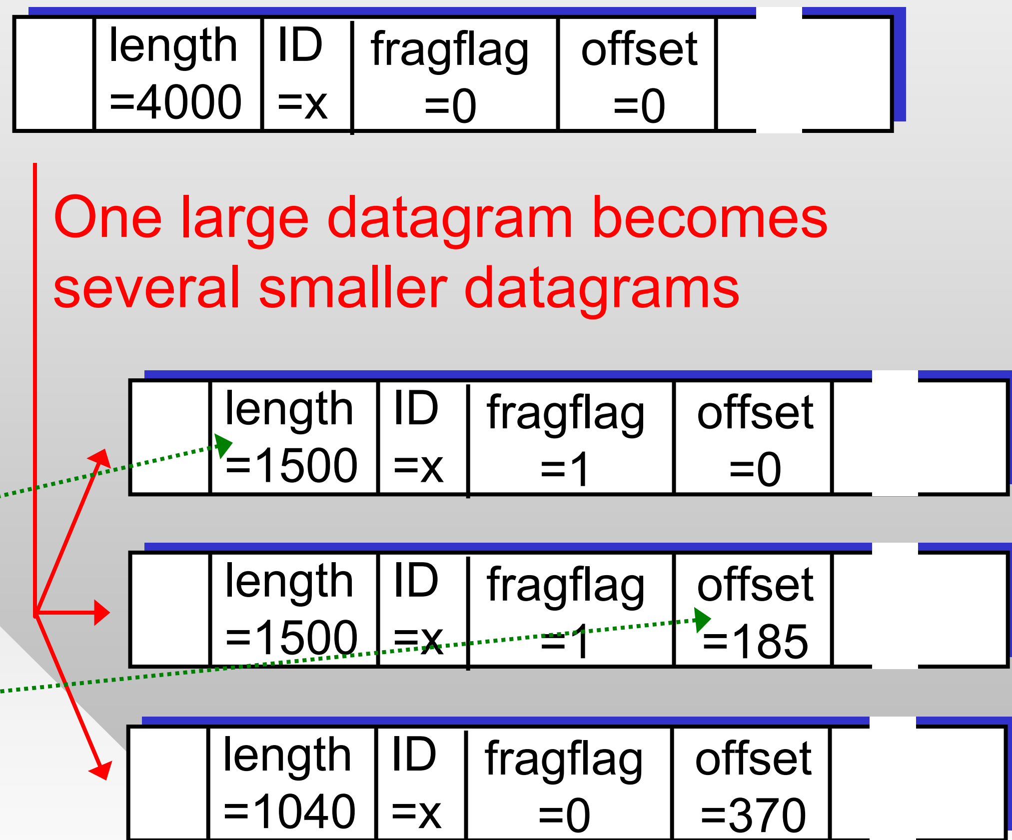
- Network links have varying MTUs (maximum transmission units) – largest possible link-level frames
  - Different link types, different MTUs (most common 1500)
- Large IP datagram divided ("fragmented") within network
  - One datagram becomes several datagrams
  - "Reassembled" only at final destination
  - IP header bits used to identify, order related fragments



IP Fragmentation and Reassembly

Example

- 4000 byte datagram (including IP header)
- MTU = 1500 bytes



1480 bytes in payload

offset in 8-byte words: 185 = 1480/8

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- Datagram format
- IPv4 addressing
- ICMP
- IPv6

4.5 Routing algorithms

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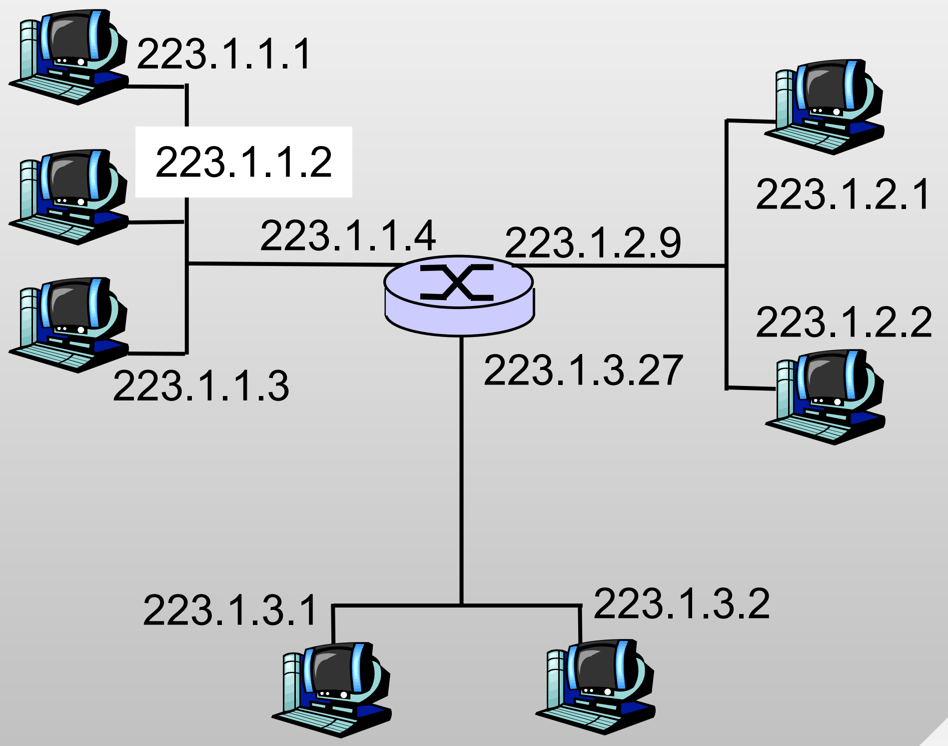
IP Addressing: Introduction

- IP address: 32-bit identifier for host or router *interface*
- *Interface:* connection between host/router and physical link
  - Also called a port
  - Routers have many interfaces
- Can hosts have multiple interfaces?
  - Yes, it's called multi-homing

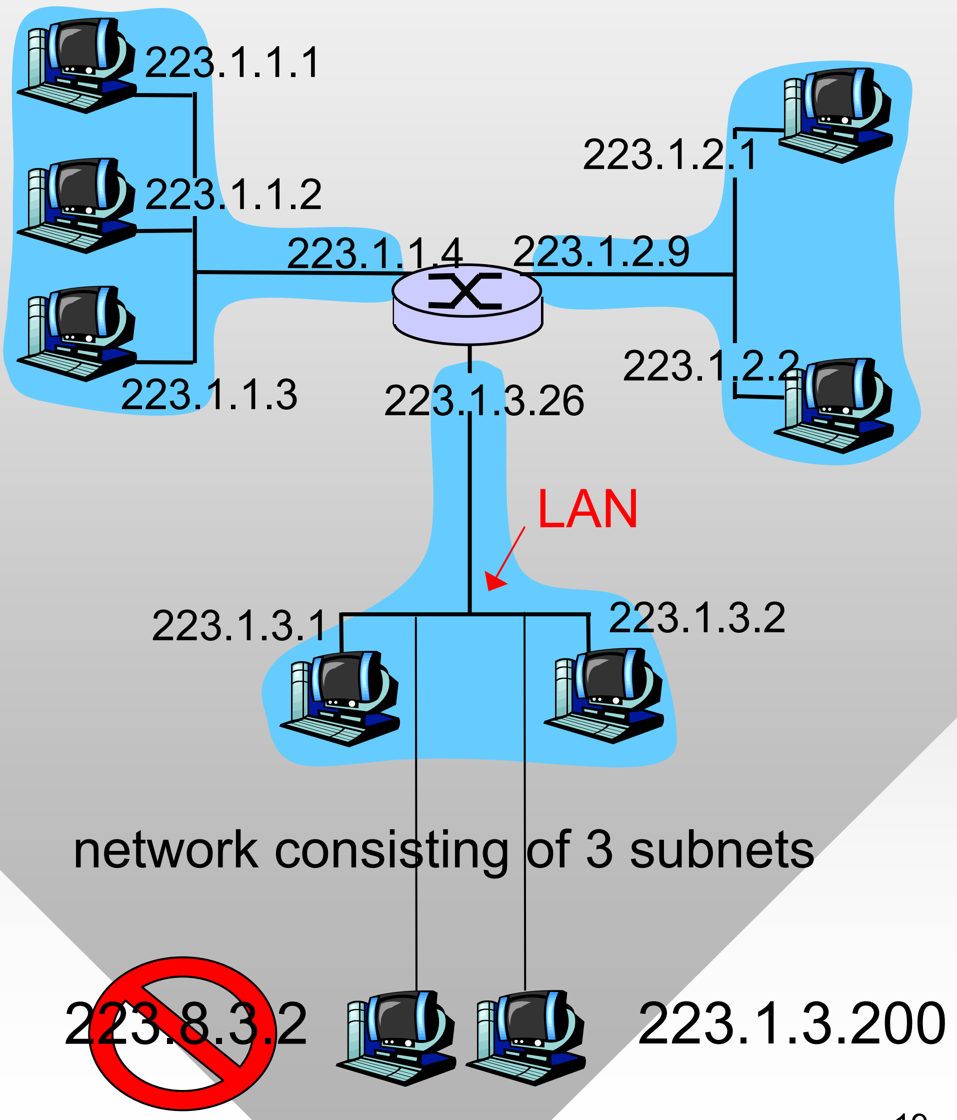


223.1.1.1 = 11011111 00000001 00000001 00000001

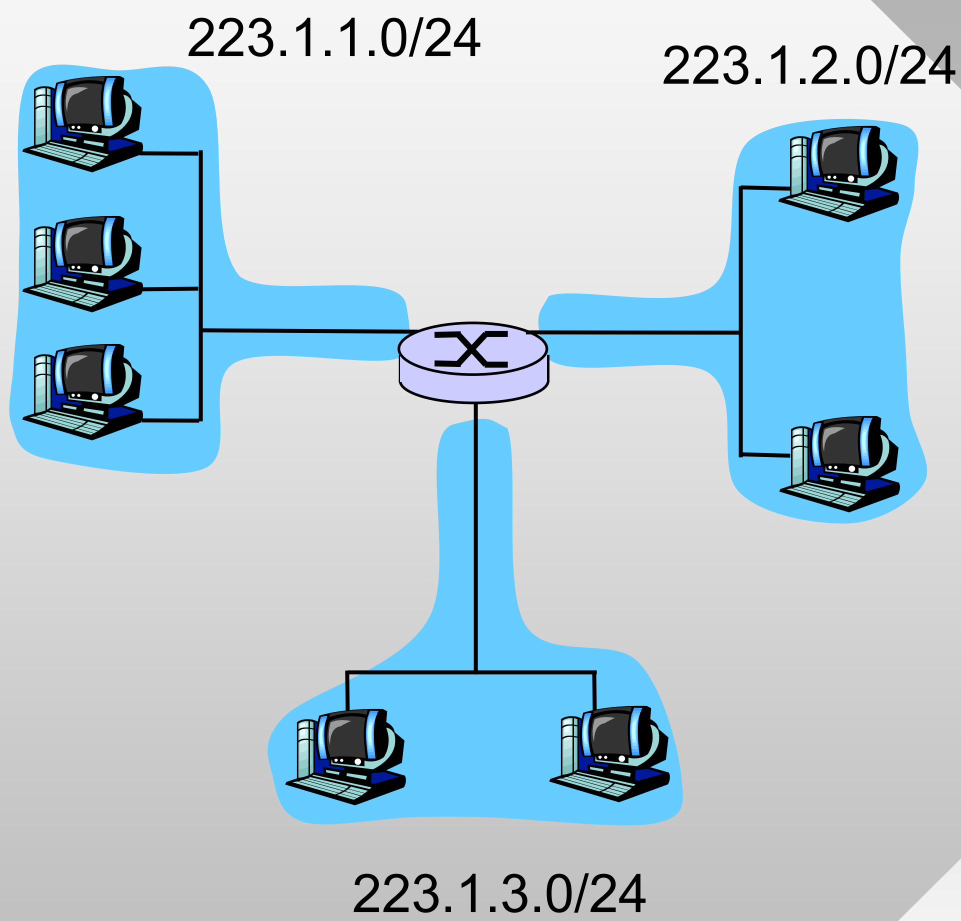
$$\underbrace{11011111}_{223}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}$$

Subnets

- IP address:
  - Subnet prefix: *k* bits
  - Host suffix: 32-*k* remaining bits
- *What's a subnet (LAN)?*
  - Network composed of devices with the same subnet prefix of IP address
  - Can physically reach each other without intervening router



Subnets



Recipe

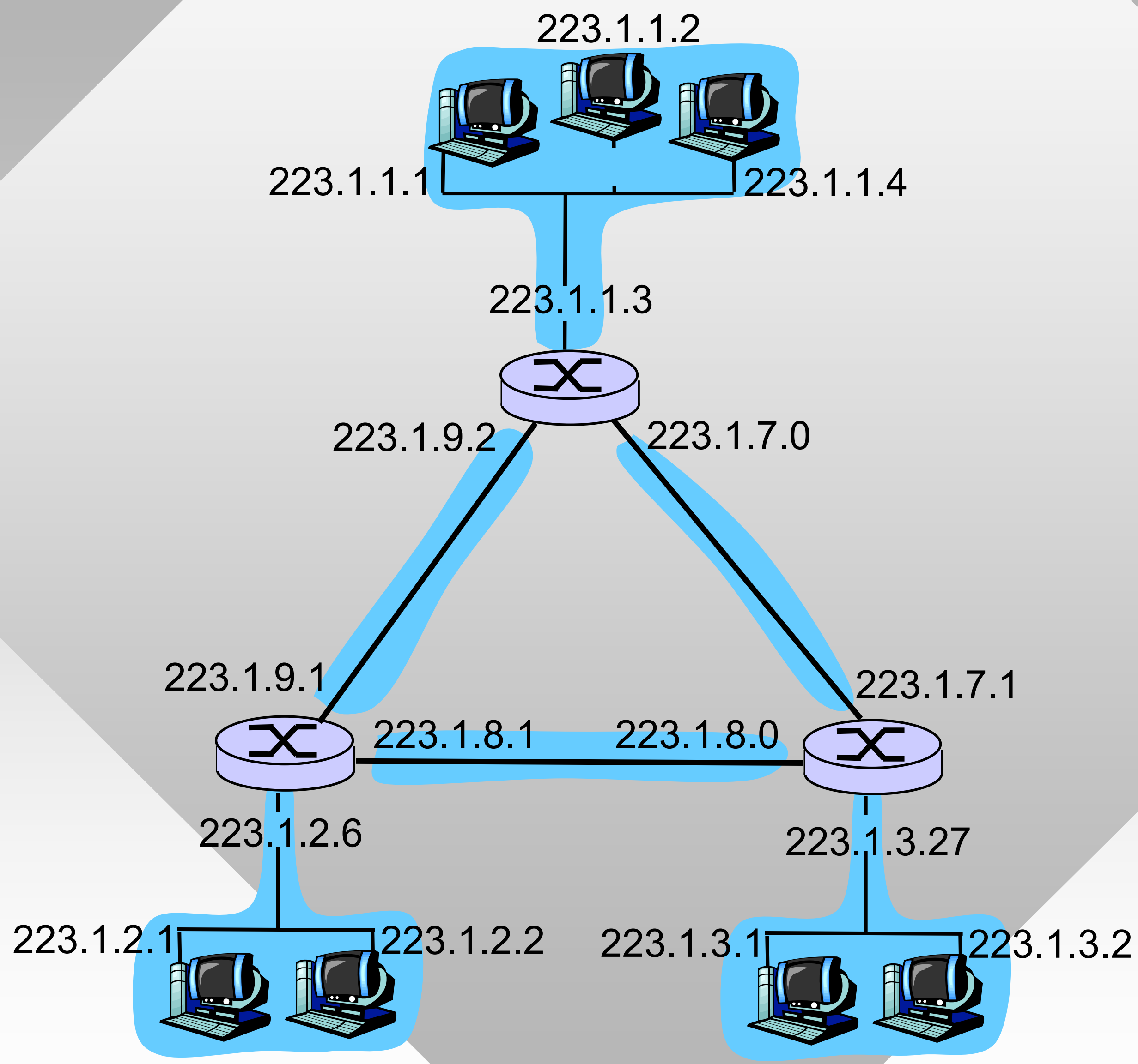
- To determine the subnets, detach each interface from its host or router, creating islands of isolated networks
- Each isolated network is a subnet

Subnet mask:

- 255.255.255.0
- or /24

Subnets

How many?



IP Addressing: CIDR

- In the early Internet, only subnets with 8, 16, or 24 bit prefixes were allowed (“class A, B, C” networks)
- This was inflexible and wasteful as well

CIDR: Classless InterDomain Routing

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

subnet part ←→ host part

11001000 00010111 00010000 00000000

200.23.16.0/23

IP Addresses: How to Get One?

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

- Either hard-coded by system admin in a file
  - Windows: Control-panel → network → configuration → tcp/ip → properties
  - Linux: /etc/rc.config
- Or dynamically assigned by DHCP (Dynamic Host Configuration Protocol)
  - "Plug-and-play" (more in Chapter 5)

IP Addresses: How to Get One?

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

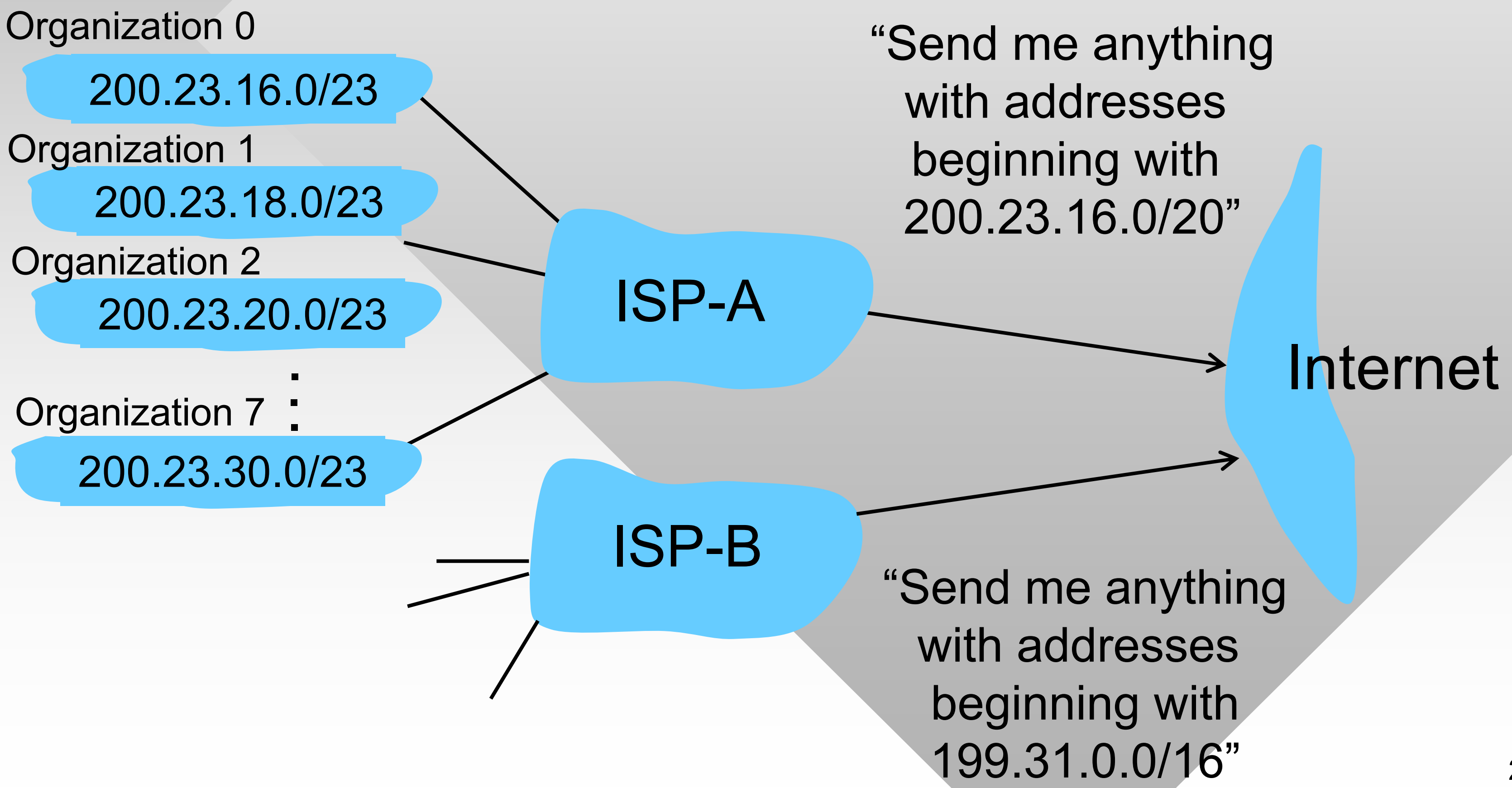
A: Gets allocated portion of its provider ISP's address space

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

- Task: split this ISP into one /21, three /23, and eight /26

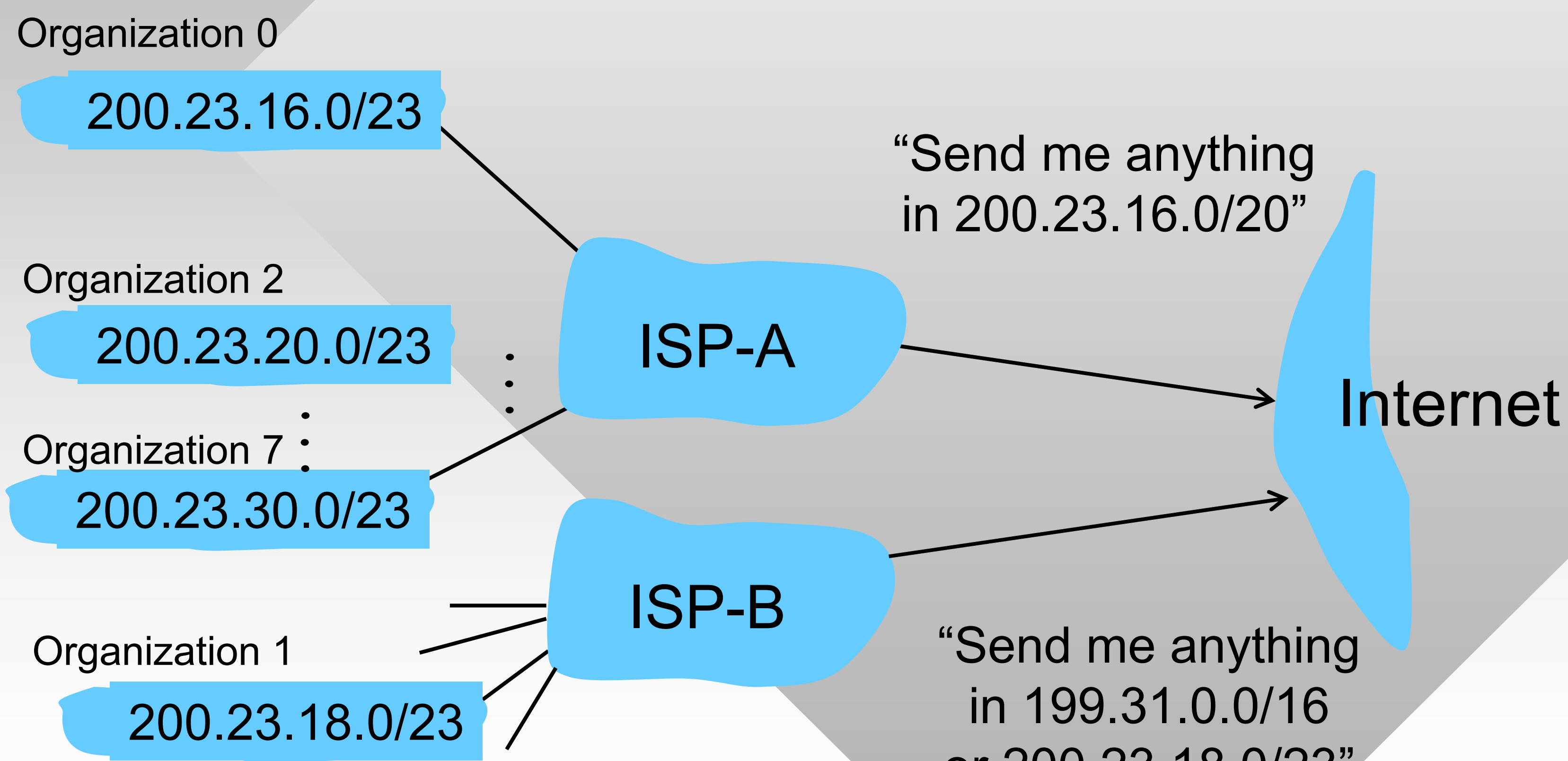
Hierarchical Addressing: Route Aggregation

Hierarchical addressing allows efficient advertisement of routing information:



Hierarchical Addressing: More Specific Routes

ISP-B has a more specific route to Organization 1



IP Addressing: Last Word...

Q: How does an ISP get a block of addresses?

A: ICANN: Internet Corporation for Assigned Names and Numbers assigns IPs to regional registries

- These are ARIN (North/South America), RIPE (Europe), APNIC (Asia-Pacific), and AfriNIC (Africa)

- These registries process ISP and user requests for subnet space
  - Also manage DNS and resolve disputes
- Quiz #3 covers
  - Chapter 3: P7-9, 22-24, 26-28, 31-37, 40-41, 43-49
  - Chapter 4: P1-17 (including today’s lecture)