Chapter 4
Network Layer: Data Plane

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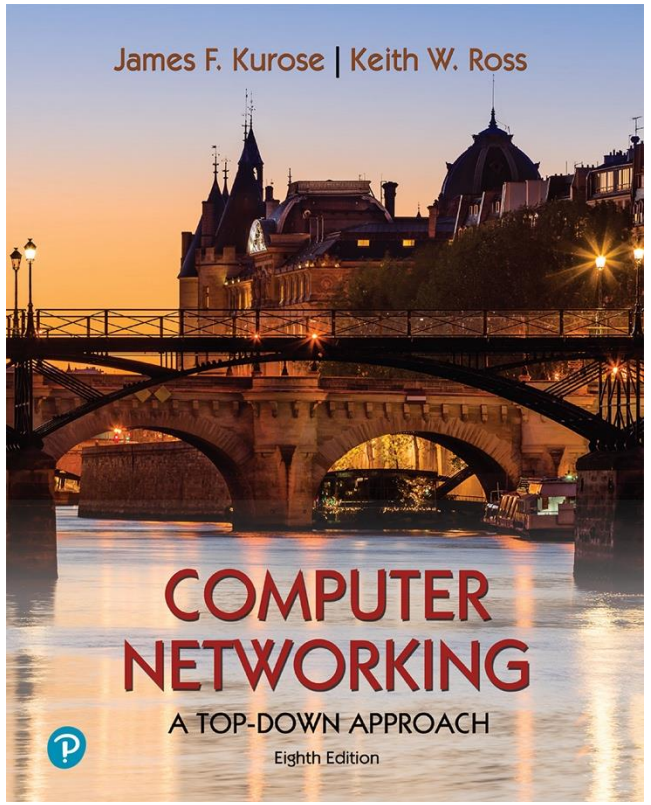
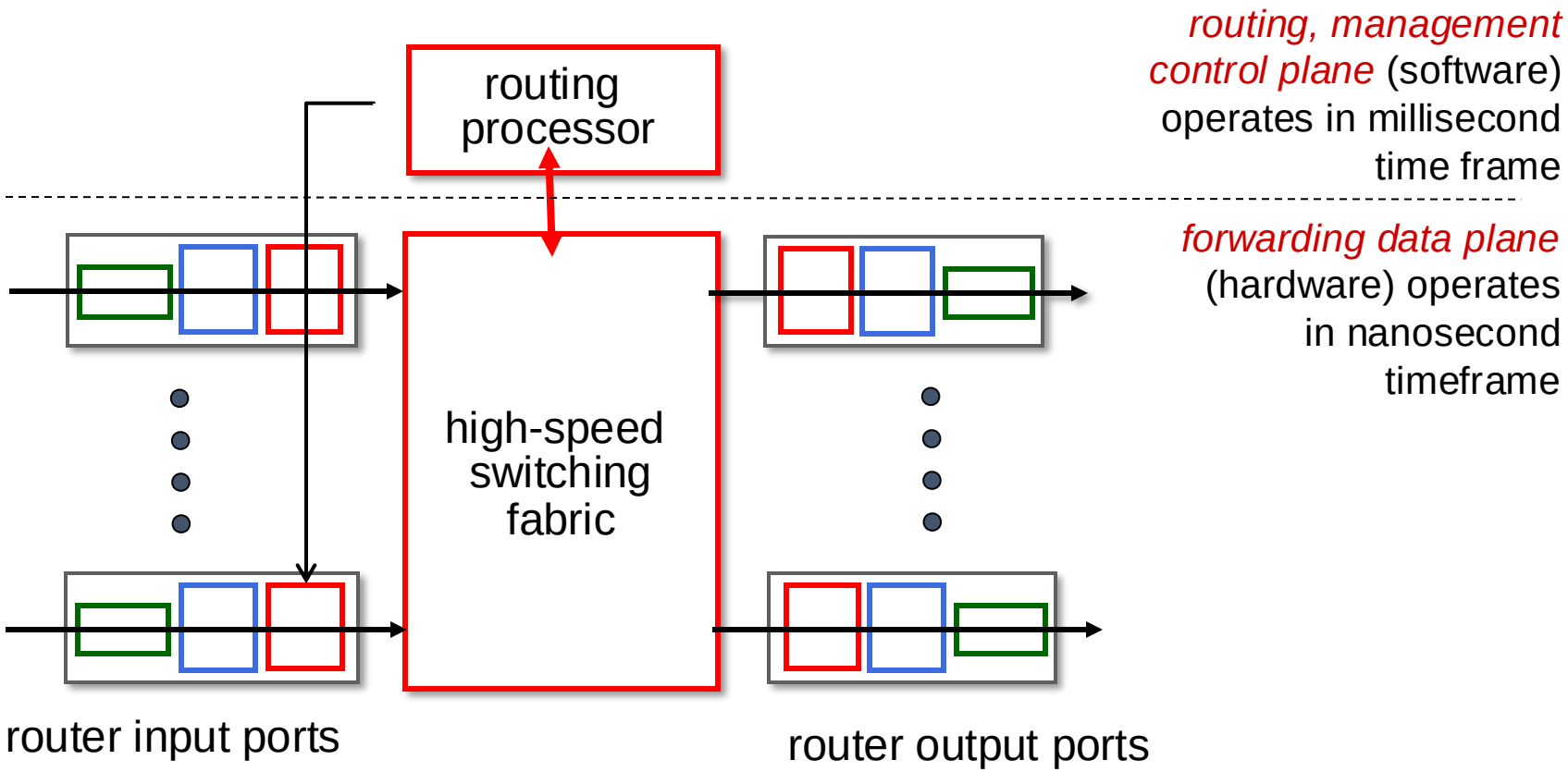


Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

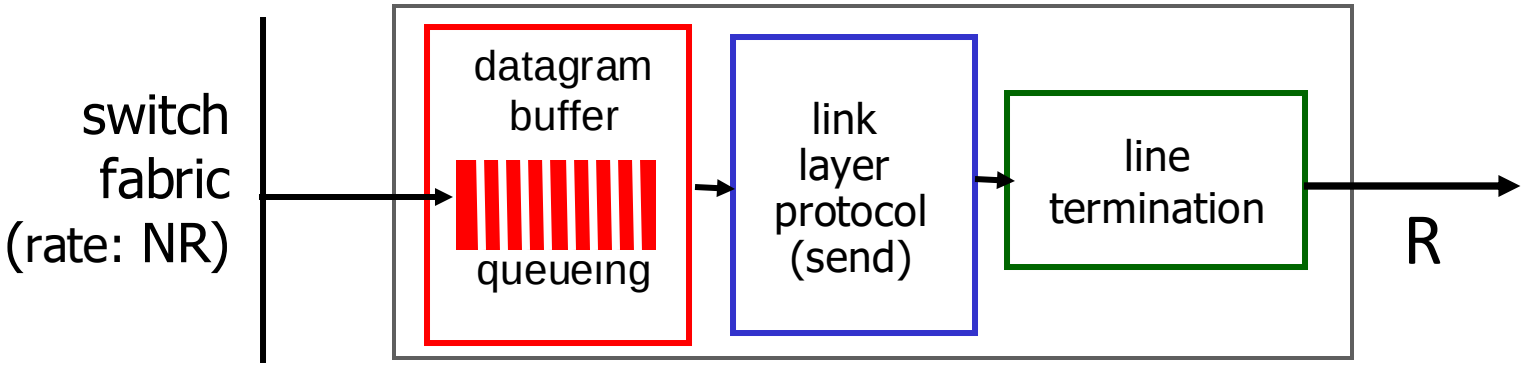
Adapted from the slides of the book's authors

Router architecture overview

high-level view of generic router architecture:



Output port queuing



This is a really important slide

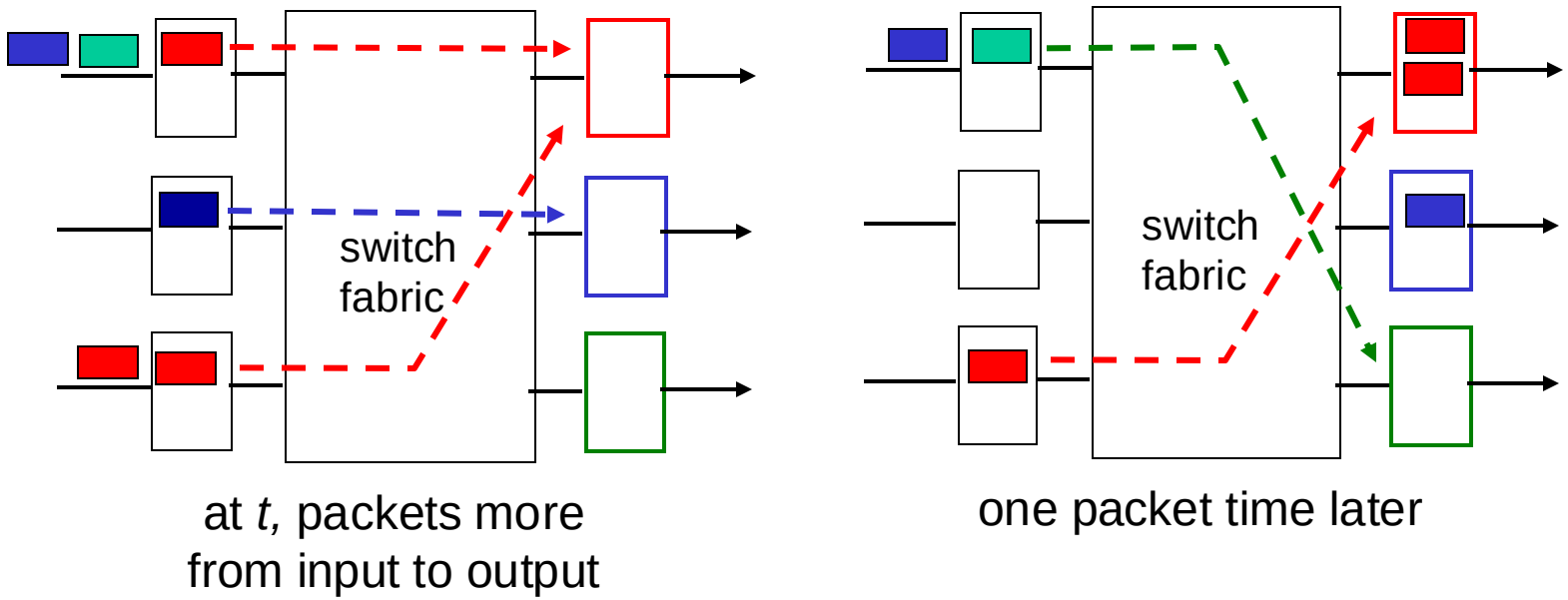
- *Buffering* required when datagrams arrive from fabric faster than link transmission rate. *Drop policy:* which datagrams to drop if no free buffers?

→ Datagrams can be lost due to congestion, lack of buffers

- *Scheduling discipline* chooses among queued datagrams for transmission

→ Priority scheduling – who gets best performance, network neutrality

Output port queuing



at *t*, packets more from input to output

one packet time later

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

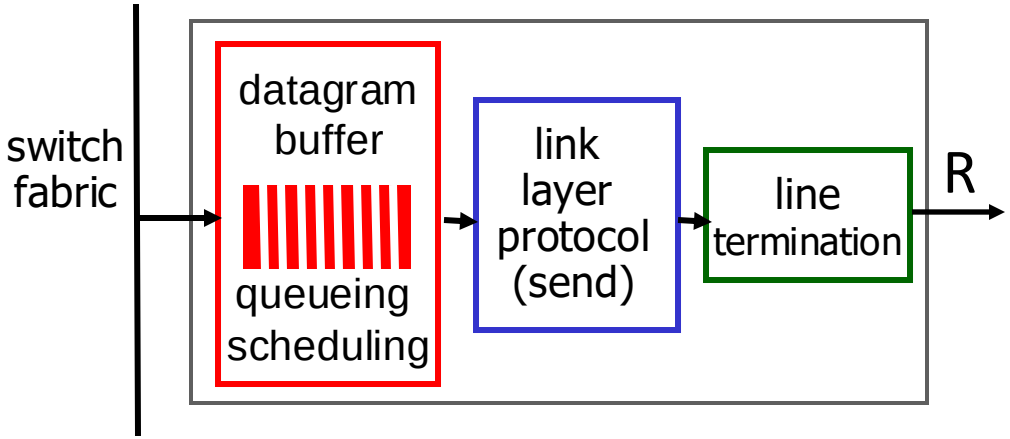
How much buffering?

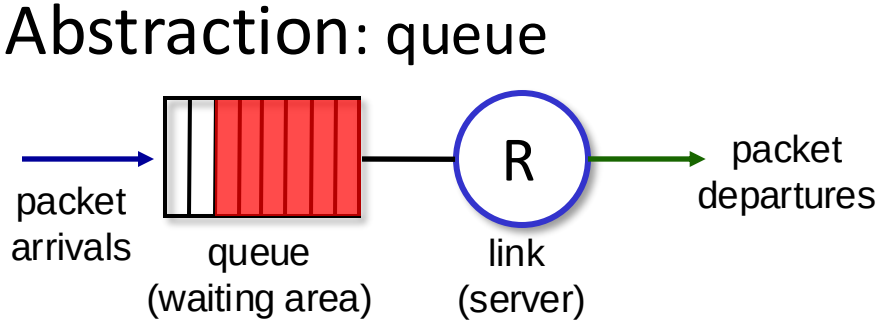
- RFC 3439 rule of thumb: average buffering equal to “typical” RTT (say 250 msec) times link capacity C
  - e.g., C = 10 Gbps link: 2.5 Gbit buffer
- more recent recommendation: with *N* flows, buffering equal to

$$\frac{RTT \cdot C}{\sqrt{N}}$$

- but *too* much buffering can increase delays (particularly in home routers)
  - long RTTs: poor performance for real-time apps, sluggish TCP response
  - recall delay-based congestion control: “keep bottleneck link just full enough (busy) but no fuller”

Buffer Management





buffer management:

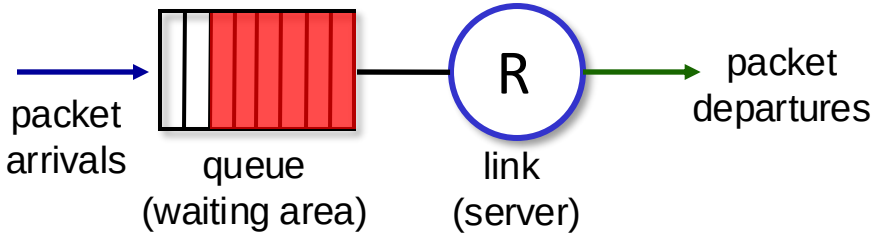
- drop: which packet to add, drop when buffers are full
  - tail drop: drop arriving packet
  - priority: drop/remove on priority basis
- marking: which packets to mark to signal congestion (ECN, RED)

Packet Scheduling: FCFS

packet scheduling: deciding which packet to send next on link

- first come, first served
- priority
- round robin
- weighted fair queueing

Abstraction: queue



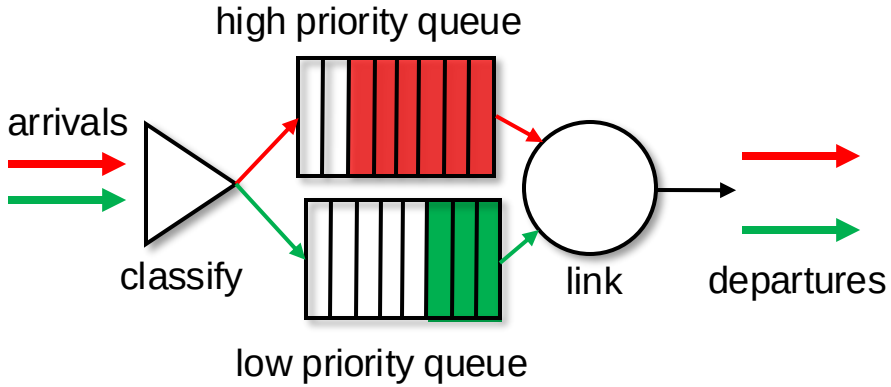
FCFS: packets transmitted in order of arrival to output port

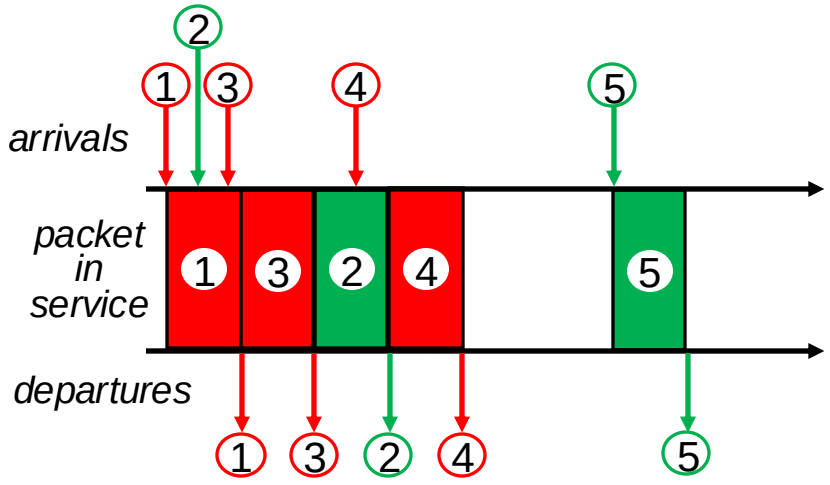
- also known as: First-in-first-out (FIFO)
- real world examples?

Scheduling policies: priority

Priority scheduling:

- arriving traffic classified, queued by class
  - any header fields can be used for classification
- send packet from highest priority queue that has buffered packets
  - FCFS within priority class

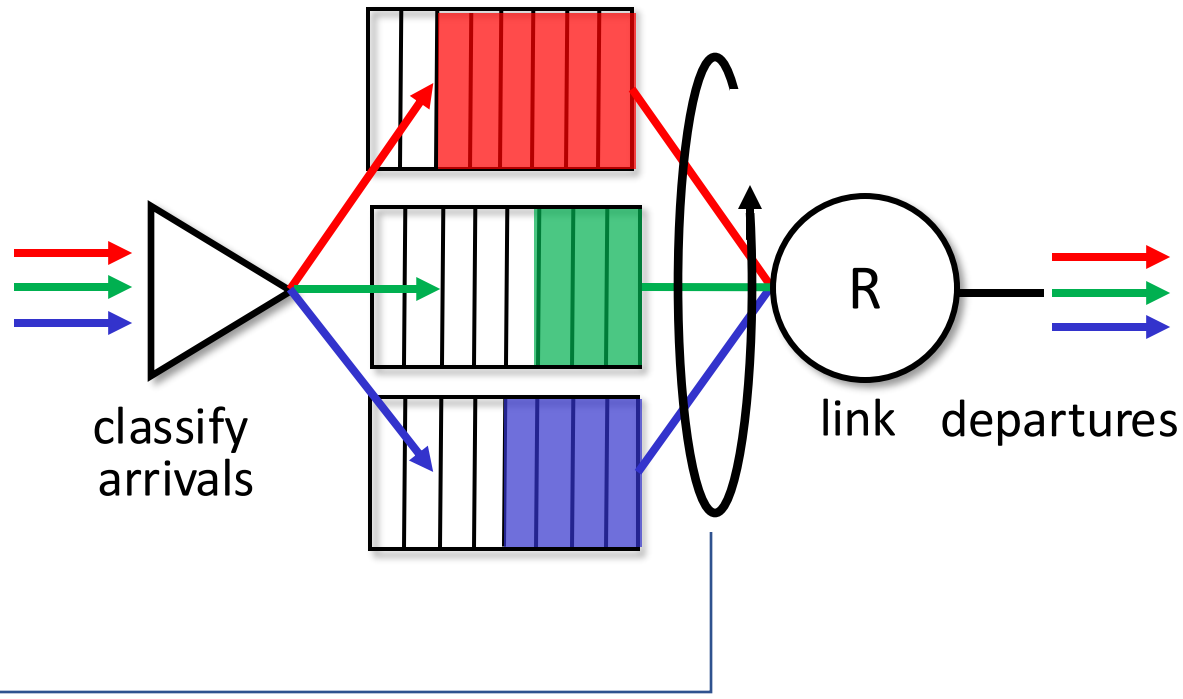




Scheduling policies: round robin

Round Robin (RR) scheduling:

- arriving traffic classified, queued by class
  - any header fields can be used for classification
- server cyclically, repeatedly scans class queues, sending one complete packet from each class (if available) in turn



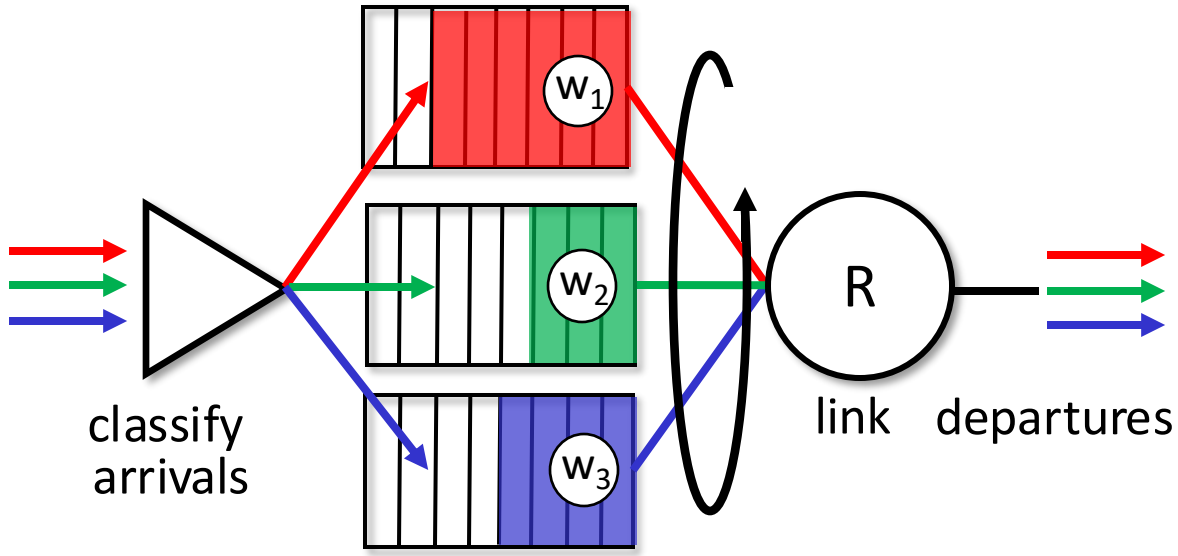
Scheduling policies: weighted fair queueing

Weighted Fair Queuing (WFQ):

- generalized Round Robin
- each class, *i*, has weight, w_i, and gets weighted amount of service in each cycle:

$$\frac{w_i}{\sum_j w_j}$$

- minimum bandwidth guarantee (per-traffic-class)



Sidebar: Network Neutrality

What is network neutrality?

- *technical:* how an ISP should share/allocation its resources
  - packet scheduling, buffer management are the *mechanisms*
- *social, economic* principles
  - protecting free speech
  - encouraging innovation, competition
- enforced *legal* rules and policies

Different countries have different "takes" on network neutrality

Sidebar: Network Neutrality

2015 US FCC *Order on Protecting and Promoting an Open Internet:* three "clear, bright line" rules:

- no blocking … "shall not block lawful content, applications, services, or non-harmful devices, subject to reasonable network management."
- no throttling … "shall not impair or degrade lawful Internet traffic on the basis of Internet content, application, or service, or use of a non-harmful device, subject to reasonable network management."
- no paid prioritization. … "shall not engage in paid prioritization"

ISP: telecommunications or information service?

Is an ISP a "telecommunications service" or an "information service" provider?

- the answer *really* matters from a regulatory standpoint!

US Telecommunication Act of 1934 and 1996:

- *Title II:* imposes "common carrier duties" on *telecommunications services*: reasonable rates, non-discrimination and *requires regulation*
- *Title I:* applies to *information services:*
  - no common carrier duties (*not regulated*)
  - but grants FCC authority "… as may be necessary in the execution of its functions"[4]

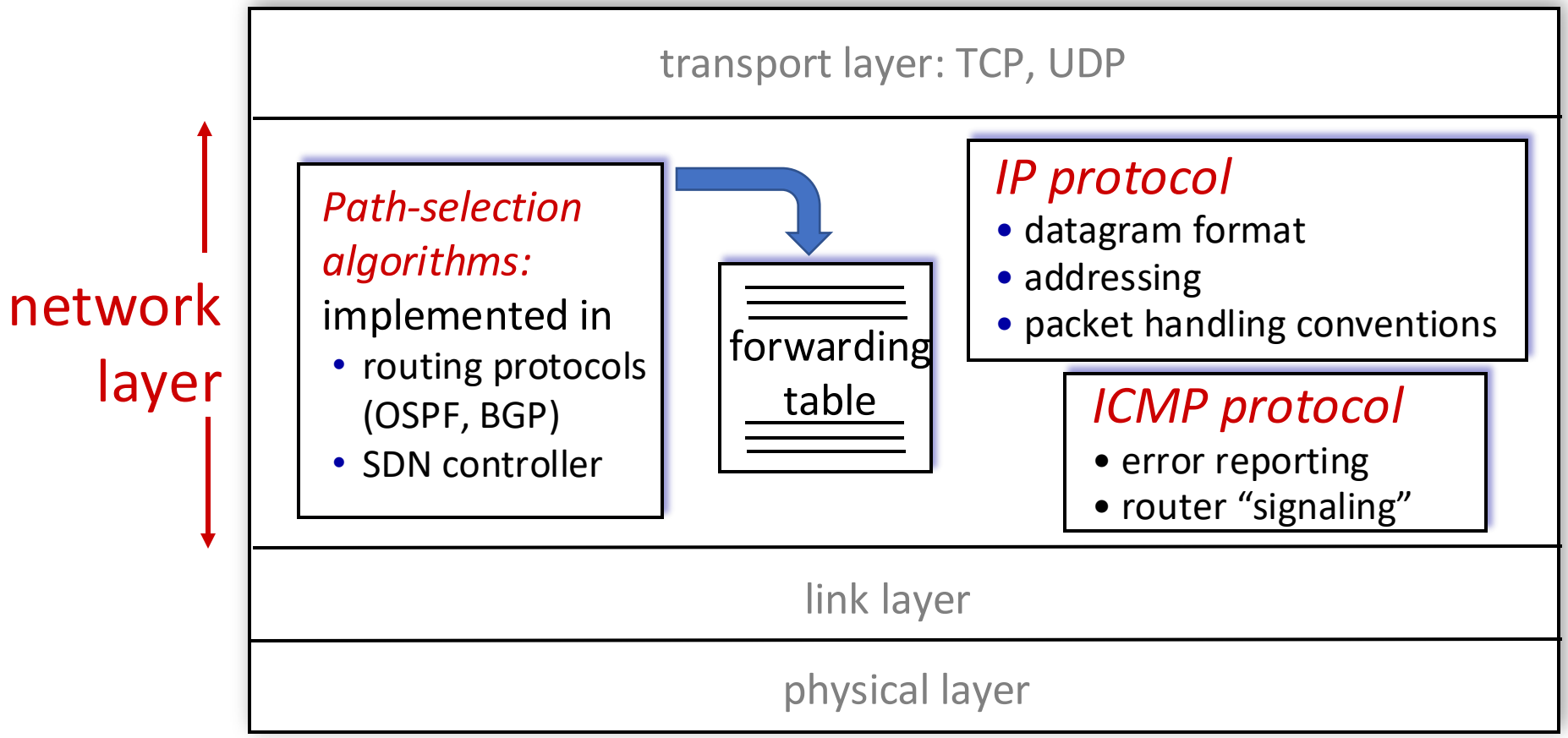
Network layer: "data plane" roadmap

- Network layer: overview
  - data plane
  - control plane
- What's inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - datagram format
  - addressing
  - network address translation
  - IPv6

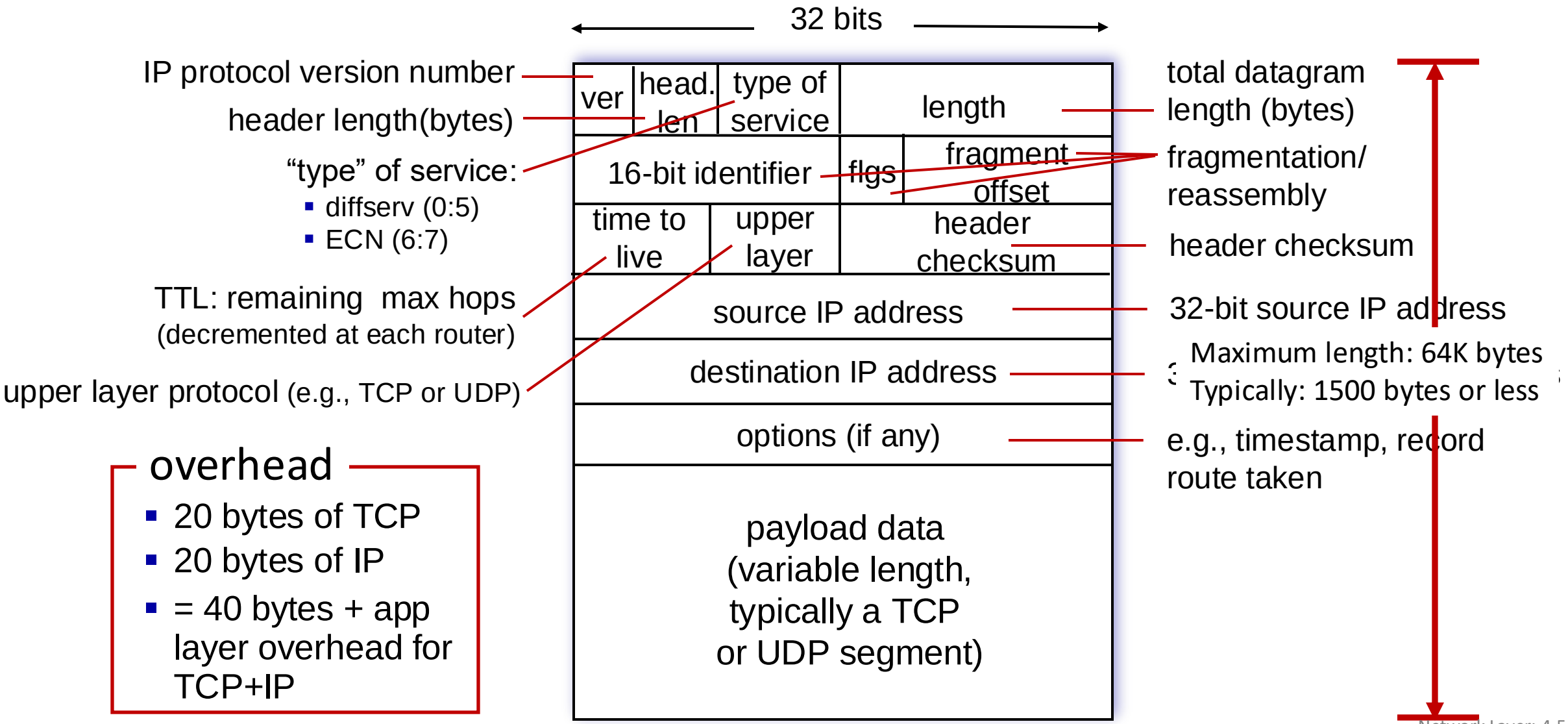
- Generalized Forwarding, SDN
  - match+action
  - OpenFlow: match+action in action
- Middleboxes

Network Layer: Internet

host, router network layer functions:



IP Datagram format

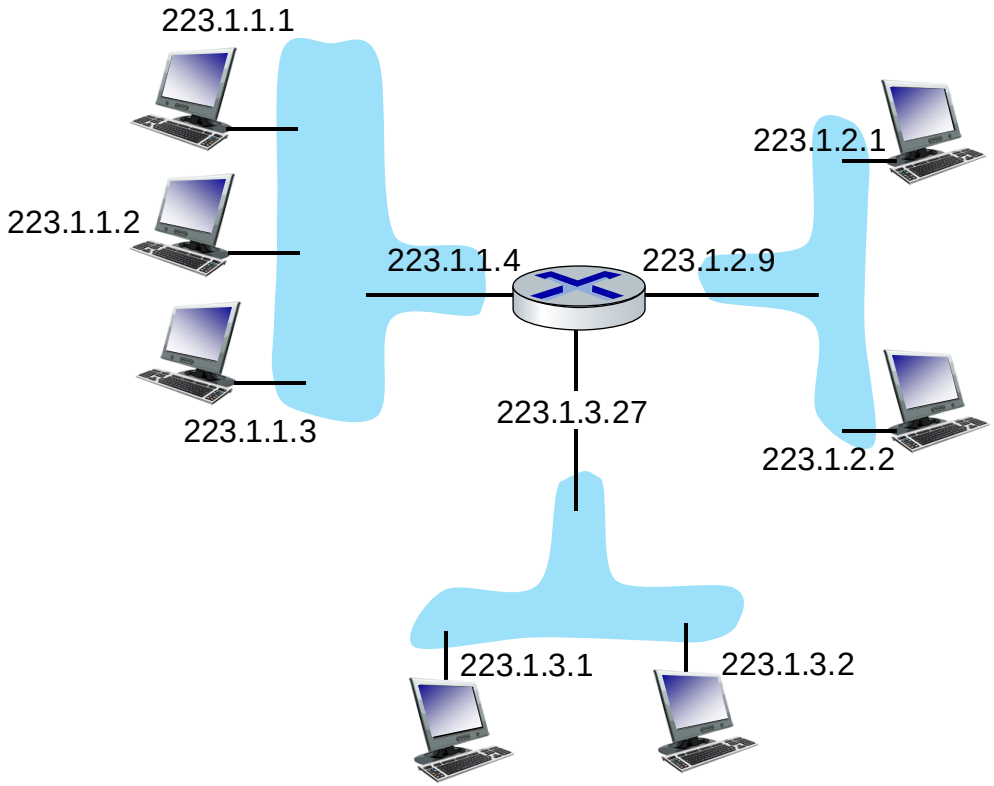


overhead

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

IP addressing: introduction

- IP address: 32-bit identifier associated with each host or 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)



dotted-decimal IP address notation:

223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

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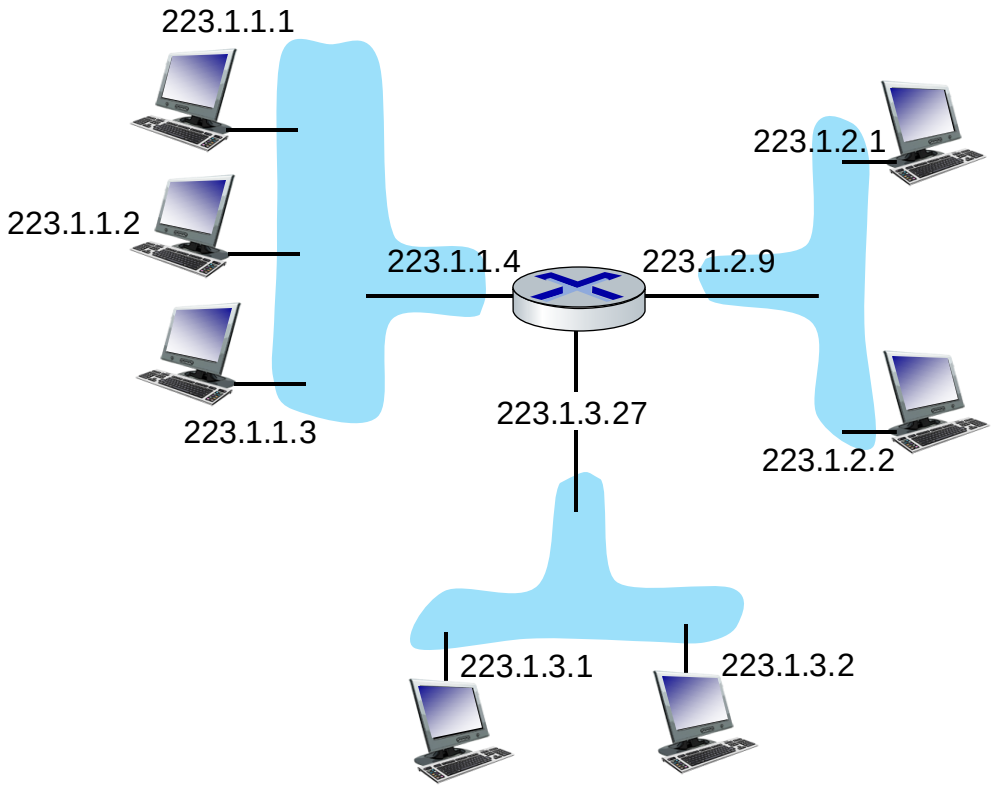

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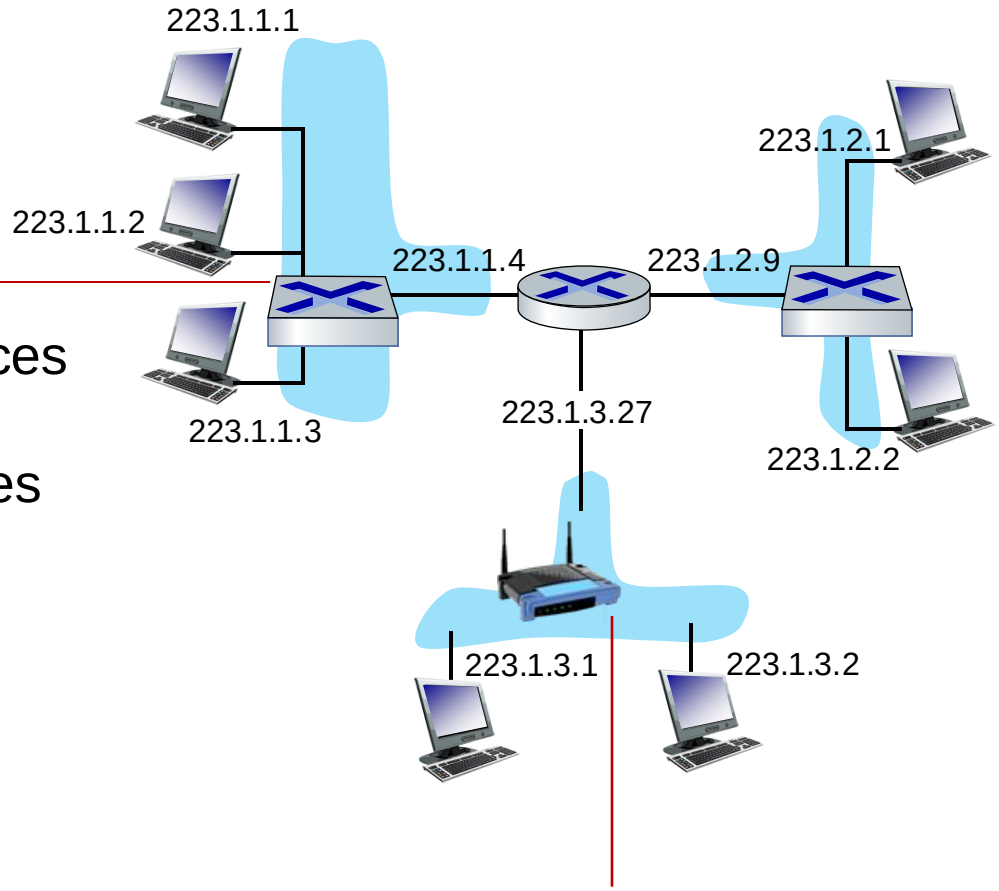
IP addressing: introduction

Q: how are interfaces actually connected?

A: we'll learn about that in chapters 6, 7



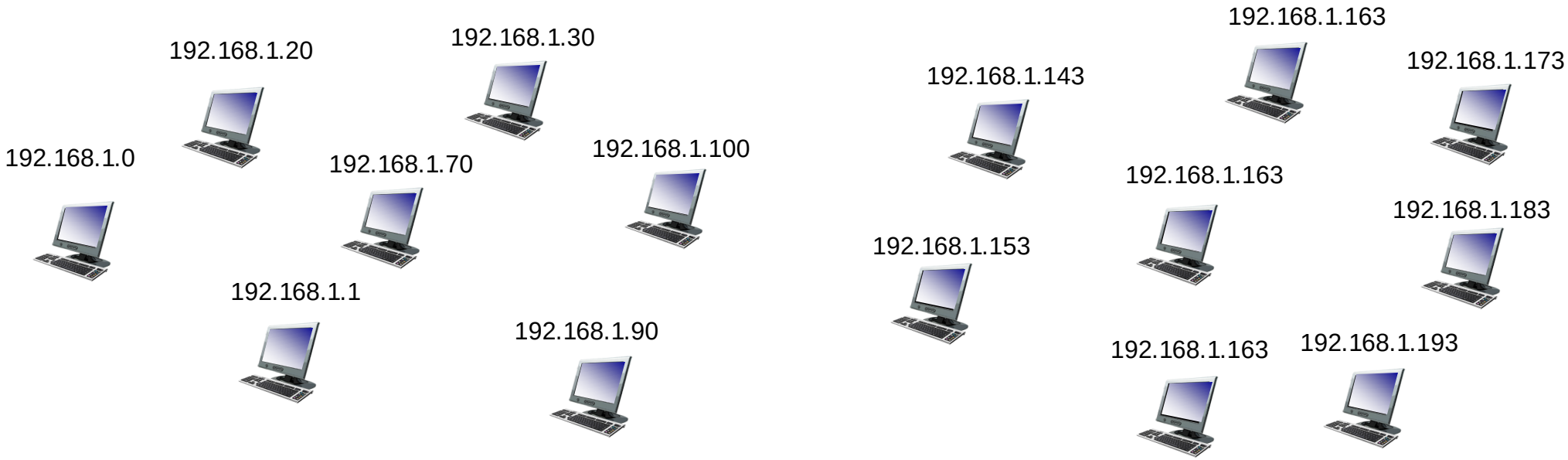
A: wired Ethernet interfaces connected by Ethernet switches

A: wireless WiFi interfaces connected by WiFi base station

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

Subnets

- *What's a subnet ?*
  - Subnet is a logical subdivision of an IP network.
  - *The practice of dividing a network into two or more networks is called subnetting*



An IP network: 192.168.1.0 to 192.168.1.255

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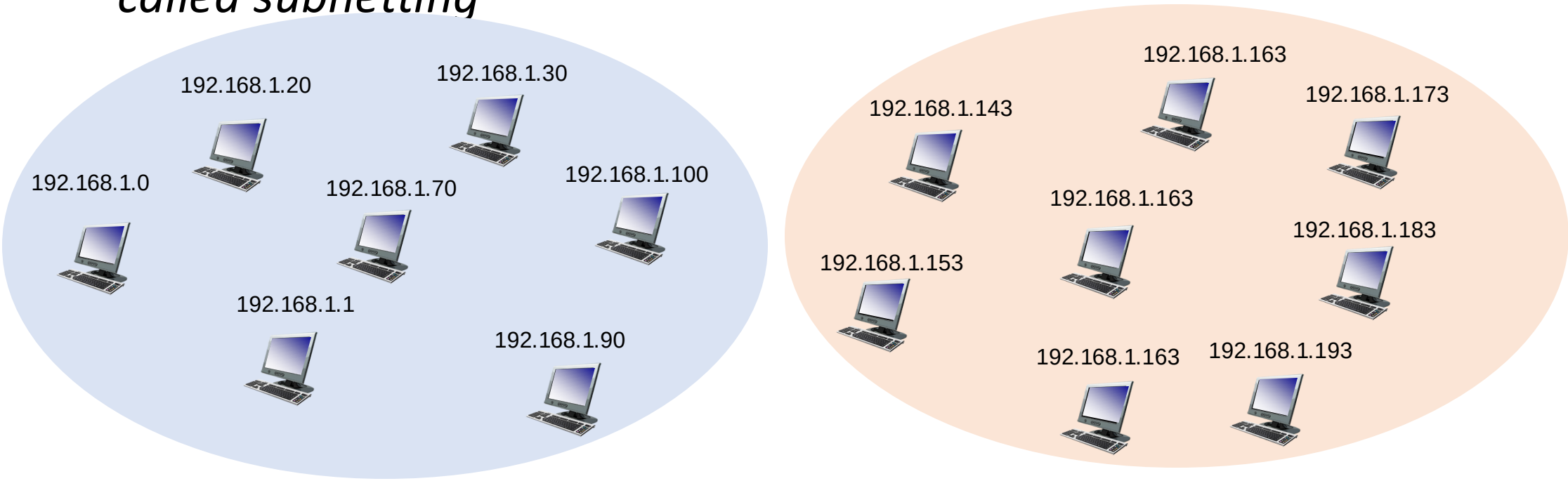

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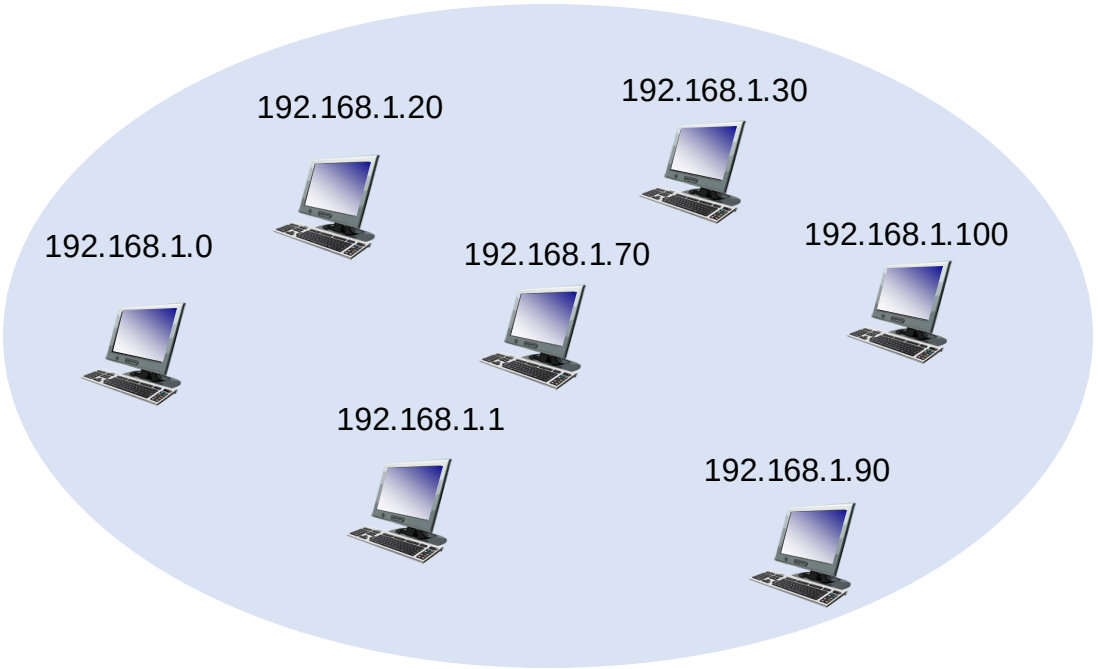
192.168.1.0 to 192.168.1.128



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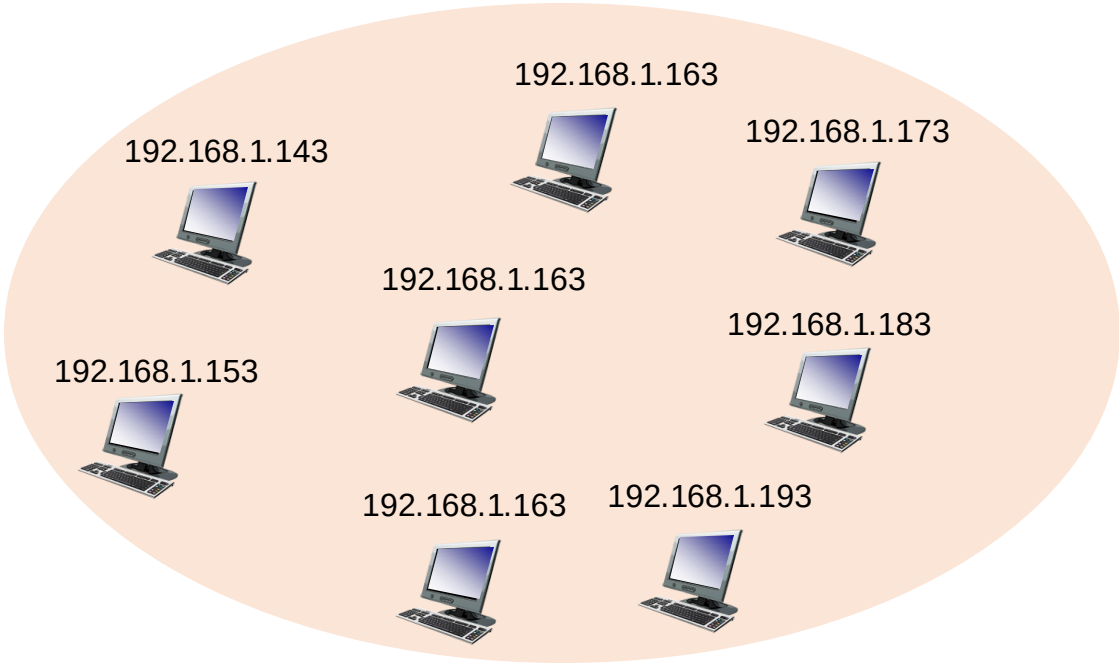
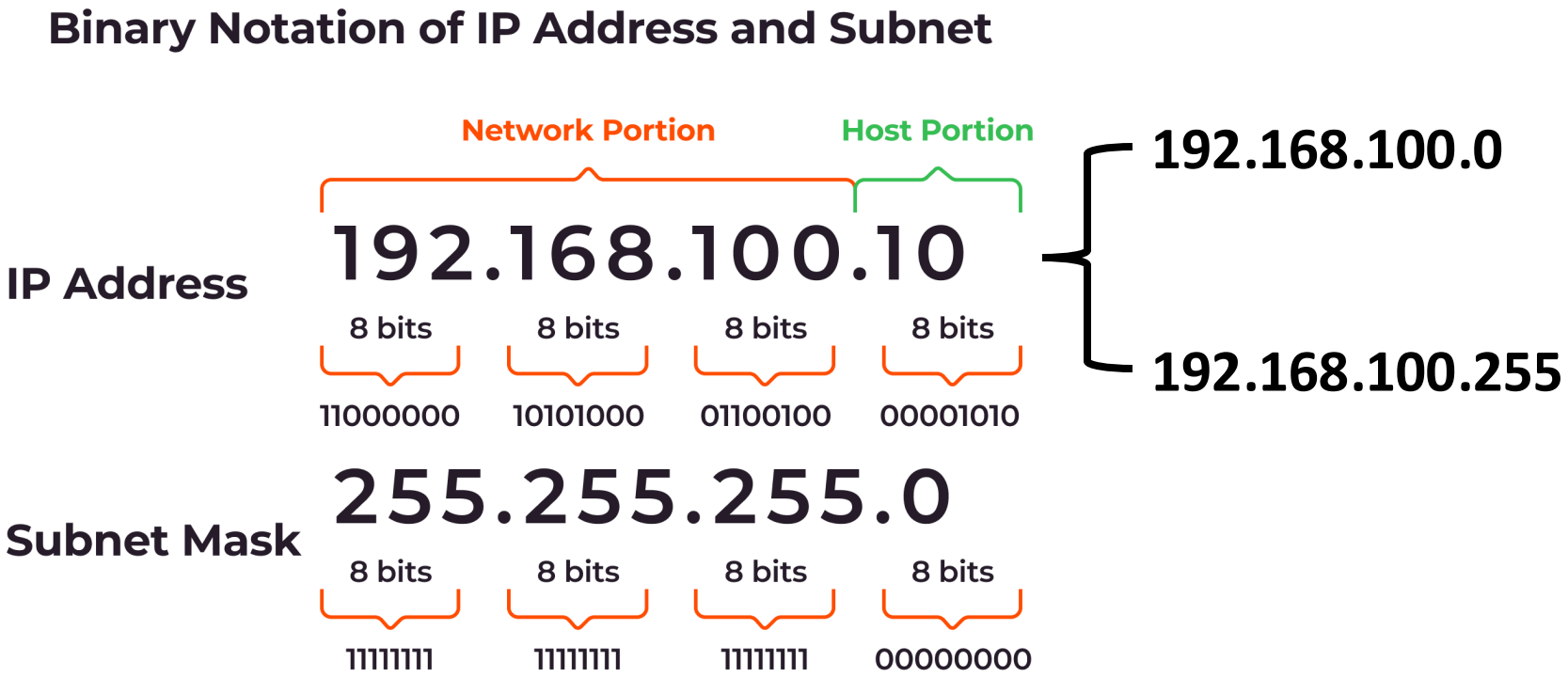


An IP network: 192.168.1.0 to 192.168.1.255

Subnet Mask

An IP address has two parts: the network portion and the host portion

- Network portion identifies the network
- Host portion identifies the specific device within that network.



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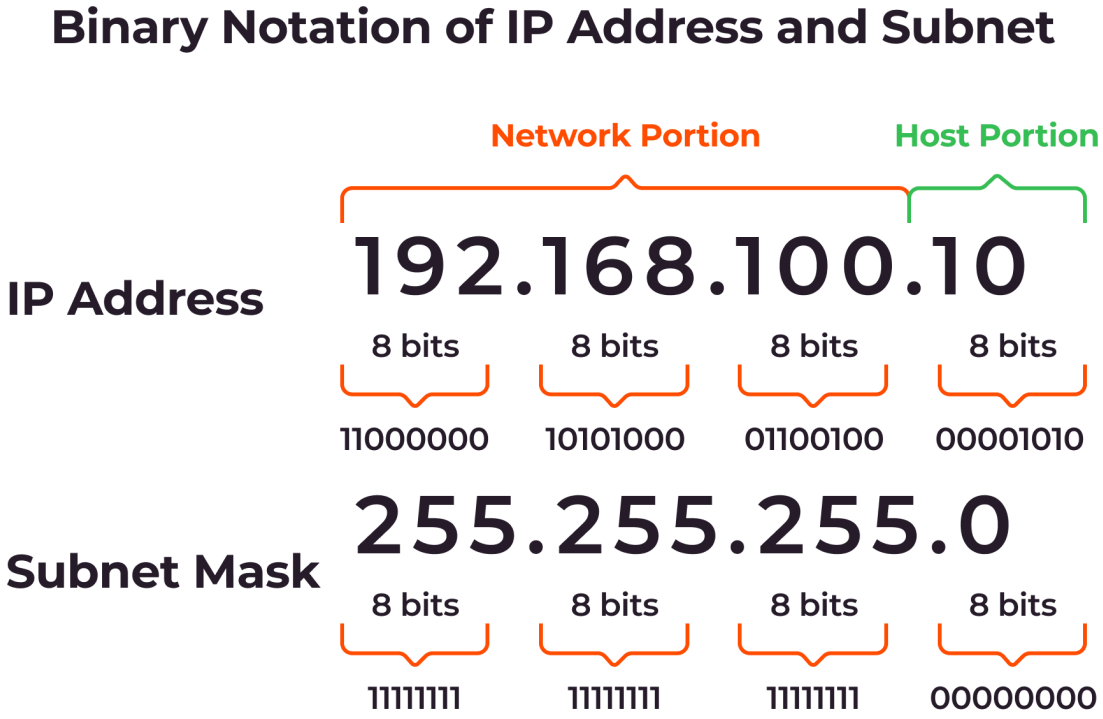

- The sequence of 1s in the subnet mask indicates which bits of the IP address belong to the network portion
- The **sequence of 0s** indicates which bits belong to the **host portion**.

Subnet and CIDR

CIDR: Classless InterDomain Routing (pronounced “cider”)

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