

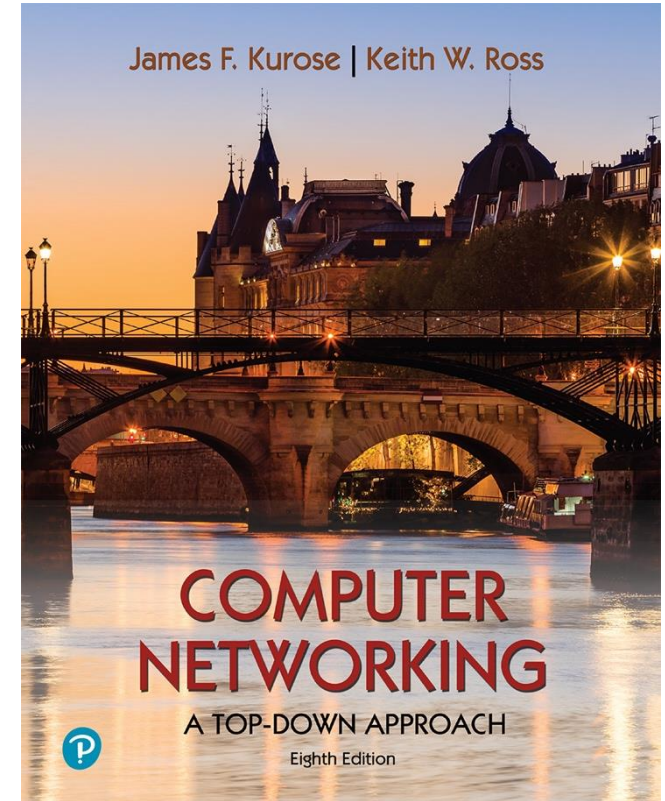
Chapter 4

Network Layer: Data Plane

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Adapted from the slides of the book's authors



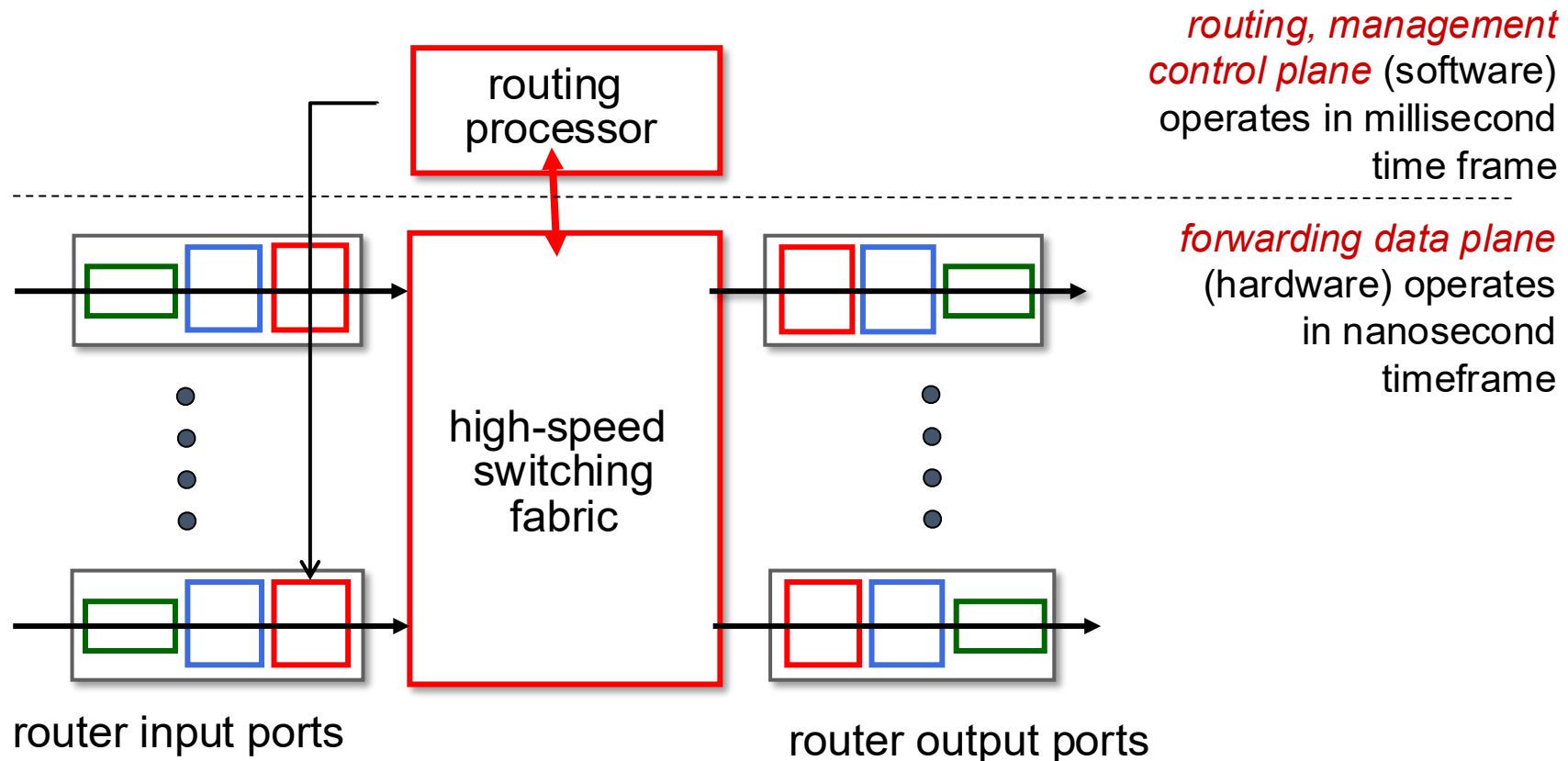
*Computer Networking: A
Top-Down Approach*

8th edition

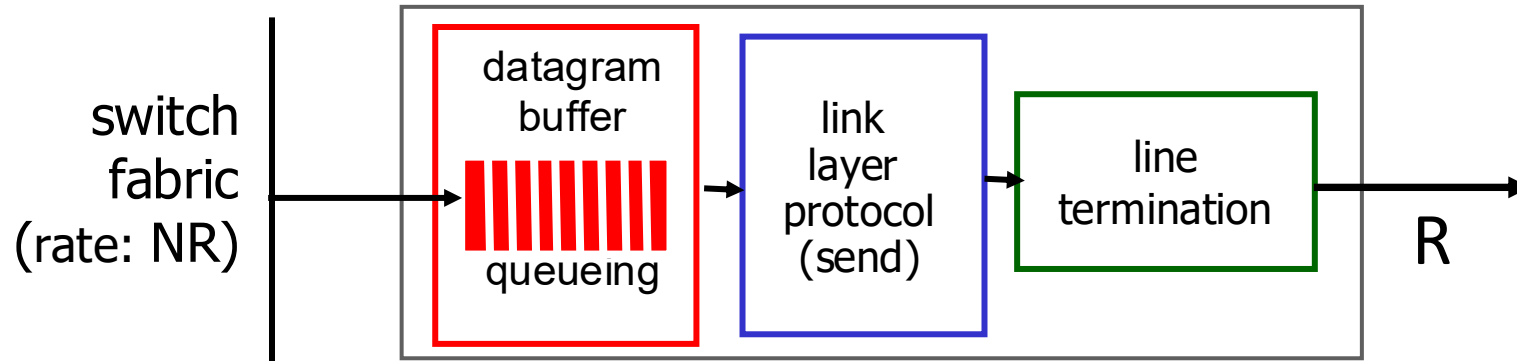
Jim Kurose, Keith Ross
Pearson, 2020

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?



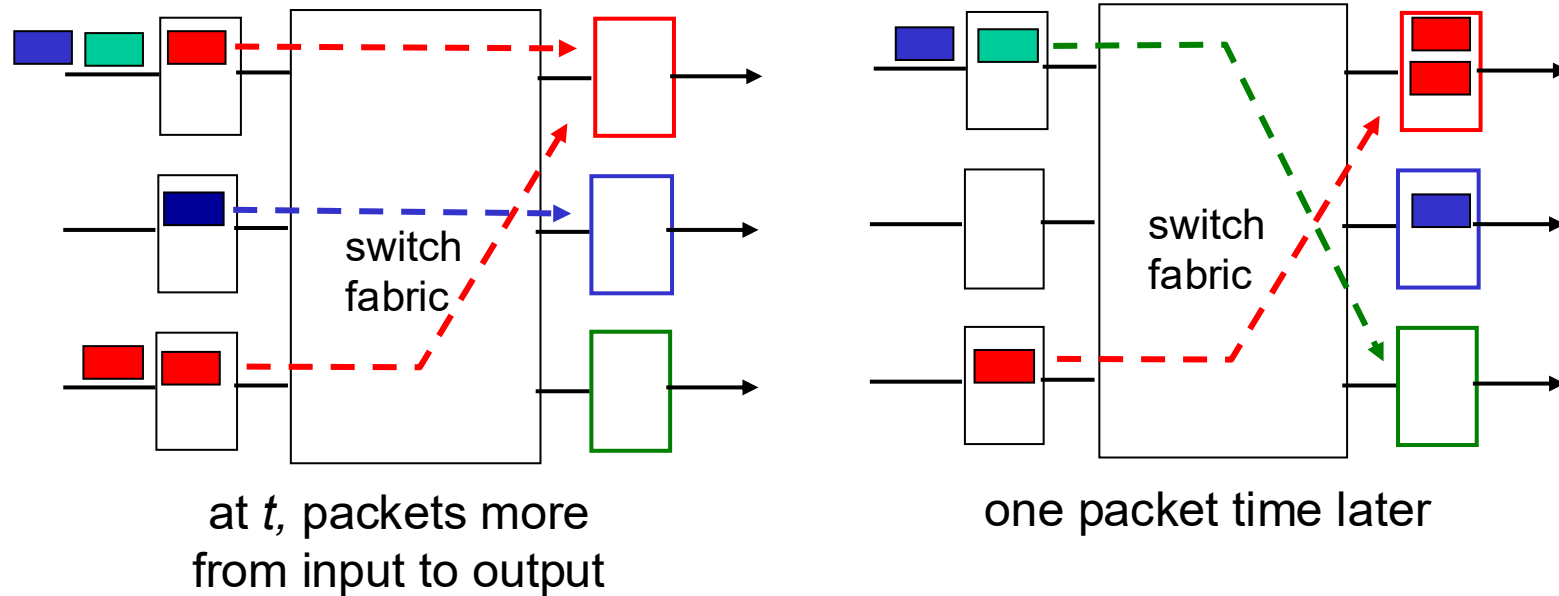
Datagrams can be lost due to congestion, lack of buffers

- **Scheduling discipline** chooses among queued datagrams for transmission



Priority scheduling – who gets best performance, network neutrality

Output port queuing



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

How much buffering?

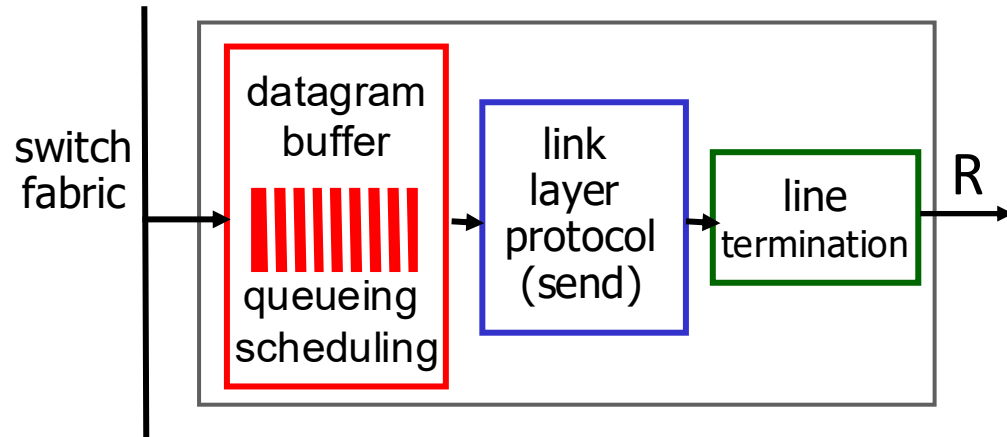
- RFC 3439 rule of thumb: average buffering equal to “typical” RTT (say 250 msec) times link capacity C
 - e.g., $C = 10$ Gbps link: 2.5 Gbit buffer

- more recent recommendation: with N flows, buffering equal to

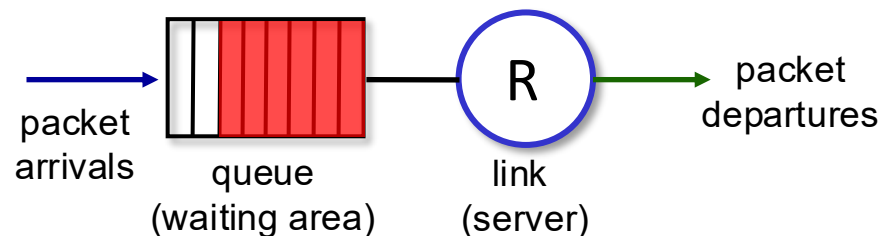
$$\frac{RTT \cdot C}{\sqrt{N}}$$

- 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



Abstraction: queue



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

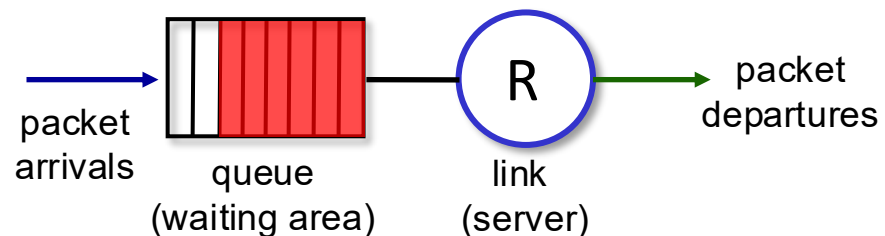
packet scheduling: deciding which packet to send next on link

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

FCFS: packets transmitted in order of arrival to output port

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

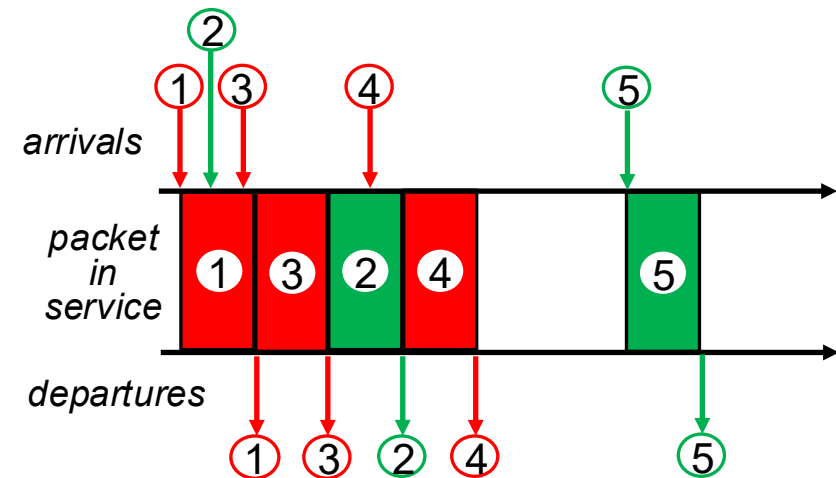
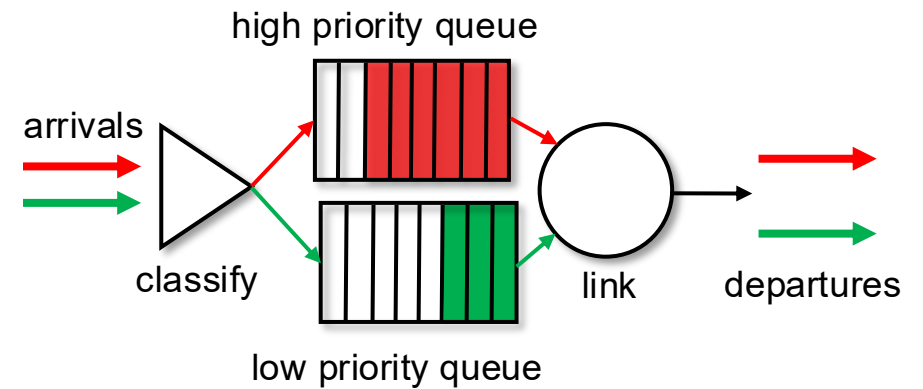
Abstraction: queue



Scheduling policies: priority

Priority scheduling:

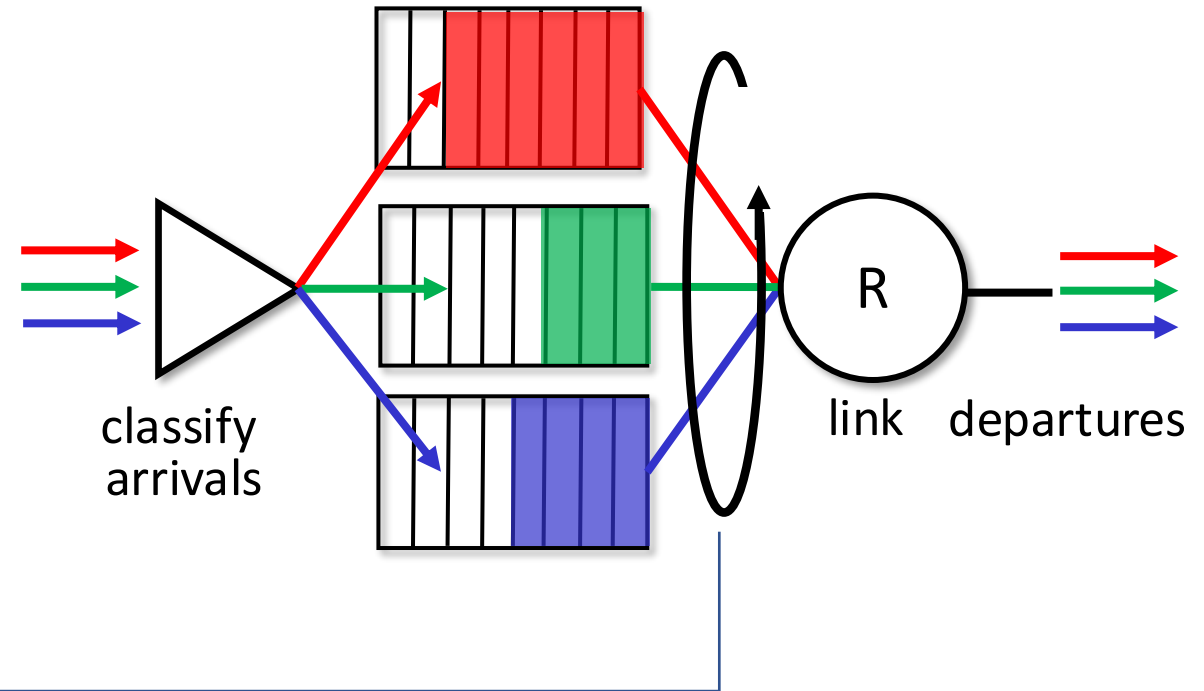
- arriving traffic classified, queued by class
 - any header fields can be used for classification
- send packet from highest priority queue that has buffered packets
 - FCFS within priority class



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



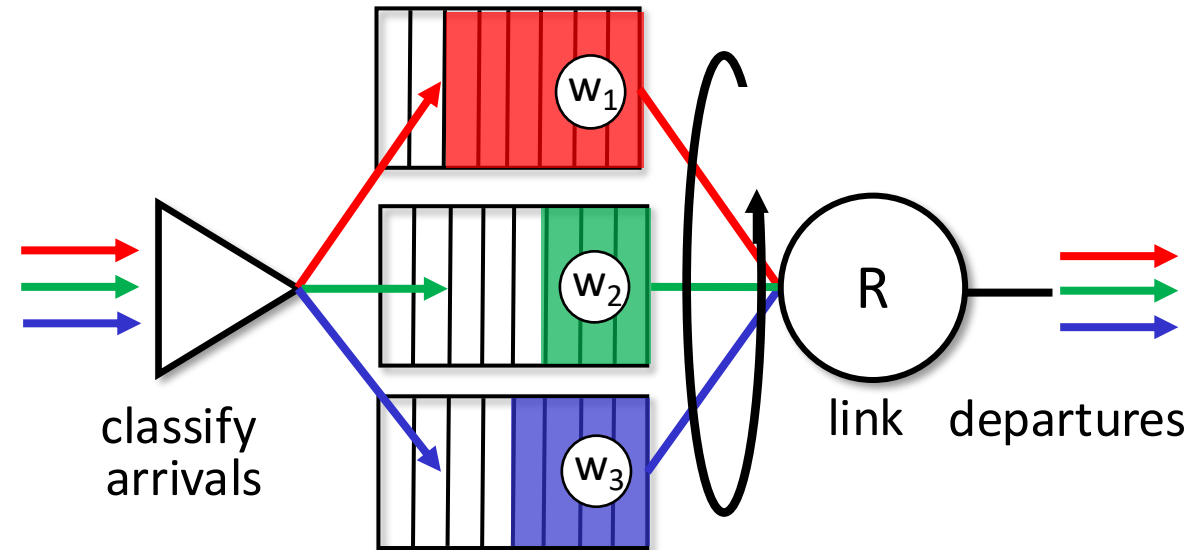
Scheduling policies: weighted fair queueing

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

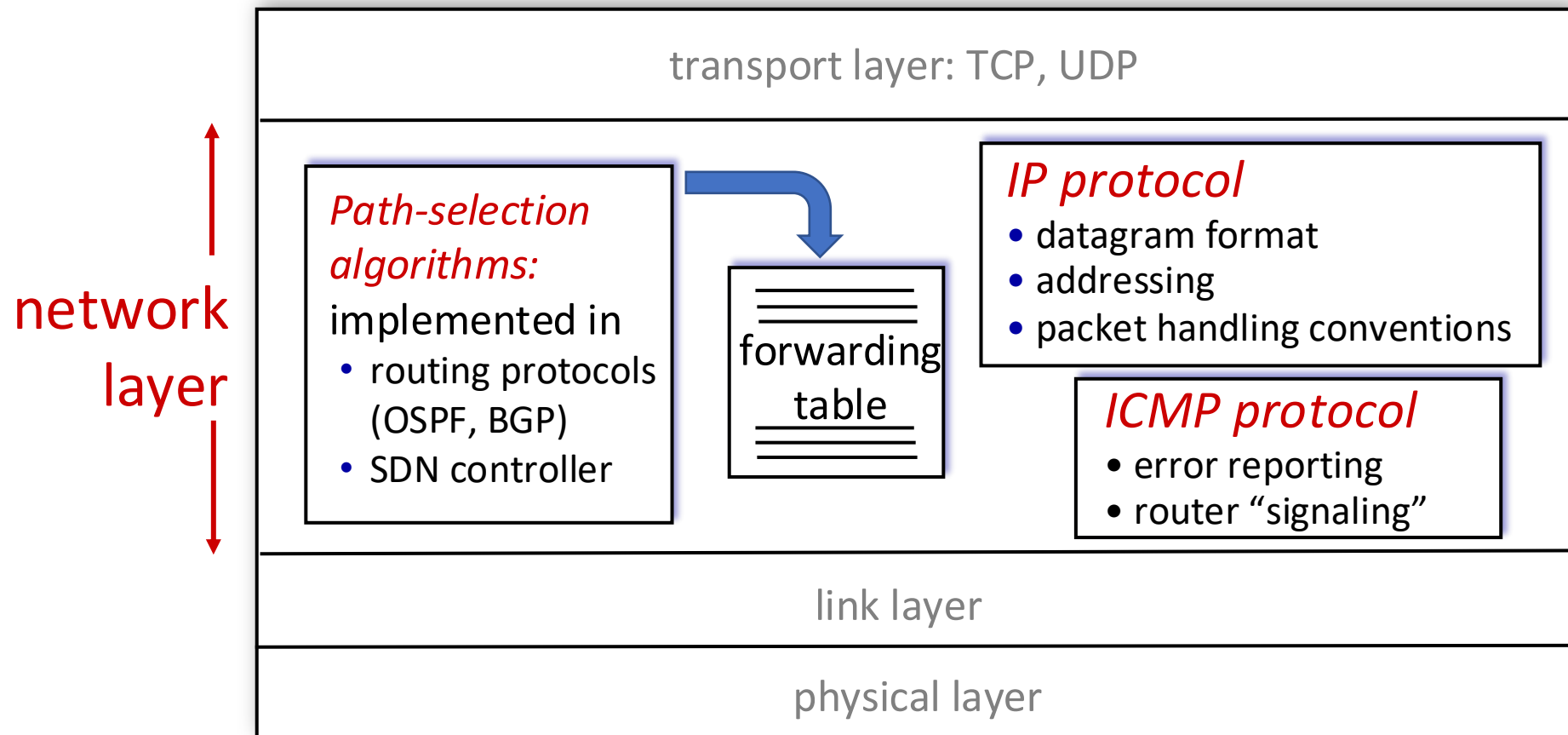
Network layer: “data plane” roadmap

- 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

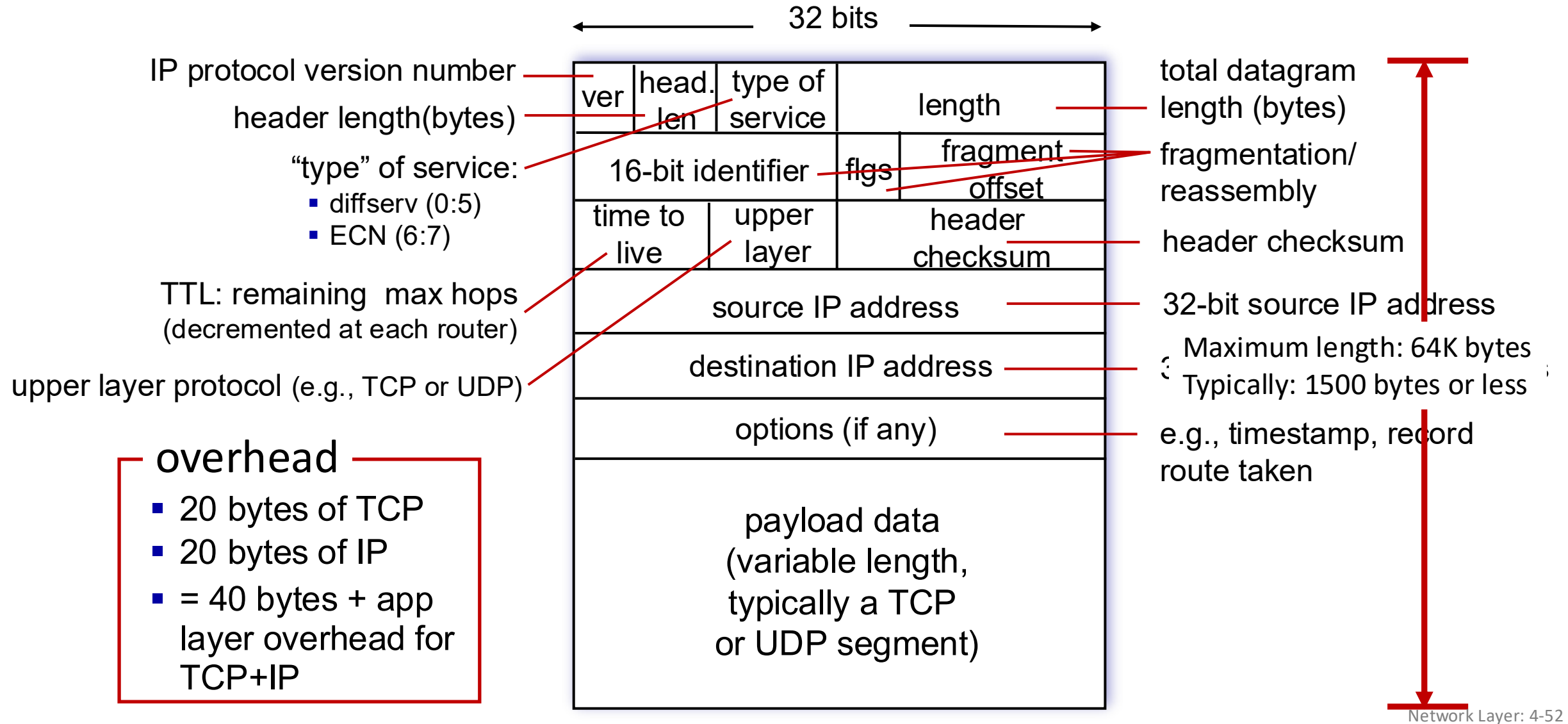


Network Layer: Internet

host, router network layer functions:

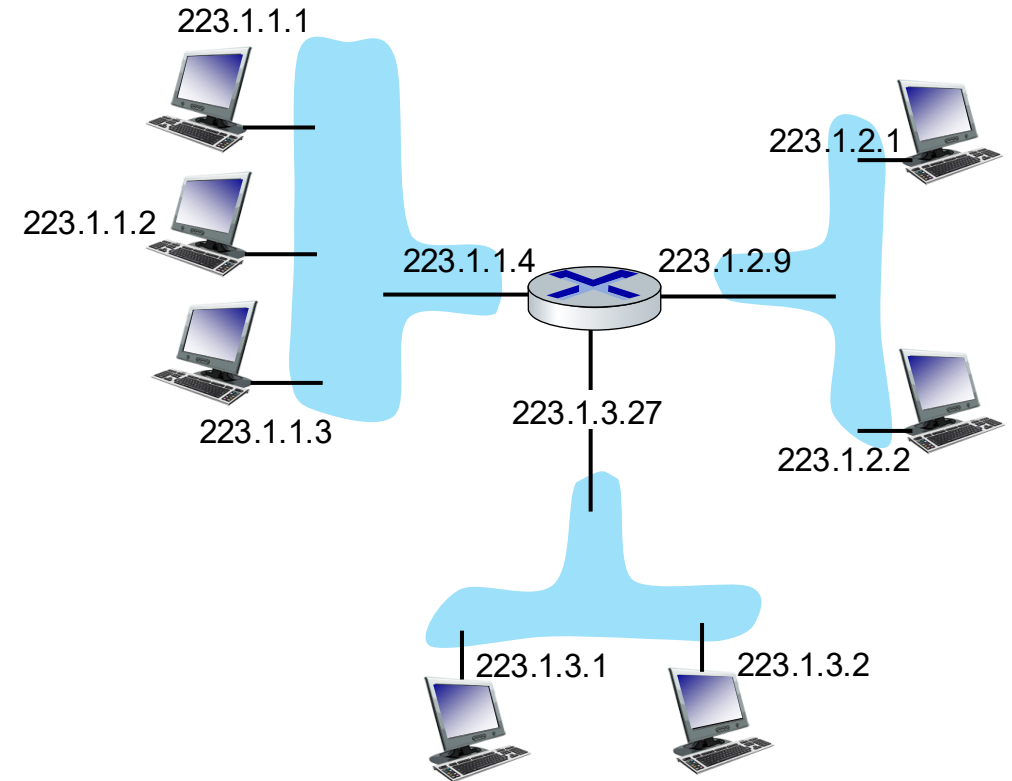


IP Datagram format



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)

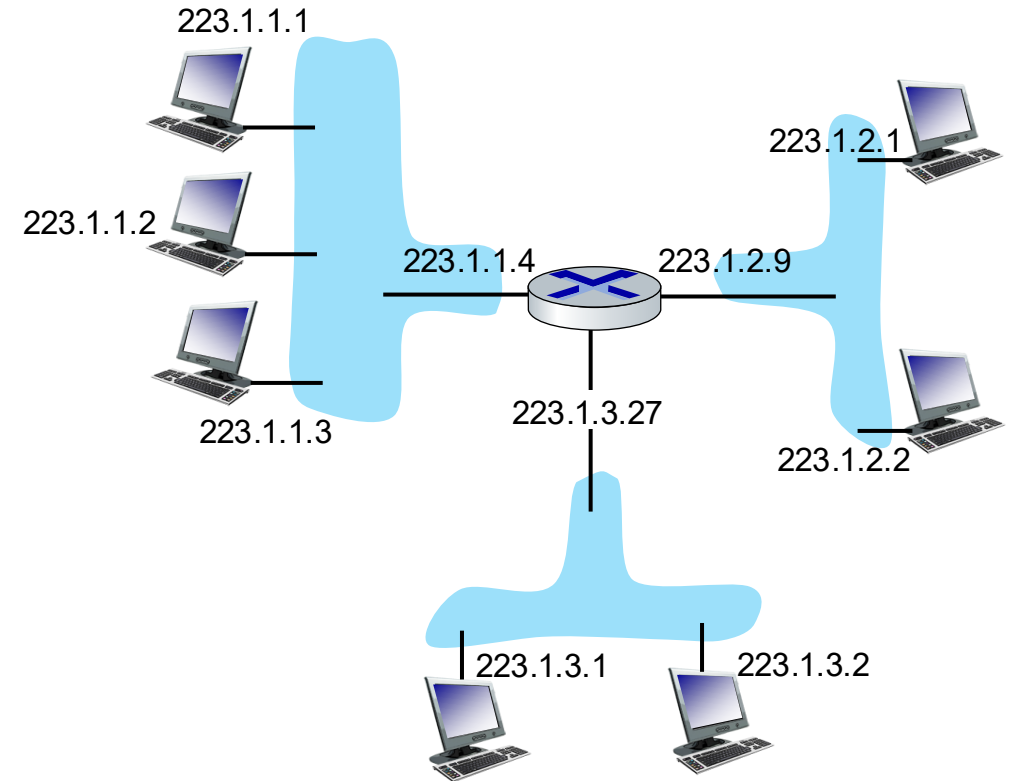


dotted-decimal IP address notation:

223.1.1.1 = $\underbrace{11011111}_{223} \underbrace{00000001}_1 \underbrace{00000001}_1 \underbrace{00000001}_1$

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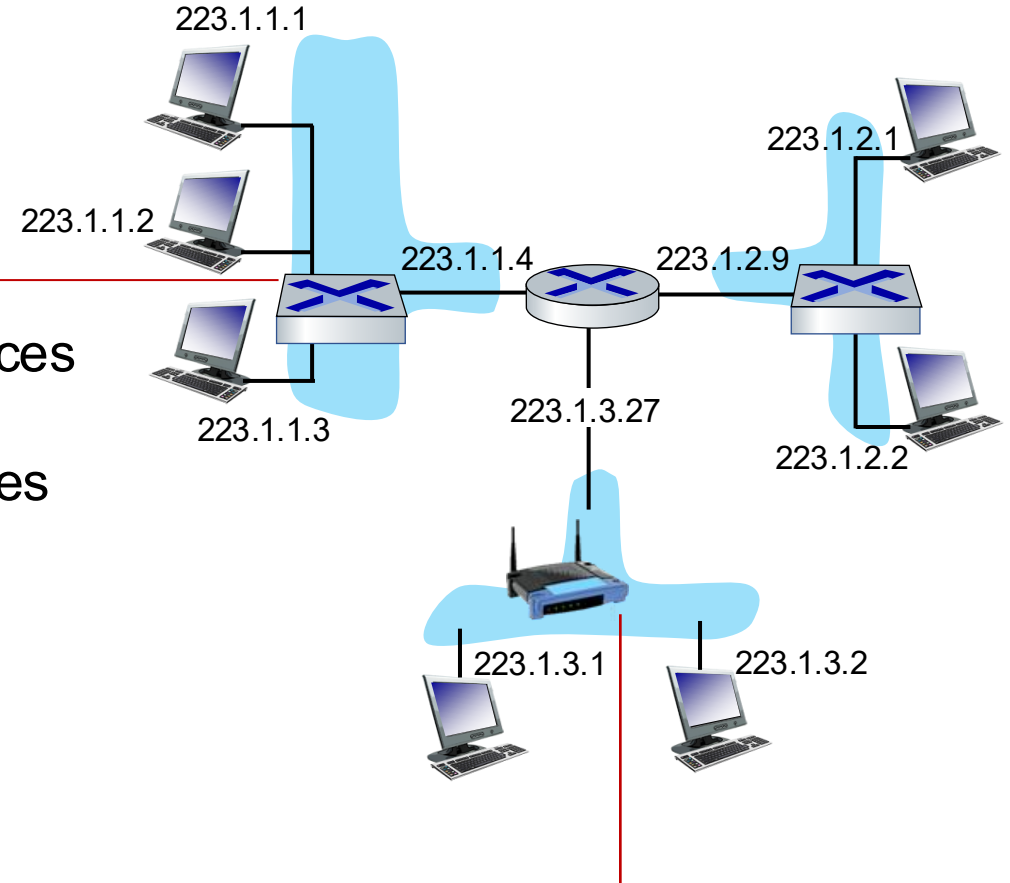
IP addressing: introduction

Q: how are interfaces actually connected?

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

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

A: wired Ethernet interfaces connected by Ethernet switches

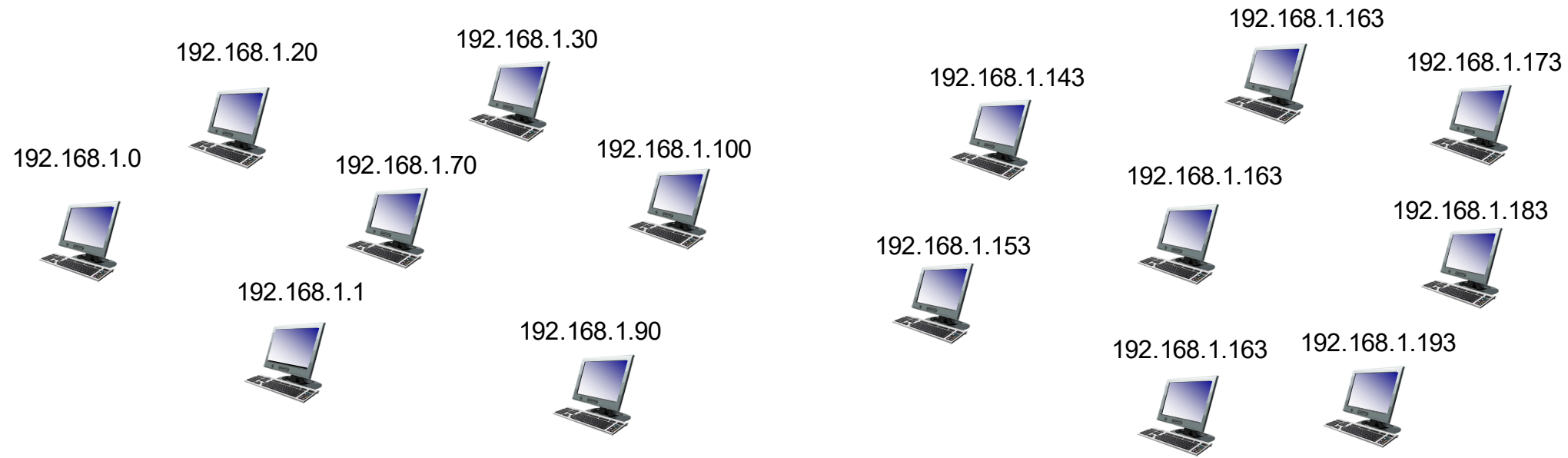


A: wireless WiFi interfaces connected by WiFi base station

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*

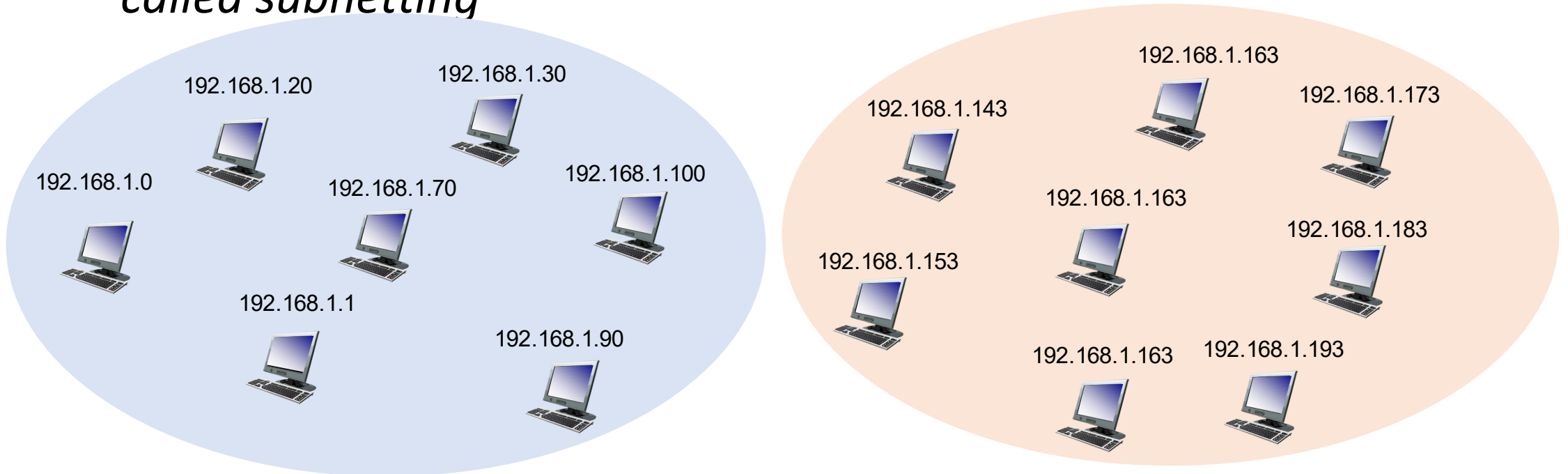


An IP network: **192.168.1.0** to **192.168.1.255**

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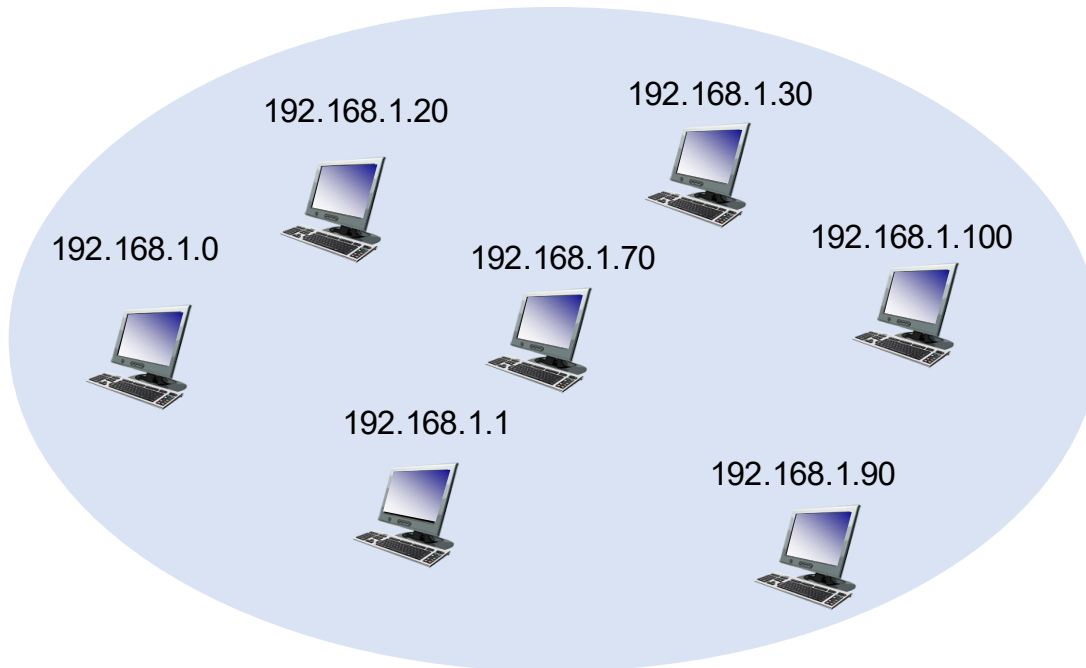
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Subnets

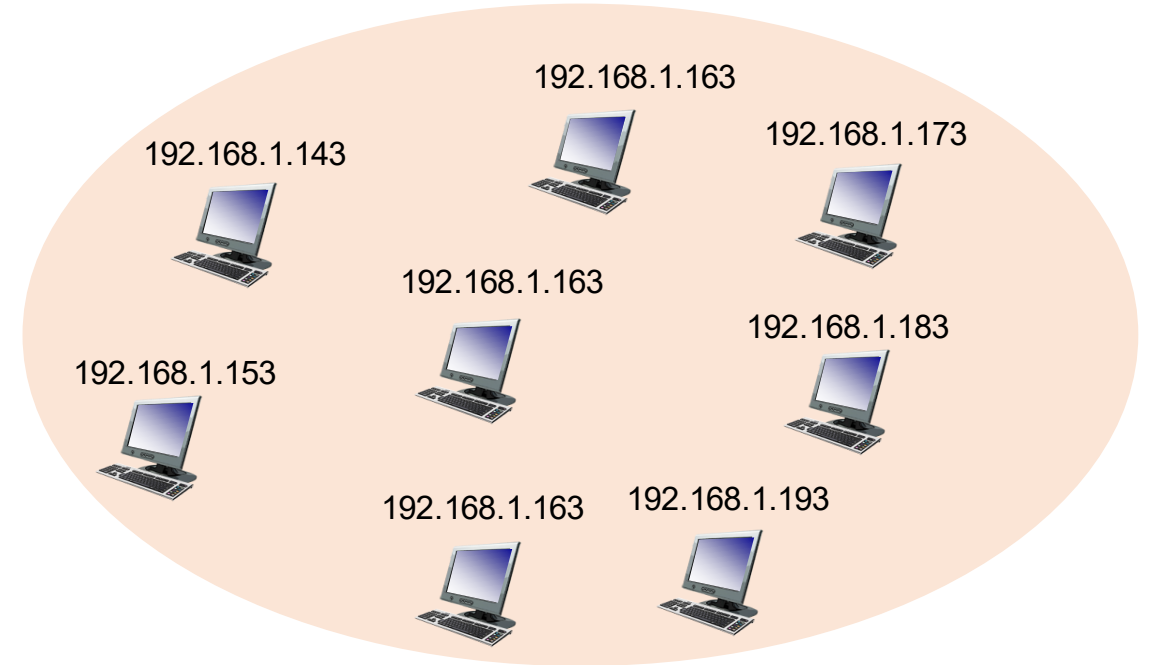
■ *What's a subnet ?*

- Subnet is a logical subdivision of an IP network.

192.168.1.0 to 192.168.1.127



192.168.1.128 to 192.168.1.255



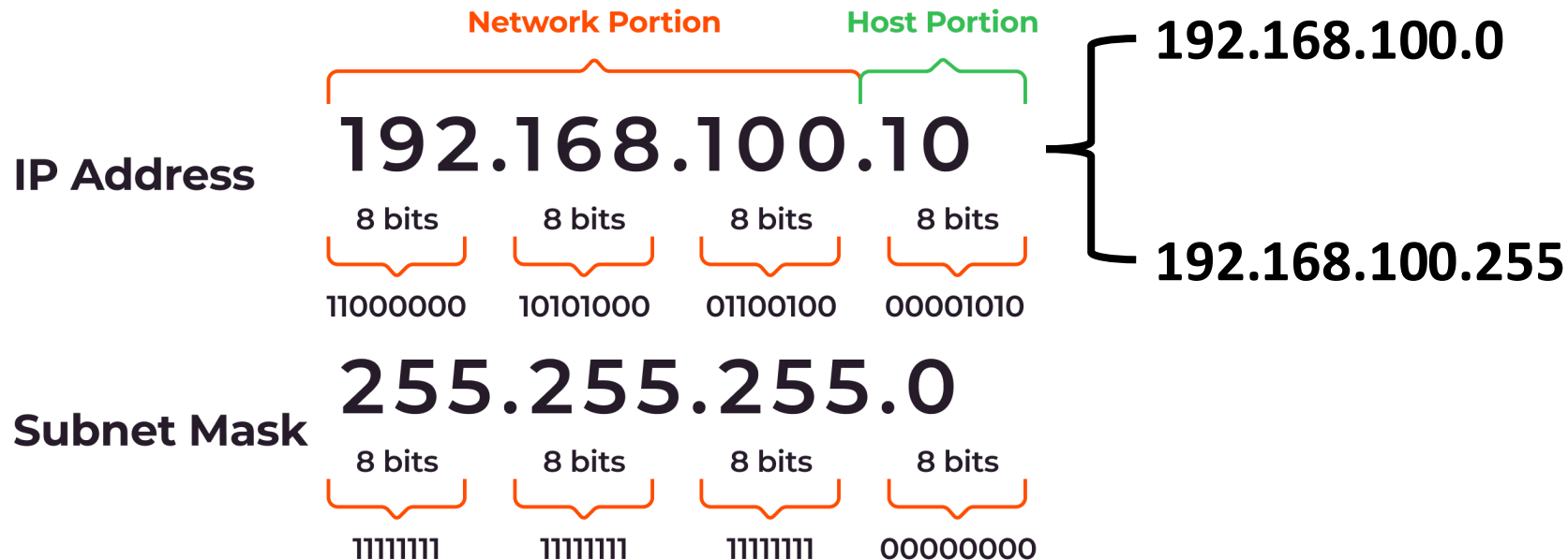
An IP network: **192.168.1.0 to 192.168.1.255**

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.

Binary Notation of IP Address and Subnet

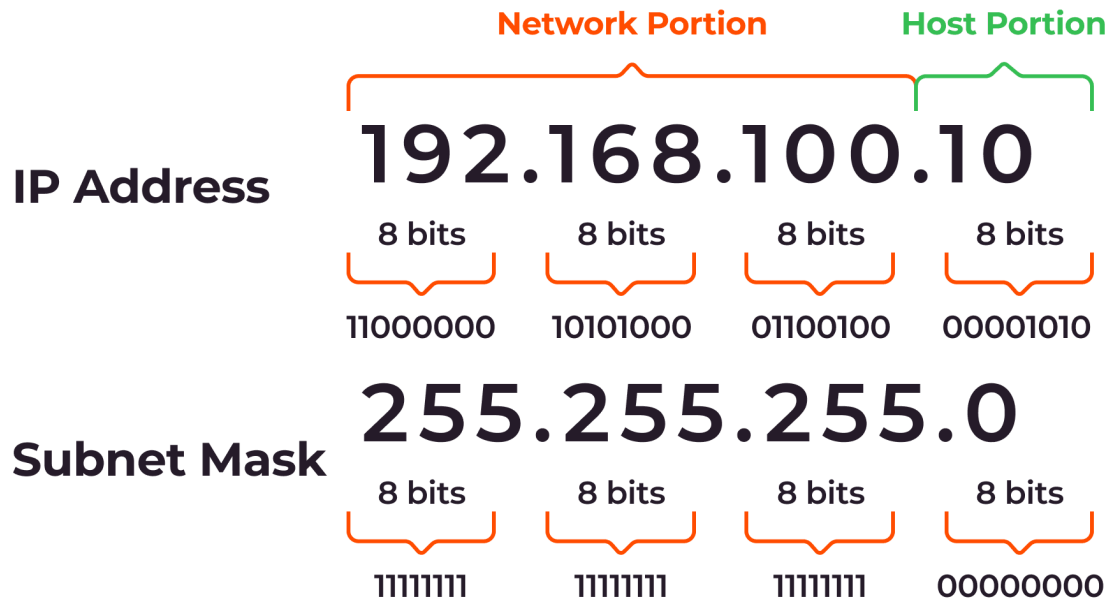


Subnet Mask

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.

Binary Notation of IP Address and Subnet



- 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

Binary Notation of IP Address and Subnet

