CSC/CPE 138

COMPUTER NETWORK FUNDAMENTALS

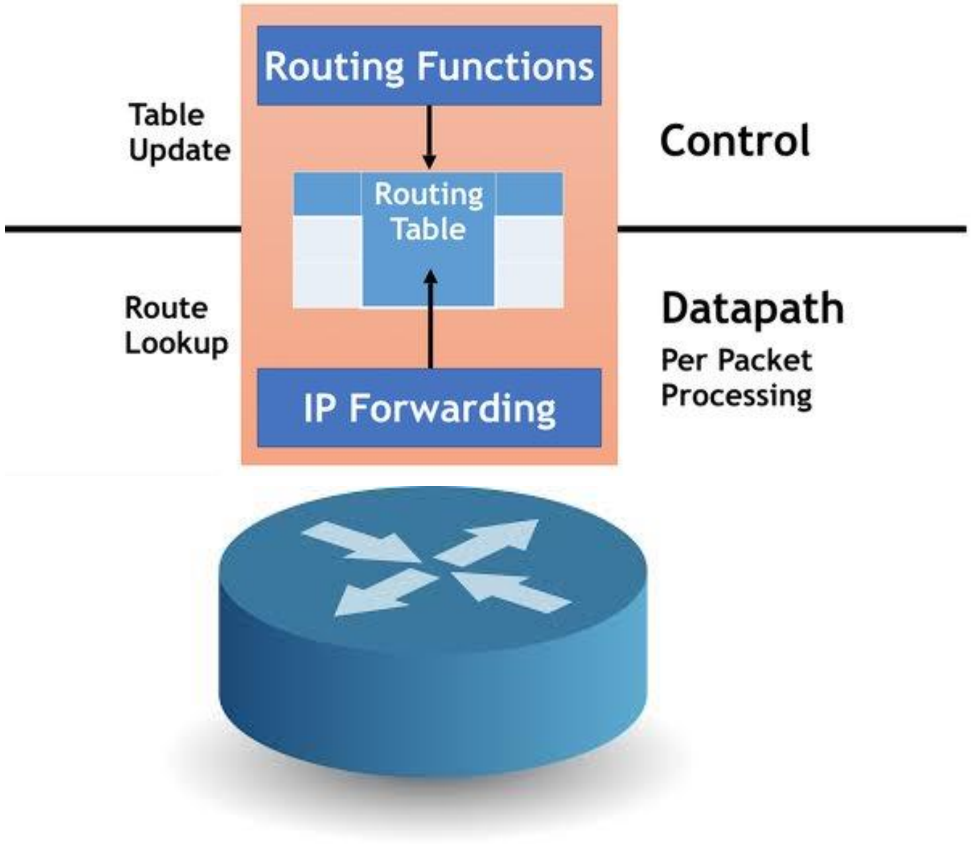
Lecture 4_1: The Network Layer (Data Plane)

California State University, Sacramento
Fall 2024

Slide Courtesy: Computer Networking: A Top-Down Approach, Kurose Ross, 8th Edition

Lecture 4_1 Overview

- Network layer
  - data plane
  - control plane
- What's inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - Datagram format
  - IP addressing



Network Layer Router Functions (Source: Quora)

Two key network-layer functions

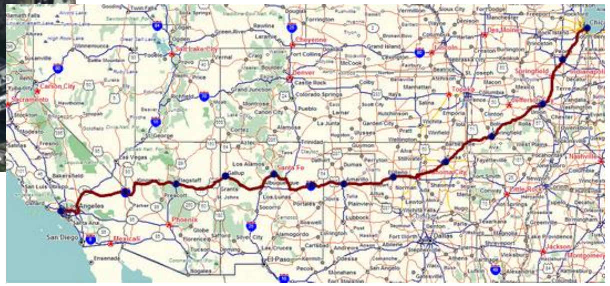
Network-layer functions:

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

Analogy: taking a trip

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

forwarding

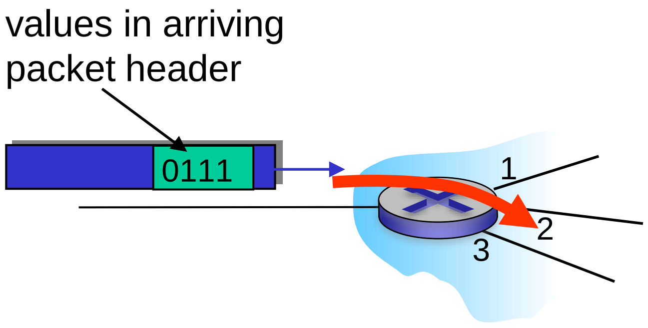


routing

Network layer: data plane, control plane

Data plane:

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

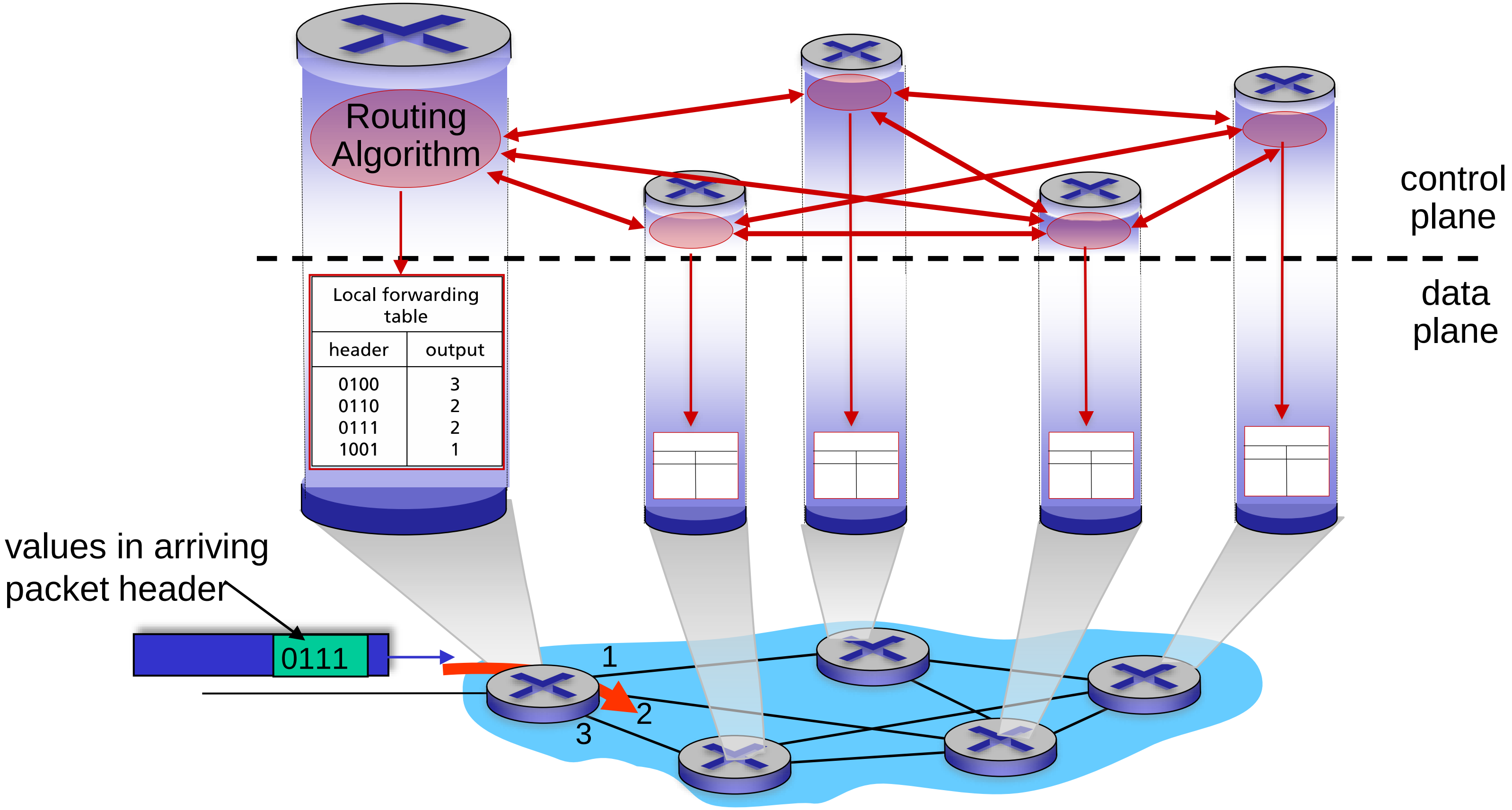


Control plane

- *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)*: implemented in (remote) servers

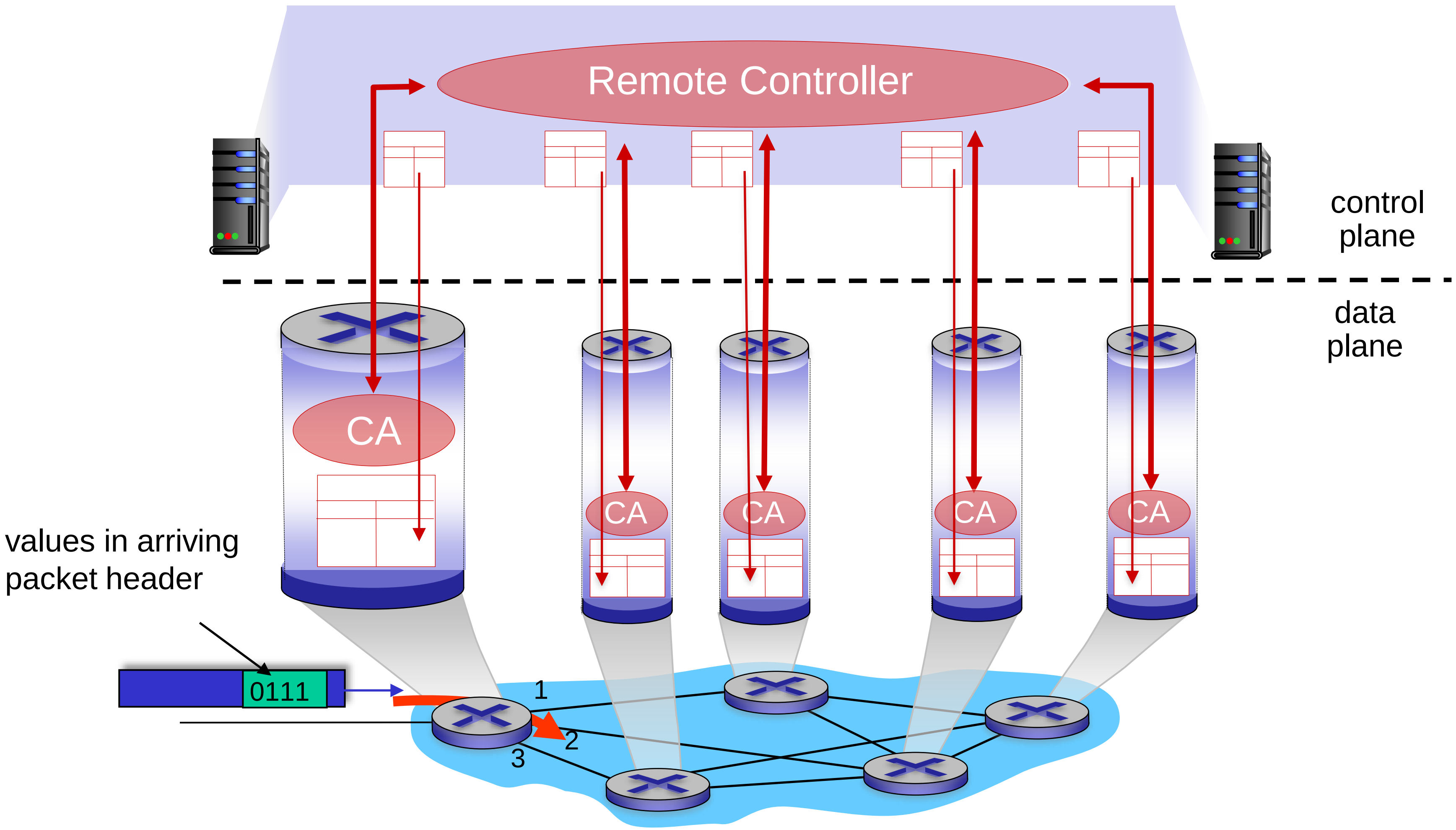
Per-router control plane

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



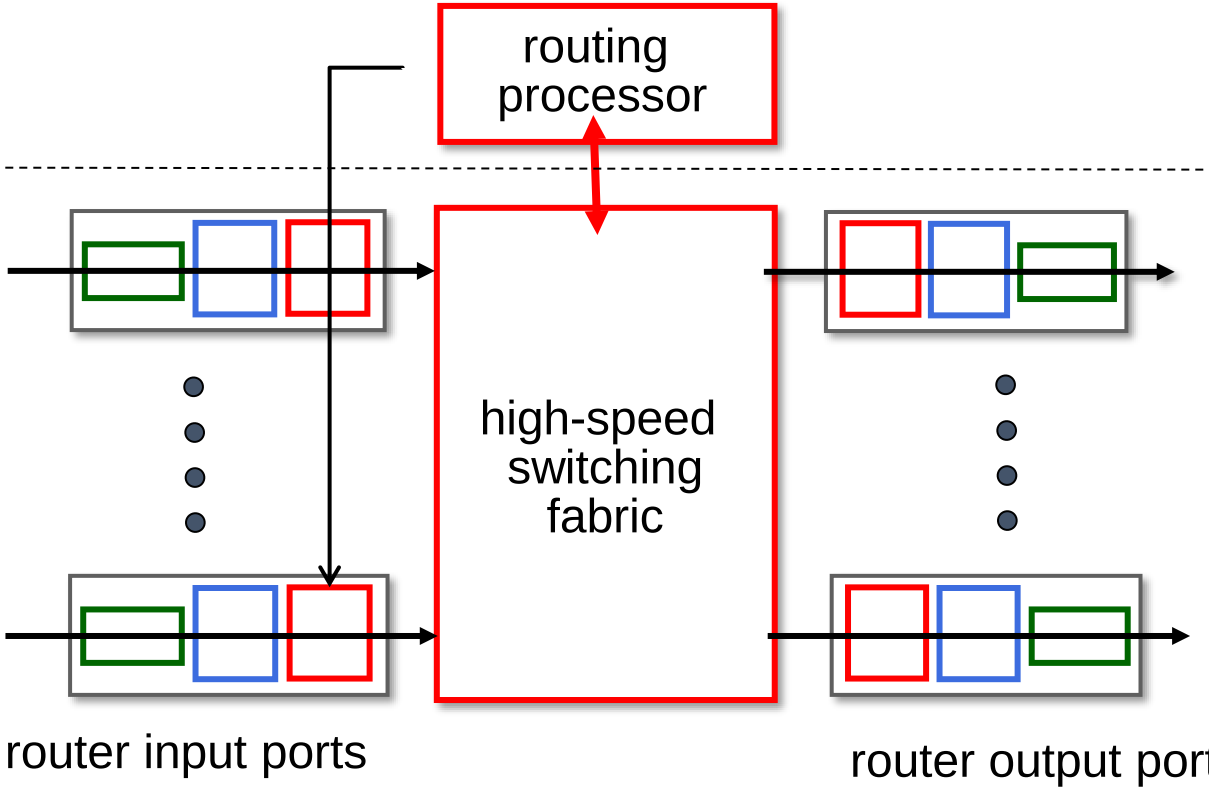
Software-Defined Networking (SDN) Control Plane

Remote controller computes, installs forwarding tables in routers



Router architecture overview

high-level view of generic router architecture:

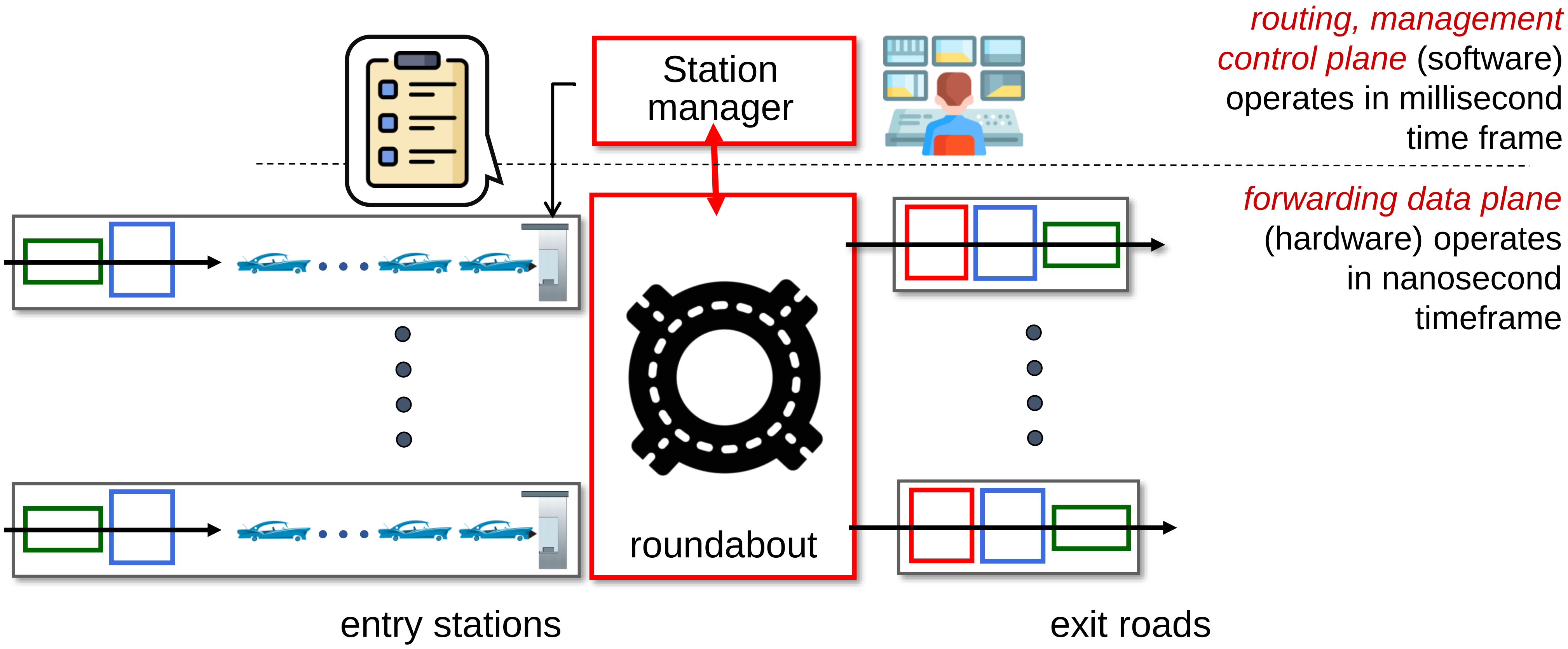


routing, management control plane (software) operates in millisecond time frame

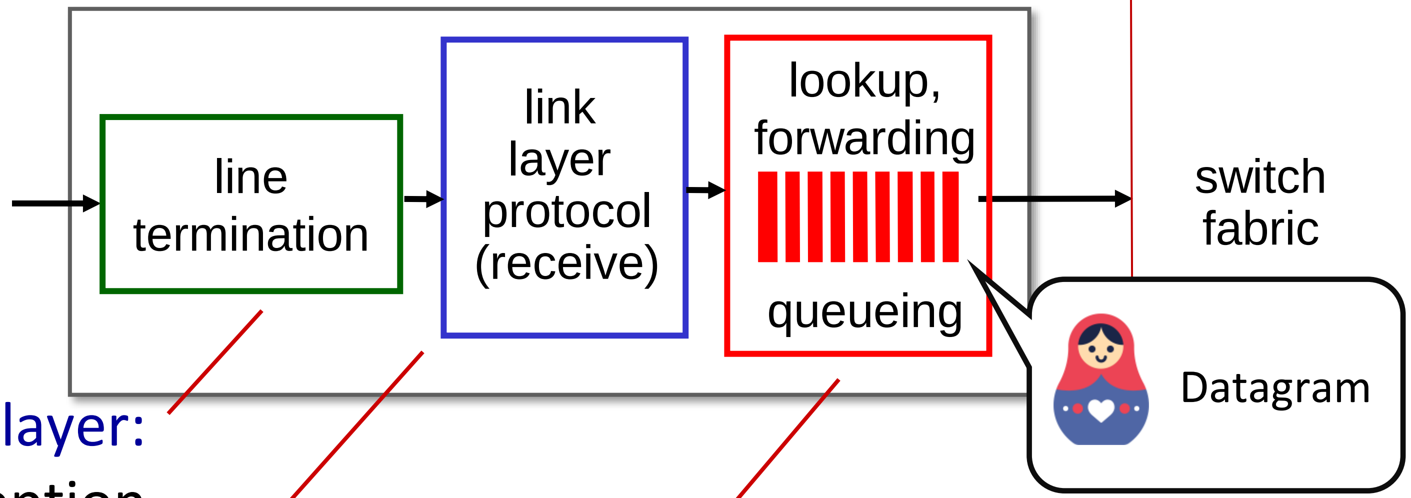
forwarding data plane (hardware) operates in nanosecond timeframe

Router architecture overview

analogy view of generic router architecture:



Input port functions



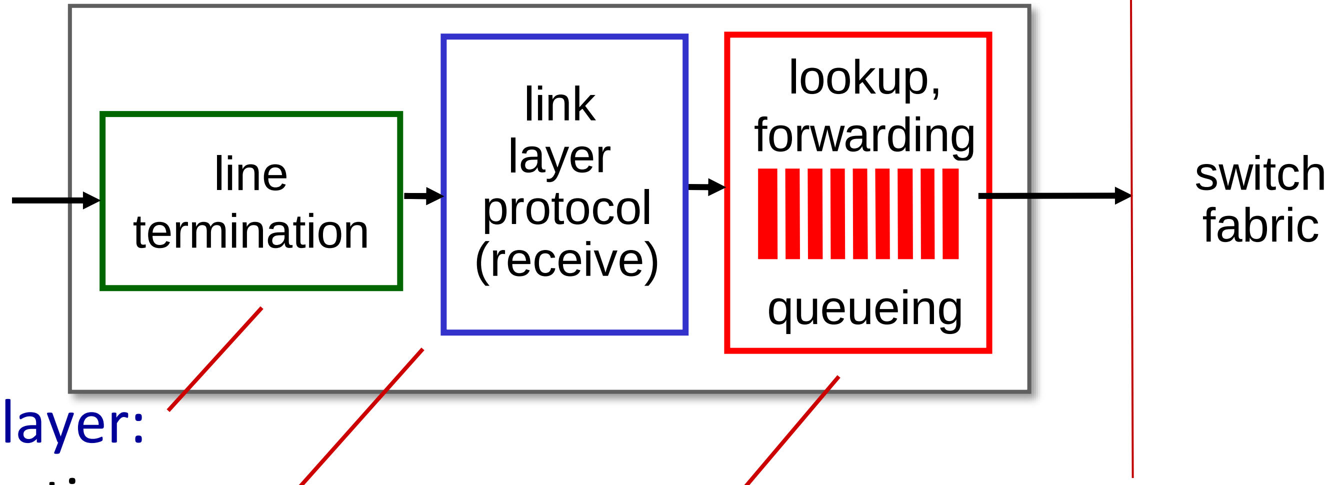
physical layer:
bit-level reception

link layer:
e.g., Ethernet
(chapter 6)

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'
- input port queuing: if datagrams arrive faster than forwarding rate into switch fabric

Input port functions



physical layer:
bit-level reception

link layer:
e.g., Ethernet
(chapter 6)

decentralized switching*:*

- using header field values, lookup output port using forwarding table in input port memory *("match plus action")*
- destination-based forwarding: forward based only on destination IP address (traditional)
- generalized forwarding: forward based on any set of header field values

Destination-based forwarding

forwarding table

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through	0
11001000 00010111 00010000 00000100 through 11001000 00010111 00010000 00000111	3
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 match

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:

11001000 00010111 00010110 10100001 which interface?

11001000 00010111 00011000 10101010 which interface?

Longest prefix matching

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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
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otherwise				3

match!

examples:

11001000 00010111 00010110 10100001 which interface?

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Longest prefix matching

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longest prefix match

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match!

examples:

11001000	00010111	00010110	10100001	which interface?
11001000	00010111	00011000	10101010	which interface?

Longest prefix matching

longest prefix match

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

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otherwise				3

match!

examples:

11001000 00010111 00010110 10100001 which interface?

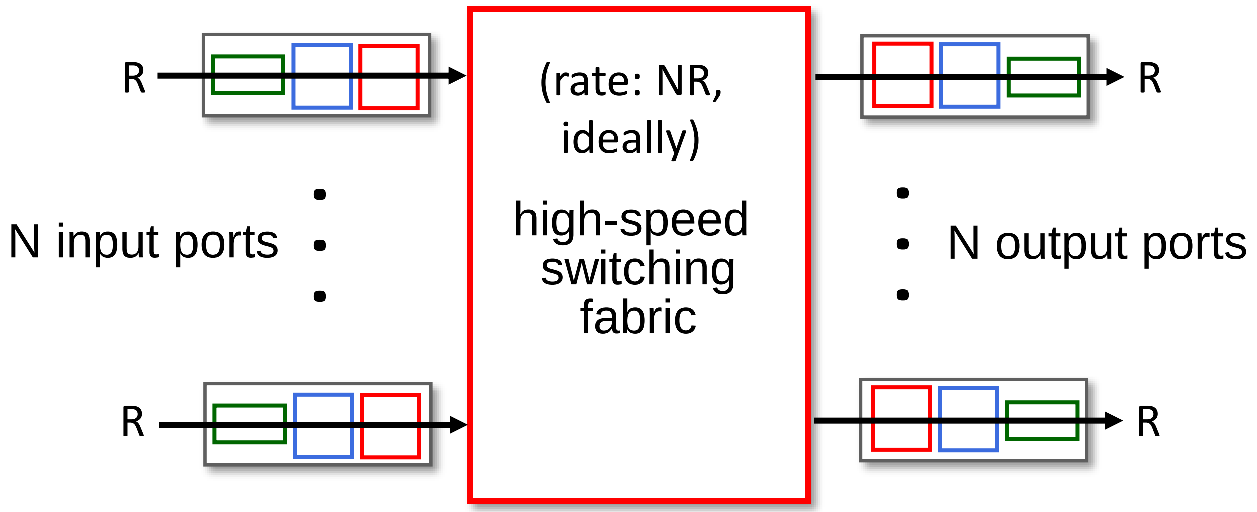
11001000 00010111 00011000 10101010 which interface?

Activity 4.1

- You are provided with below networks
  - 232.1.30.0
  - 232.1.35.0
  - 232.1.40.0
  - 232.1.42.0
  - 232.1.46.0
- Find the longest prefix match for 232.1.43.2

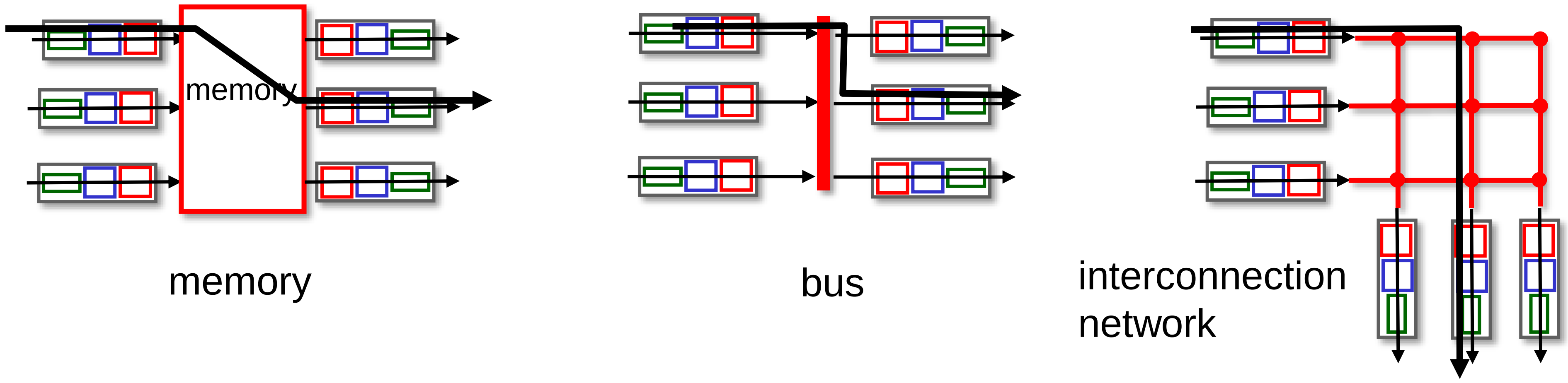
Switching fabrics

- Transfer packet from input link to appropriate output link
- 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

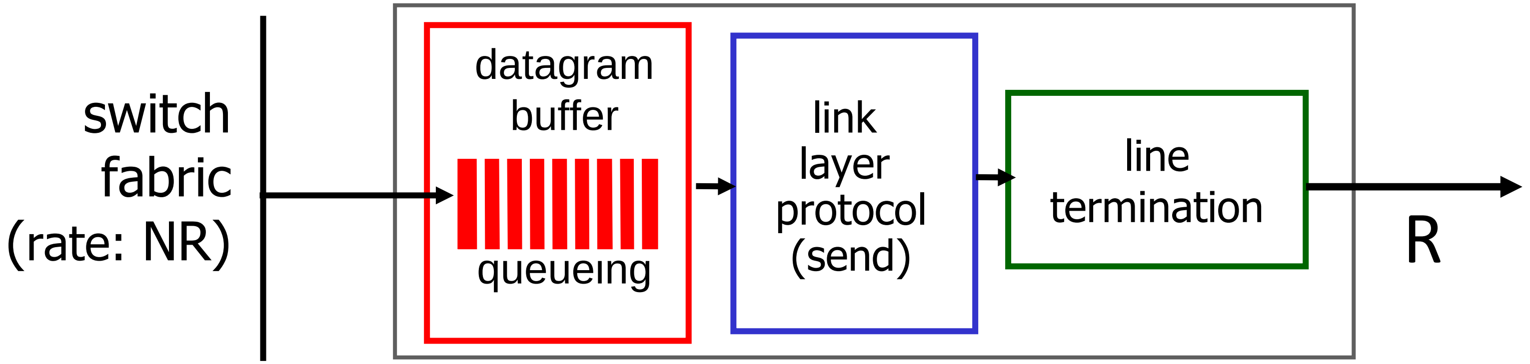


Switching fabrics

- Transfer packet from input link to appropriate output link
- 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 major types of switching fabrics:



Output port queuing



This is a really important slide

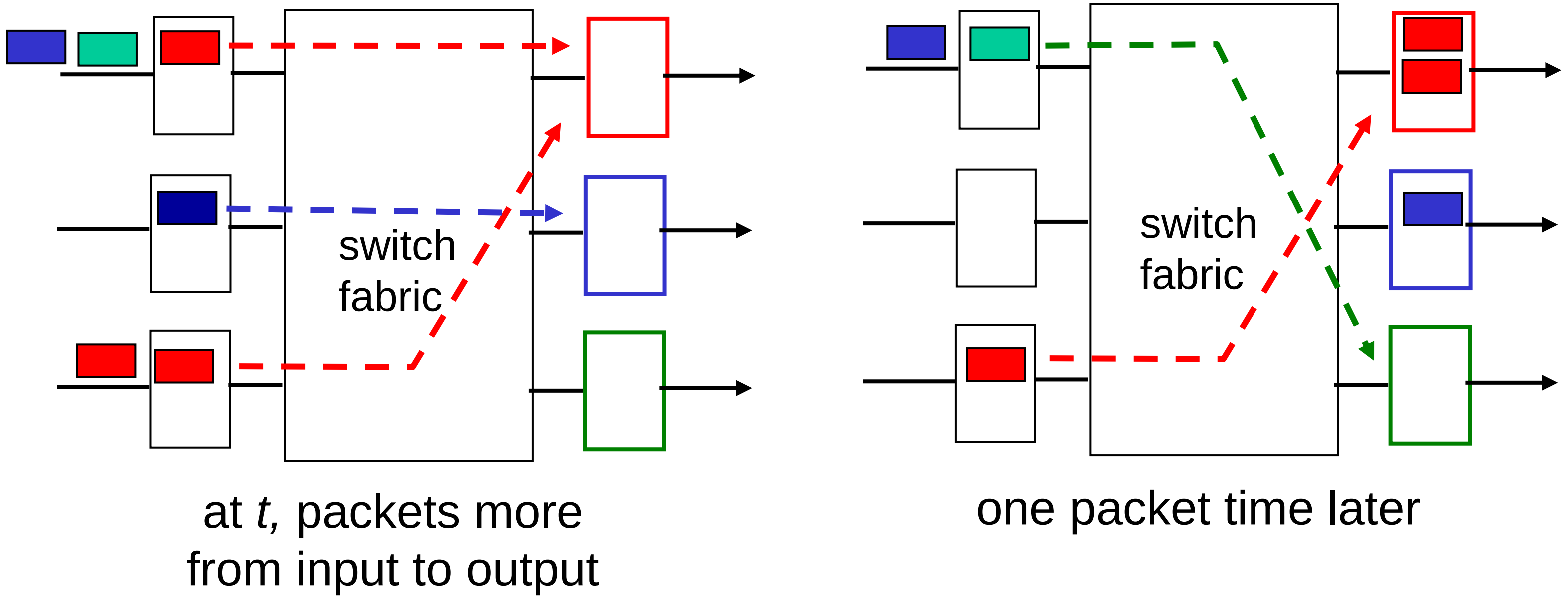
- *Buffering* required when datagrams arrive from fabric faster than link transmission rate. *Drop policy:* which datagrams to drop if no free buffers?

Datagrams can be lost due to congestion, lack of buffers

- *Scheduling discipline* chooses among queued datagrams for transmission

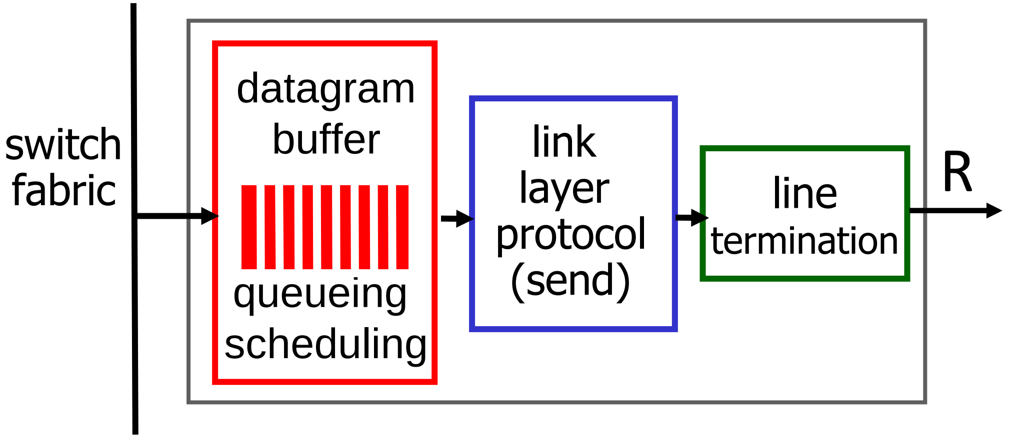
Priority scheduling – who gets best performance, network neutrality

Output port queuing

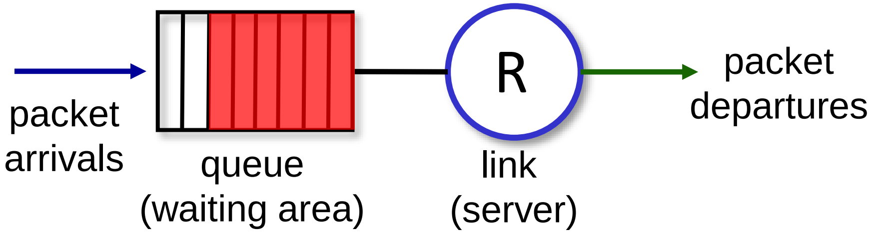


- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow!*

Buffer Management



Abstraction: queue



buffer management:

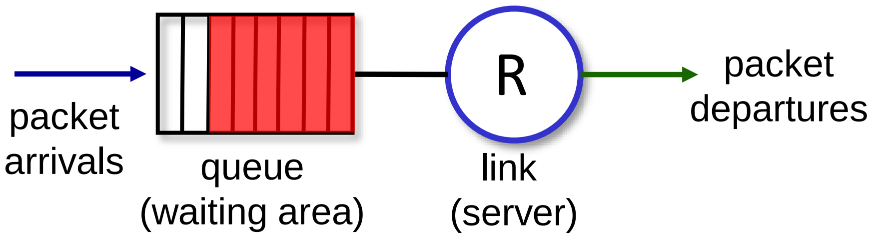
- drop: which packet to add, drop when buffers are full
  - tail drop: drop arriving packet
  - priority: drop/remove on priority basis
- marking: which packets to mark to signal congestion (ECN, RED)

Packet Scheduling: FCFS

packet scheduling: deciding which packet to send next on link

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

Abstraction: queue



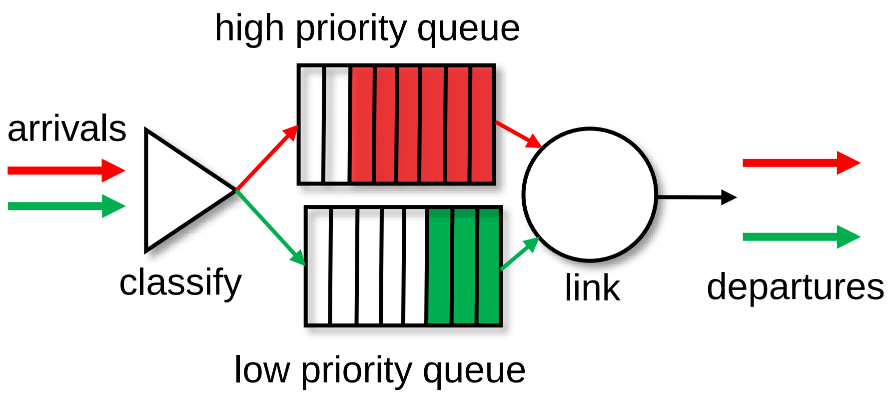
FCFS: packets transmitted in order of arrival to output port

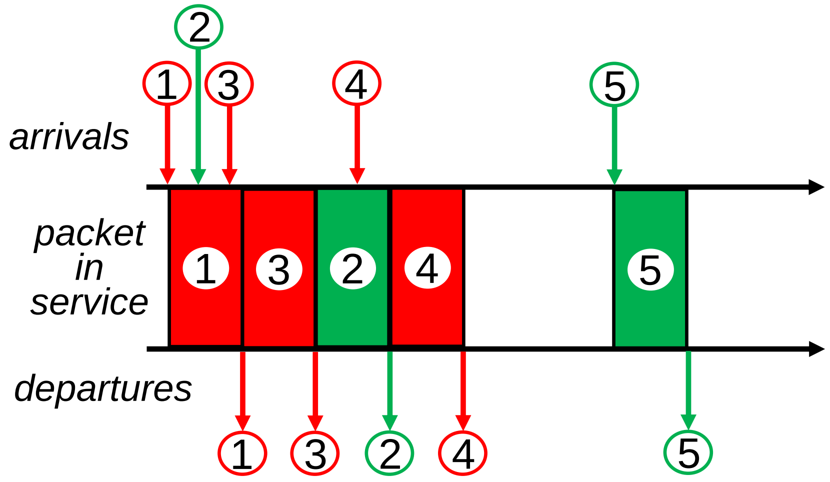
- also known as: First-in-first-out (FIFO)
- real world examples?

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

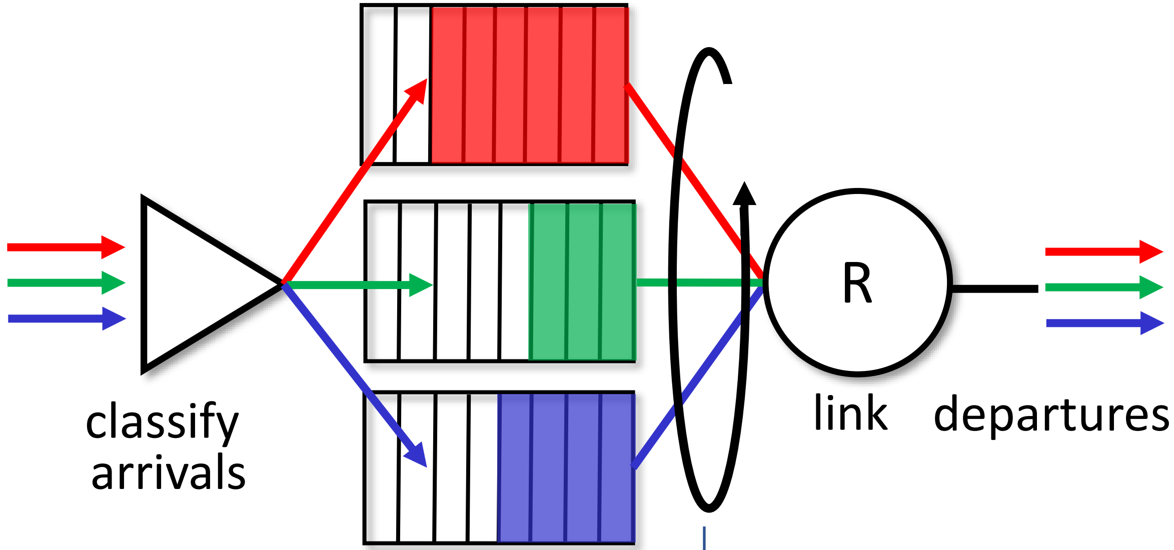




Scheduling policies: round robin

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



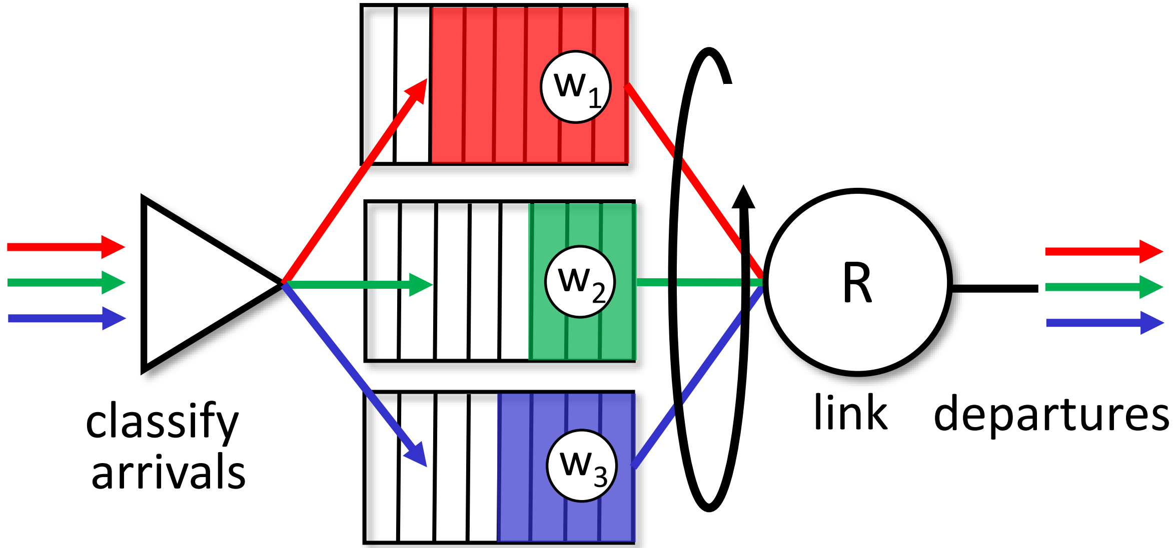
Scheduling policies: weighted fair queueing

Weighted Fair Queuing (WFQ):

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

$$\frac{w_i}{\Sigma_j w_j}$$

- minimum bandwidth guarantee (per-traffic-class)



Activity 4.2

- Scheduling policies for packets
  - Each packet has a processing delay of 2 seconds
  - Packets 1,2,3,4 and 5 arriving at 0^{th} ,1^{st} ,2^{nd} ,7^{th} and 12^{th} seconds with priority 10,40,20,40,20
  - Use FCFS and Priority scheduling to process packets

Activity 4.2 Continued

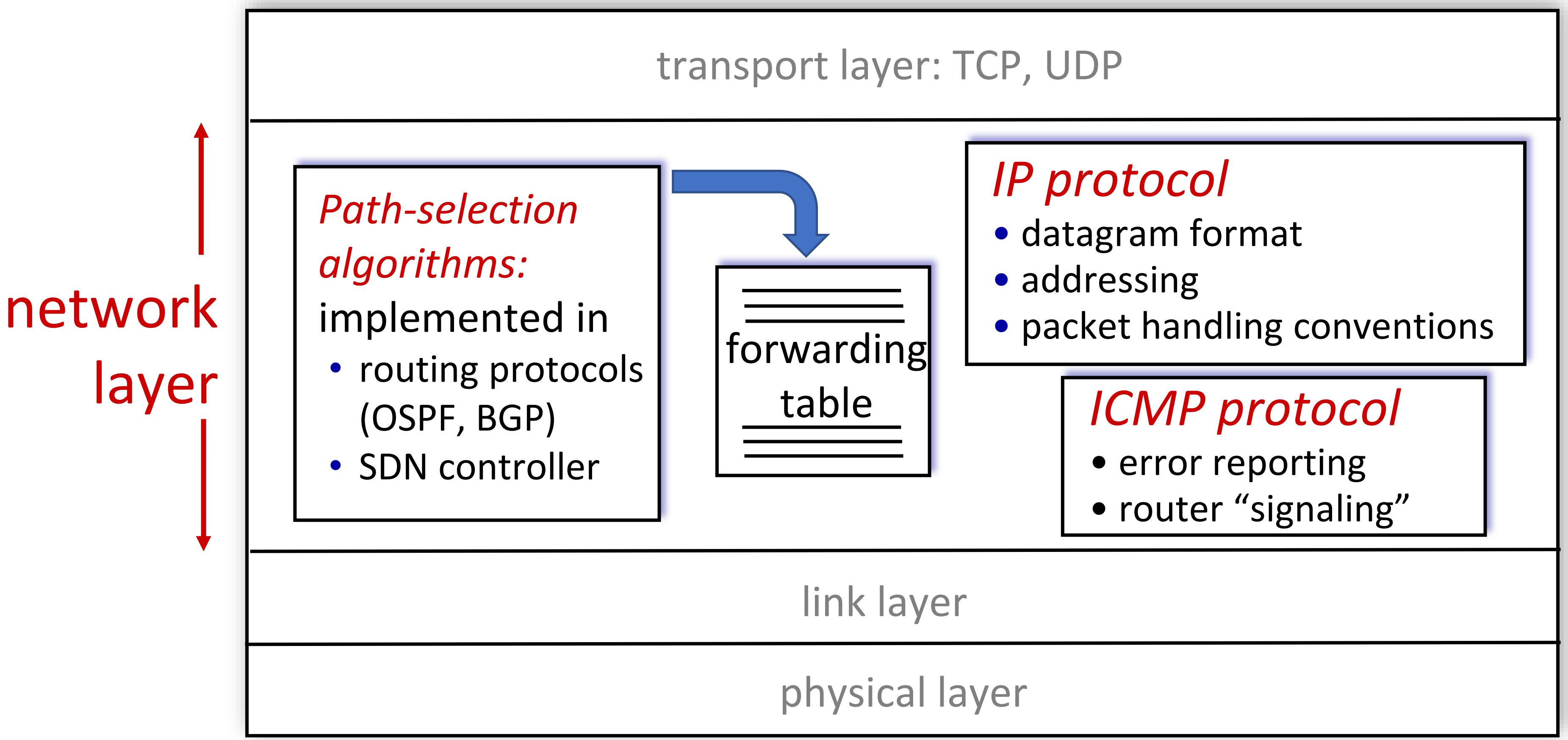
- Use round robin and WFQ scheduling for below packets to be processed

Class	Weight	Packets
3	6	24
2	3	15
1	1	5

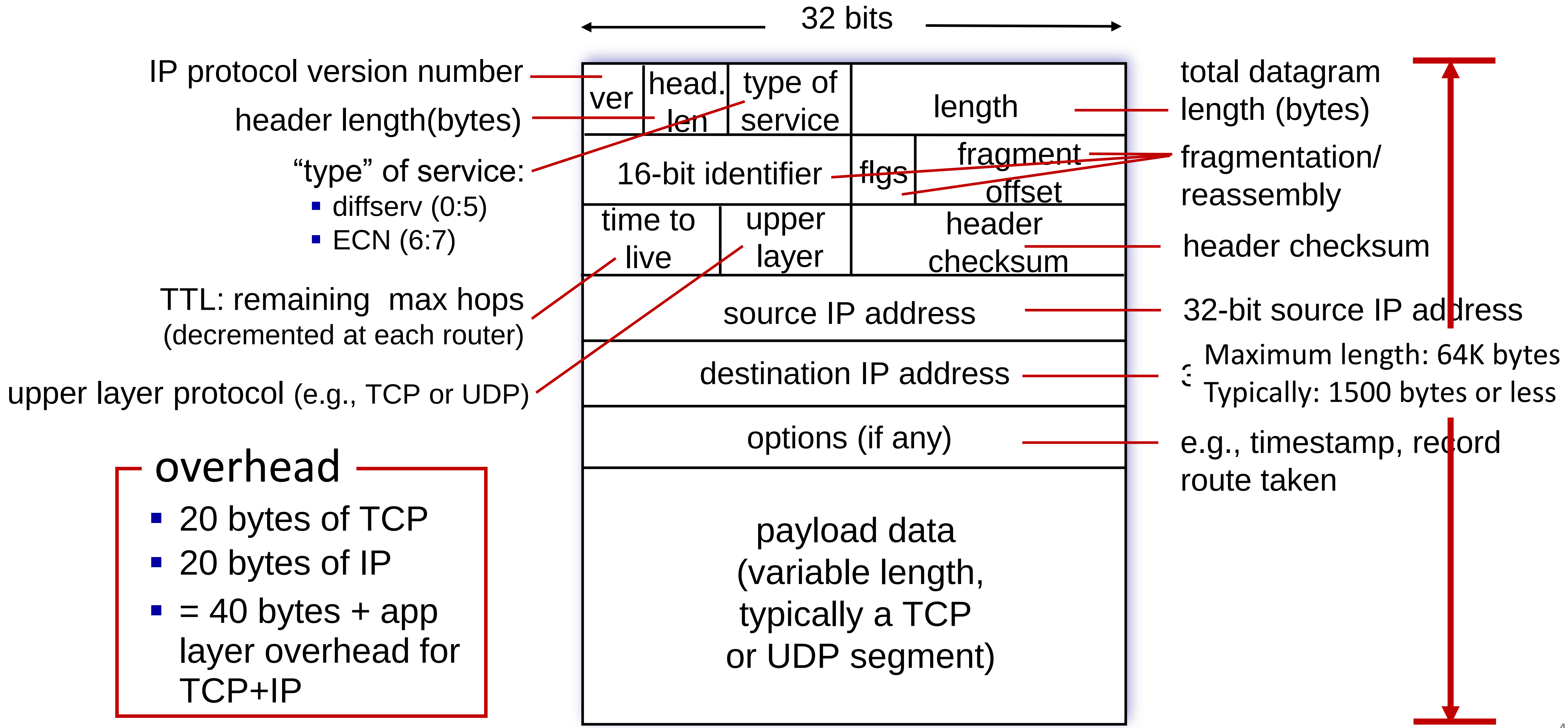
  - For round robin, consider 1 packet from each class being processed as it does not have any weight
  - Draw and time graph and identify the time in seconds for completion of above scheduling for round robin and WFQ policy if each packet takes 1 second to complete processing.

Network Layer: Internet

host, router network layer functions:



IP Datagram format (Read Textbook)

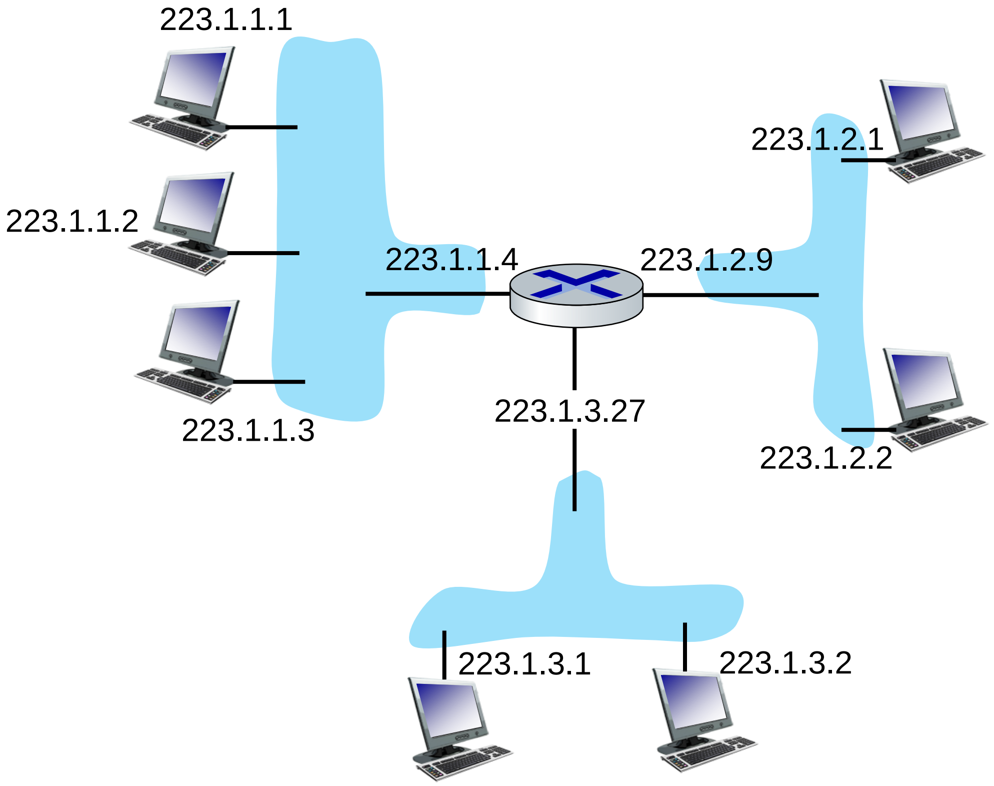


overhead

- 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:

$$223.1.1.1 = \underbrace{11011111}_{223}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}$$

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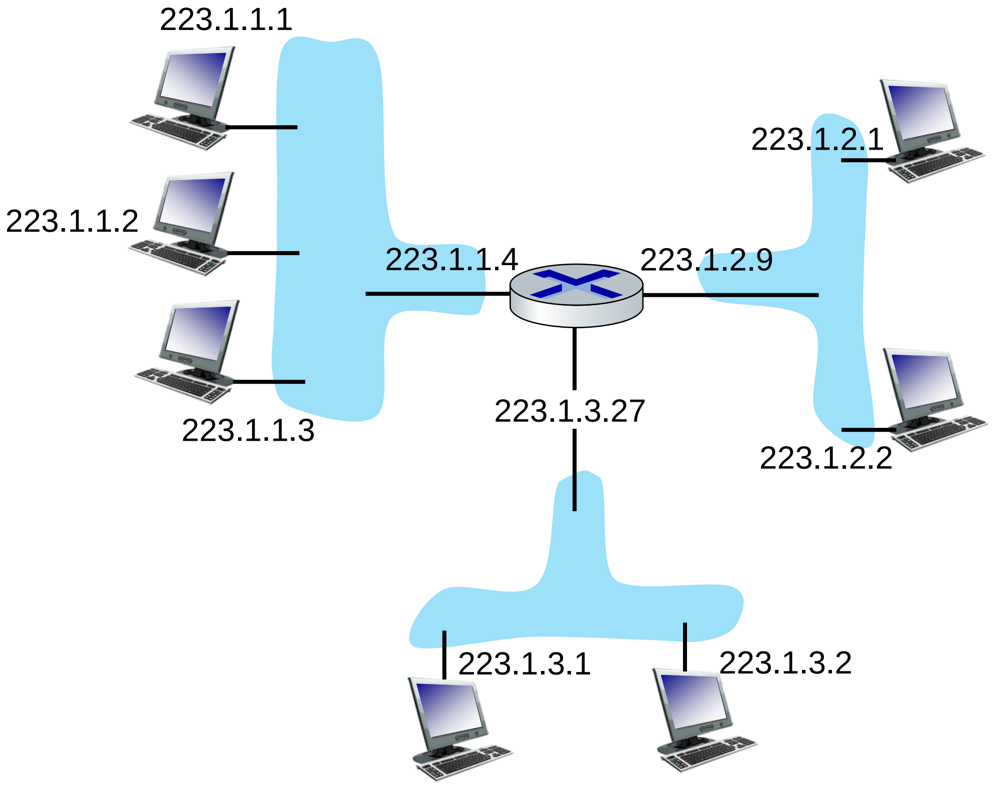


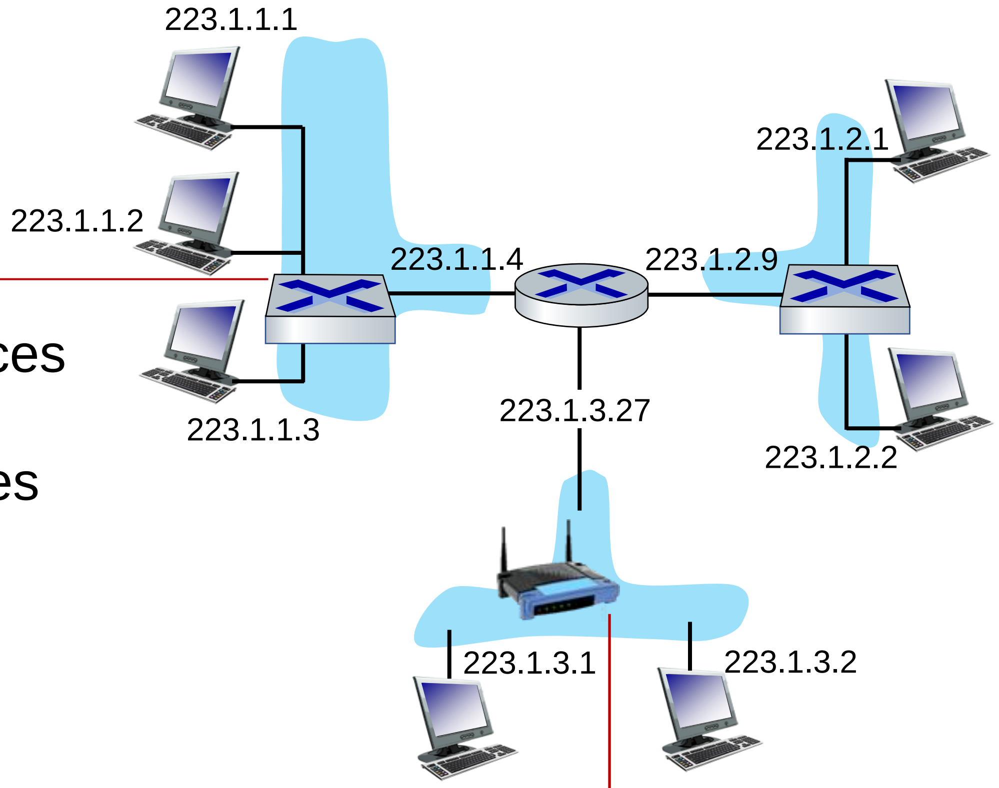
dotted-decimal IP address notation:

$$223.1.1.1 = \underbrace{11011111}_{223}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}$$

IP addressing: introduction

Q: how are interfaces actually connected?

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



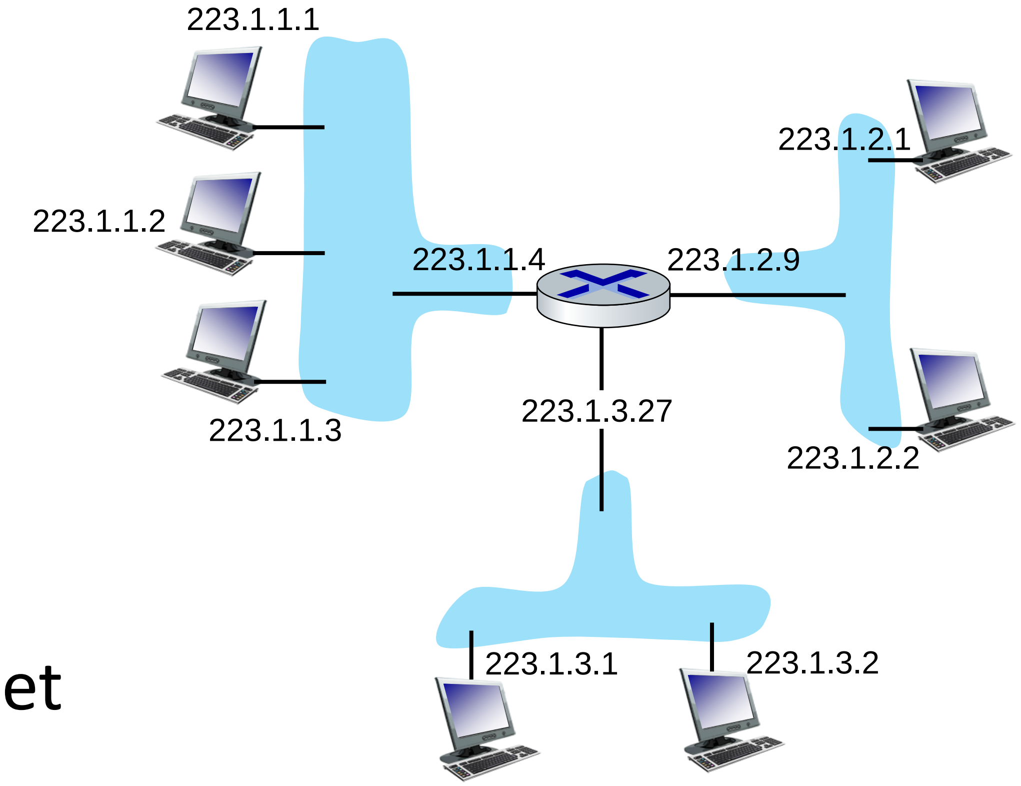
A: wired Ethernet interfaces connected by Ethernet switches

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 ?*
  - device interfaces that can physically reach each other without passing through an intervening router
- IP addresses have structure:
  - subnet part: devices in same subnet have common high order bits
  - host part: remaining low order bits

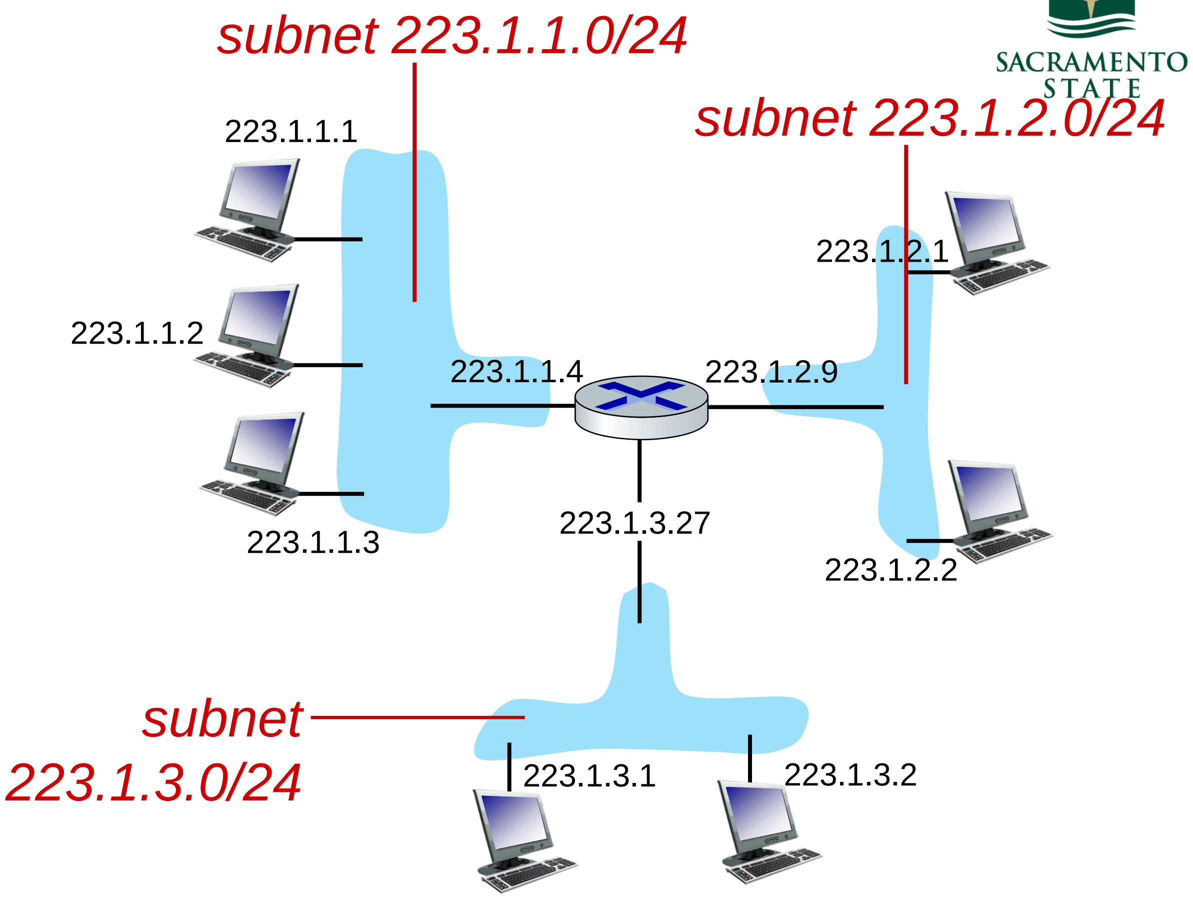


network consisting of 3 subnets

Subnets

Recipe for defining subnets:

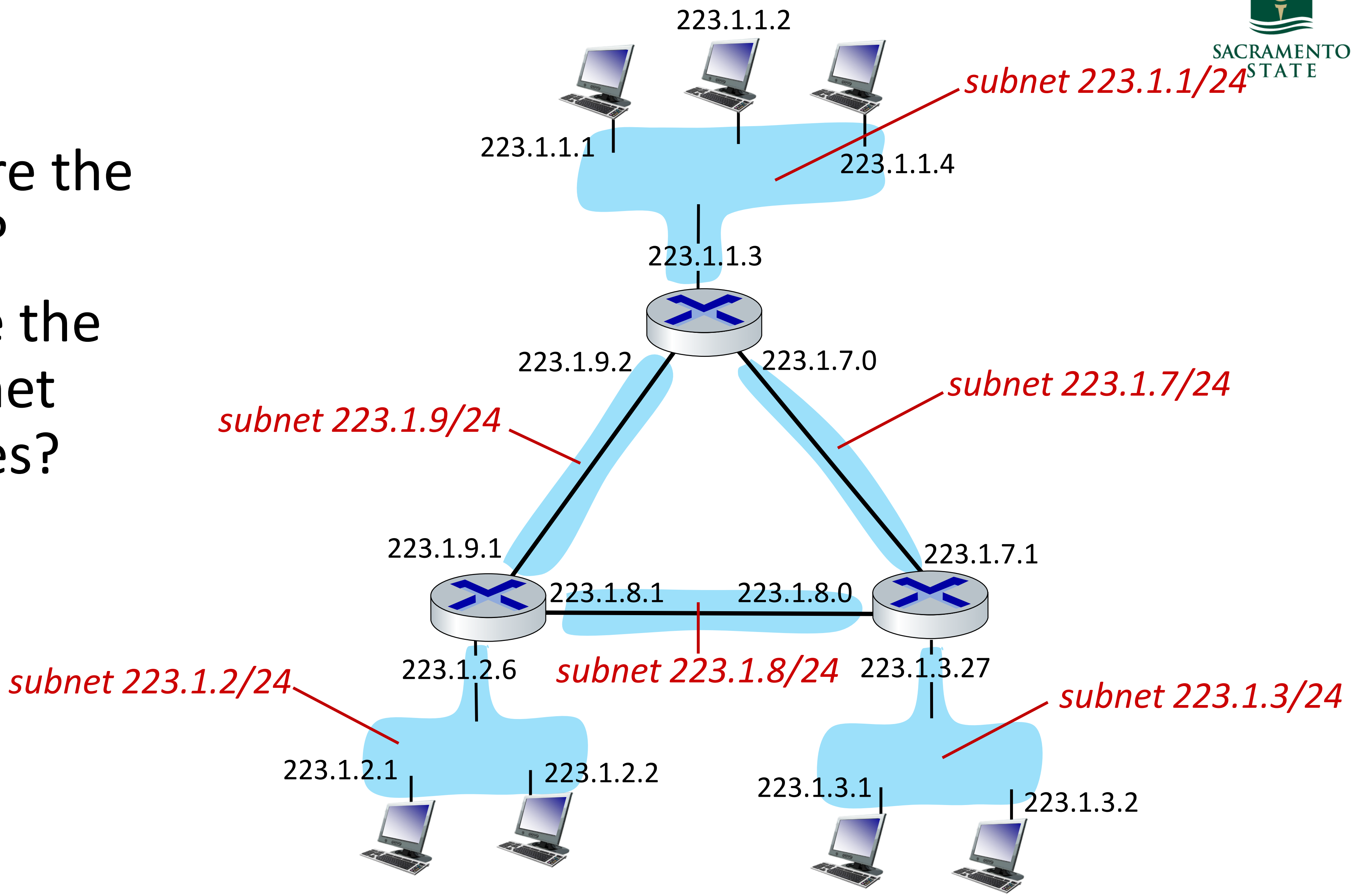
- detach each interface from its host or router, creating "islands" of isolated networks
- each isolated network is called a *subnet*



subnet mask: /24
(high-order 24 bits: subnet part of IP address)

Subnets

- where are the subnets?
- what are the /24 subnet addresses?



IP addressing: CIDR

CIDR: Classless InterDomain Routing (pronounced “cider”)

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

subnet part

host part

11001000 00010111 00010000 00000000

200.23.16.0/23

Activity 4.3

- IP Subnetting
  - Given an IP address of 192.168.1.0/24
    - Determine the network address, subnet mask and usable hosts
    - Create two networks out of 192.168.1.0 of 110 hosts each and identify the network addresses, subnet masks and usable hosts.

Lecture 4_1 Summary

- Principles behind network layer services
  - Network layer service models
  - Forwarding versus routing
  - How a router works
  - IP Addressing and Subnetting