

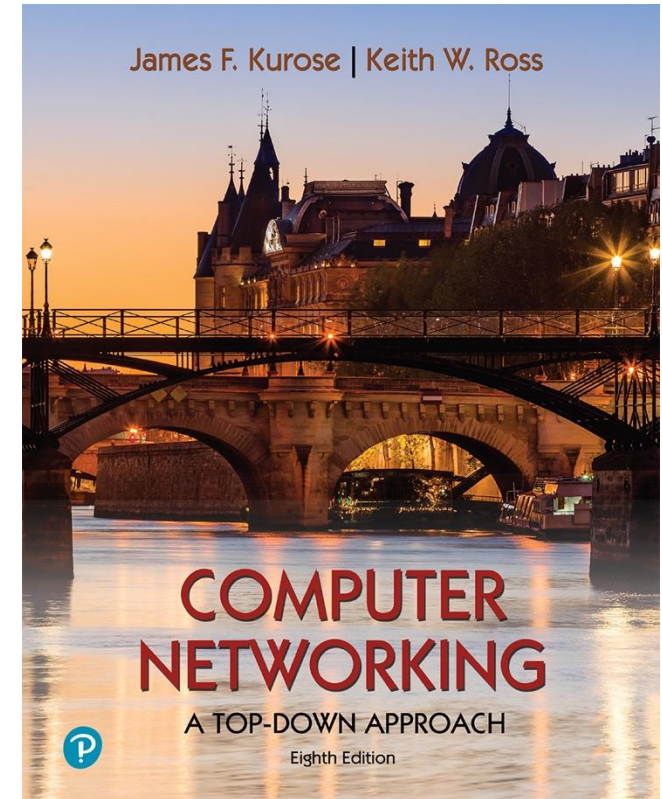


Computer Networks

Amir Mahdi Sadeghzadeh, Ph.D.

Chapter 4

Network Layer: Data Plane



Computer Networking: A Top-Down Approach

8th edition

Jim Kurose, Keith Ross
Pearson, 2020

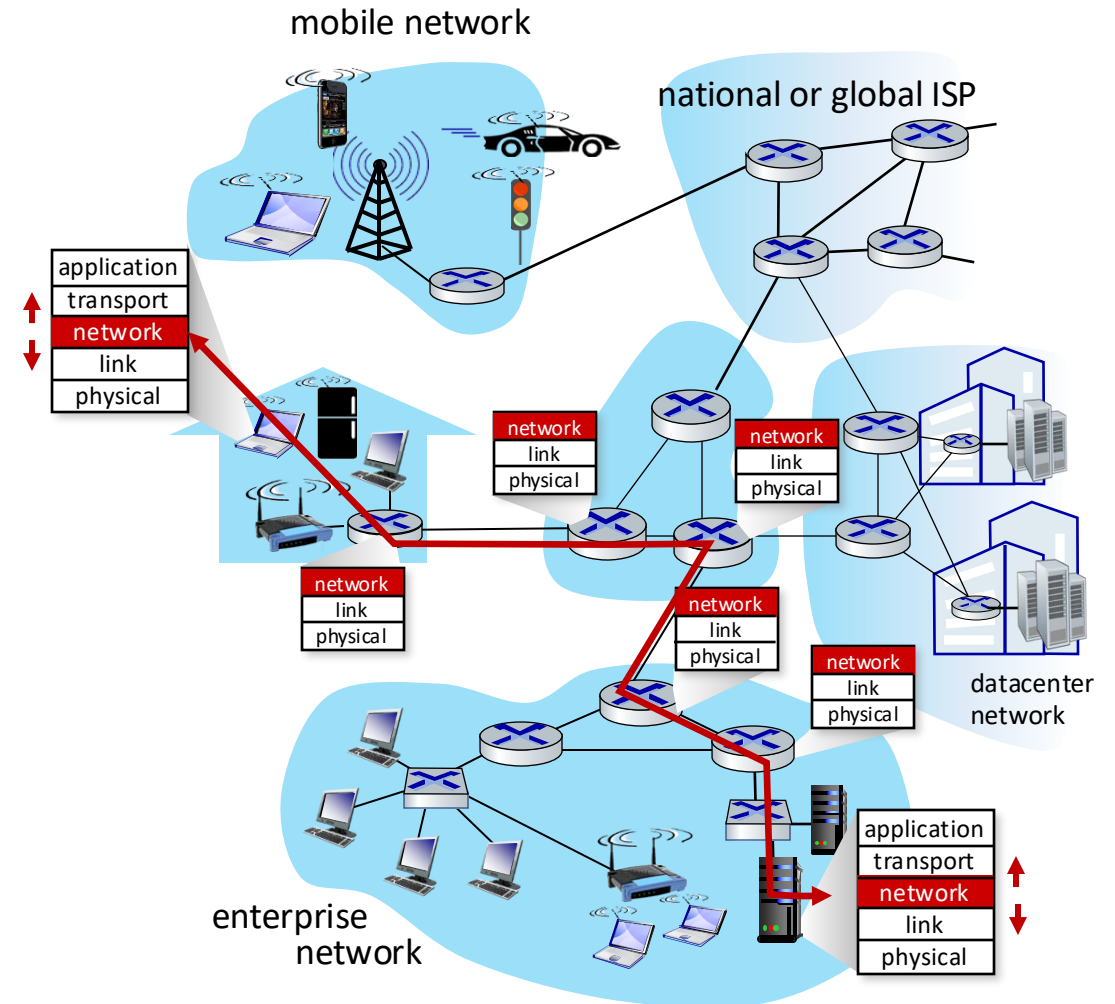
Network layer: “data plane” roadmap

- 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 services and protocols

- transport segment from sending to receiving host
 - **sender:** encapsulates segments into datagrams, passes to link layer
 - **receiver:** delivers segments to transport layer protocol
- network layer protocols in *every Internet device*: hosts, routers
- **routers:**
 - examines header fields in all IP datagrams passing through it
 - moves datagrams from input ports to output ports to transfer datagrams along end-end path



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



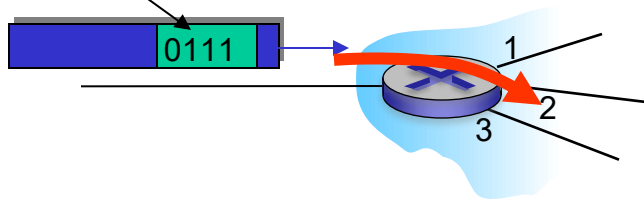
routing

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

values in arriving
packet header

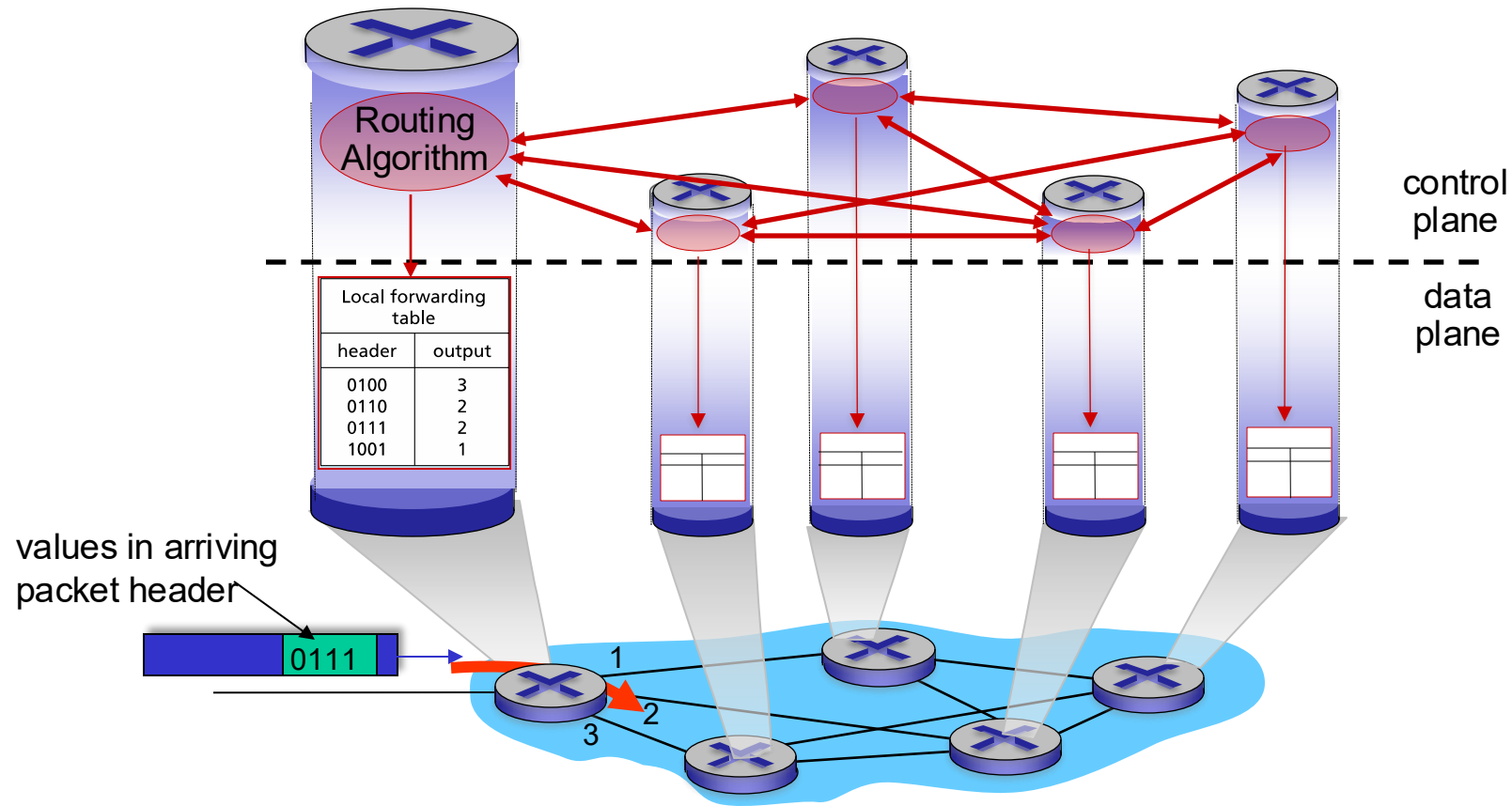


Control plane

- *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

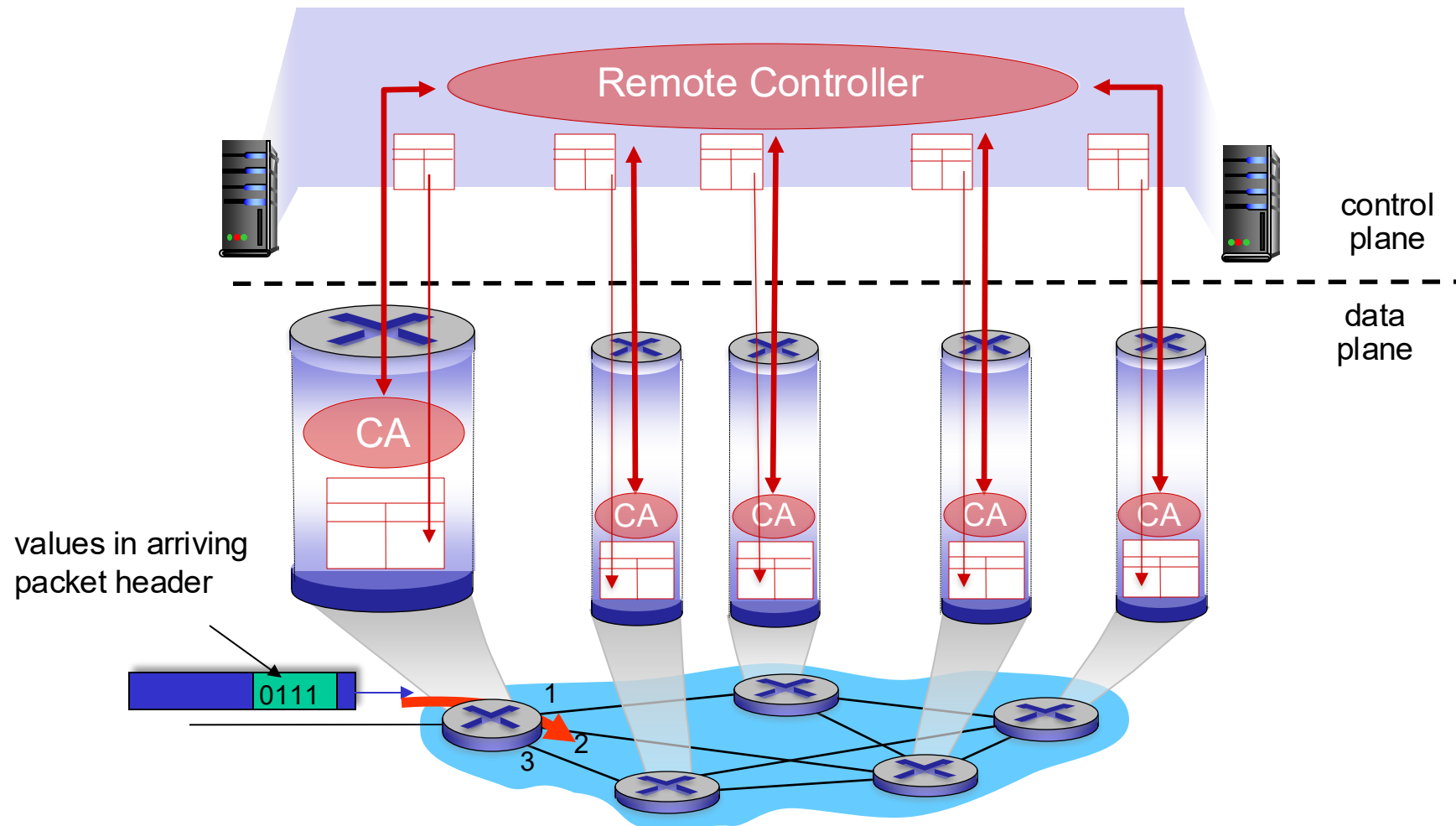
Per-router control plane

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



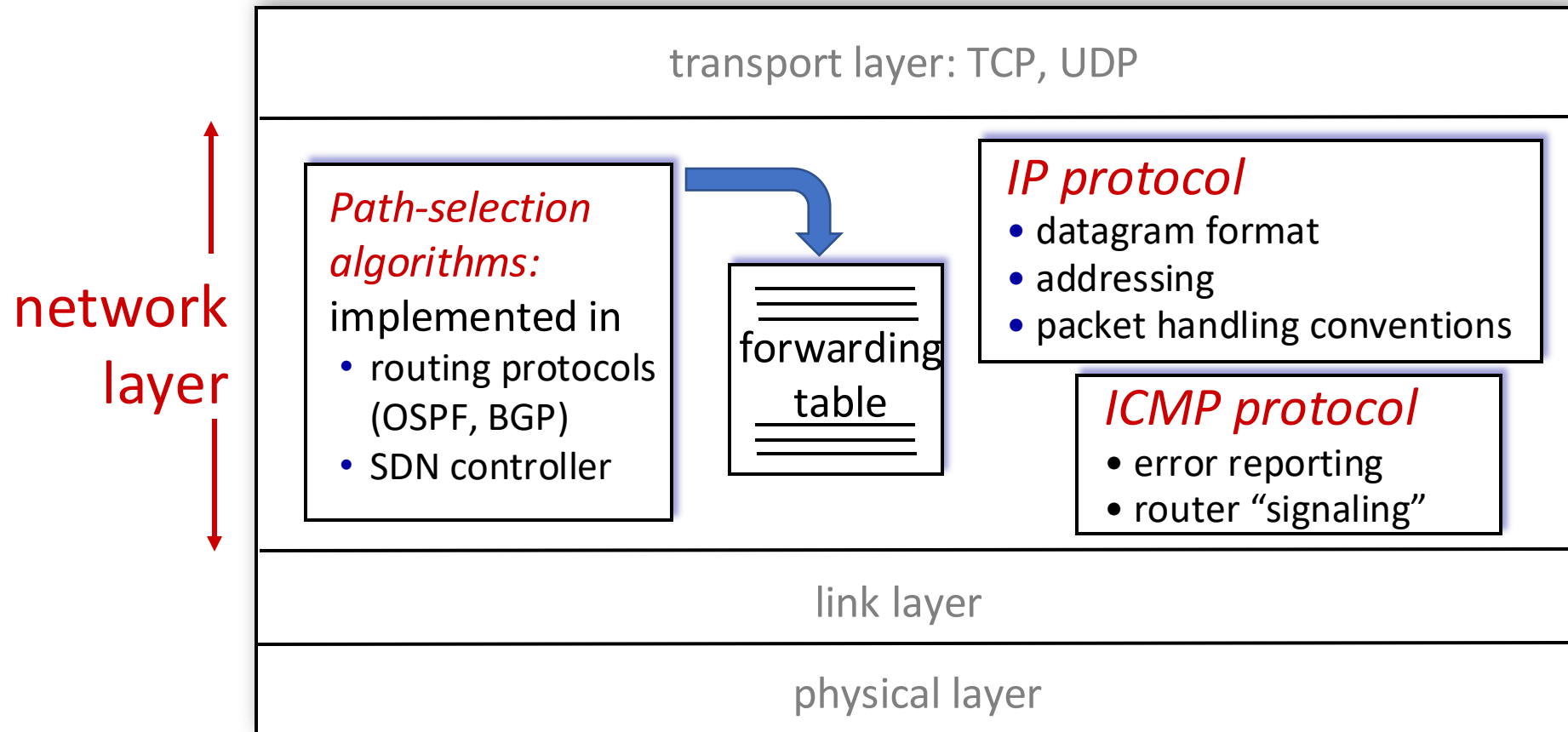
Network layer: “data plane” roadmap

- 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

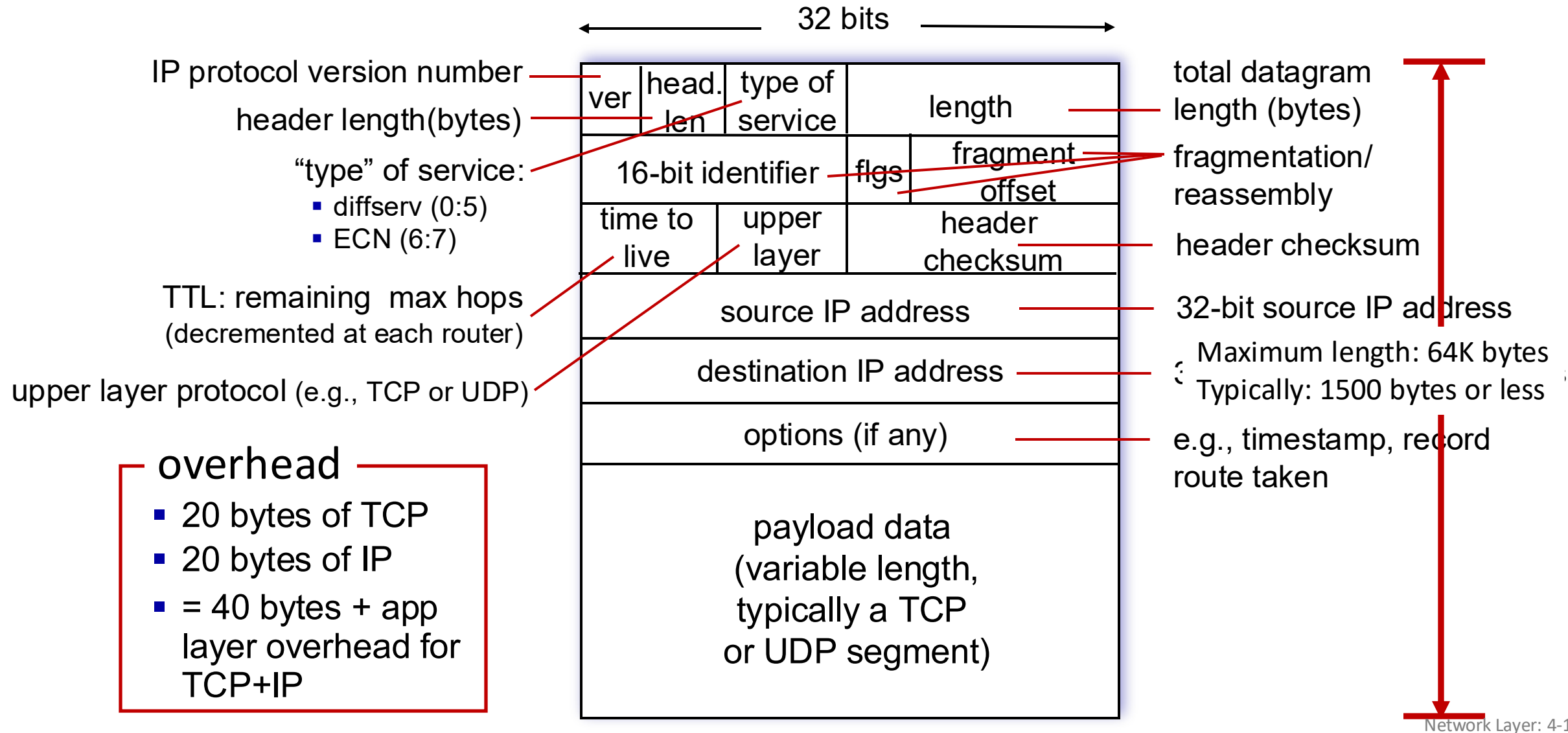


Network Layer: Internet

host, router network layer functions:

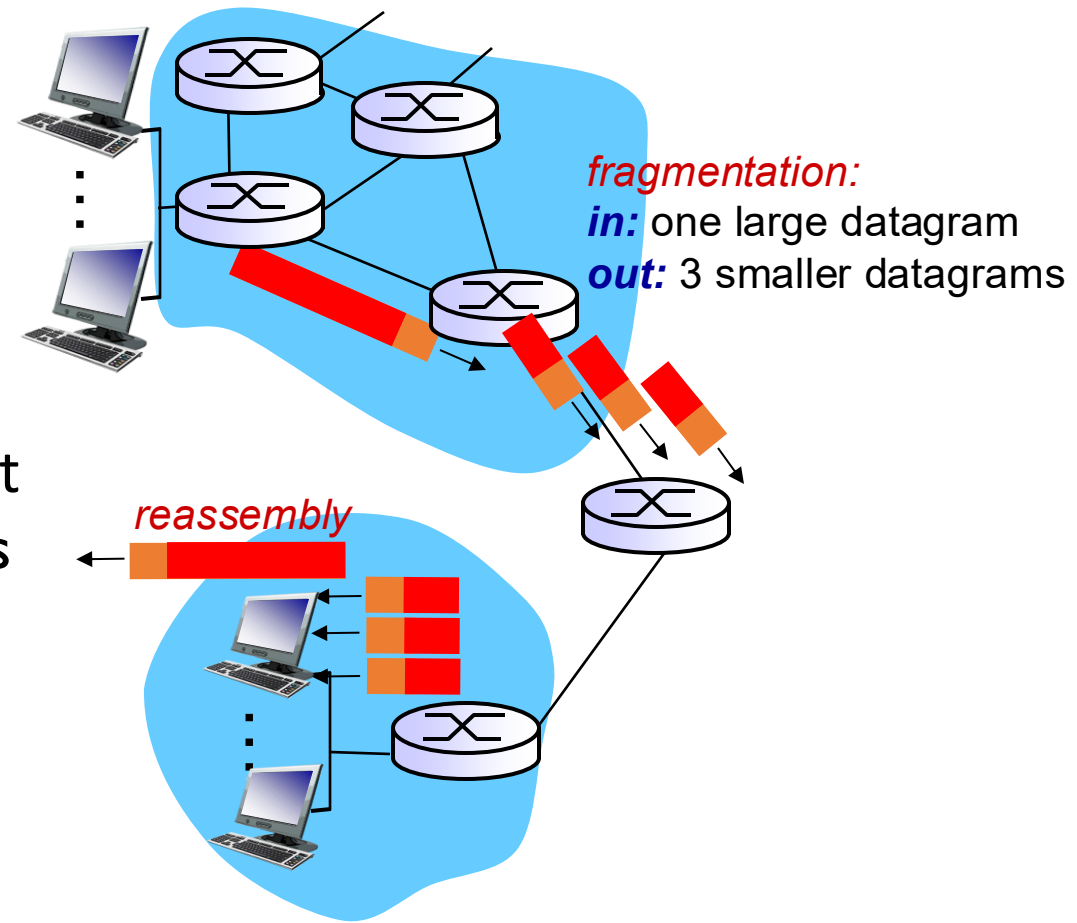


IP Datagram format



IP 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

	length =4000	ID =x	fragflag =0	offset =0	
--	-----------------	----------	----------------	--------------	--

*one large datagram becomes
several smaller datagrams*

1480 bytes in
data field

offset =
 $1480/8$

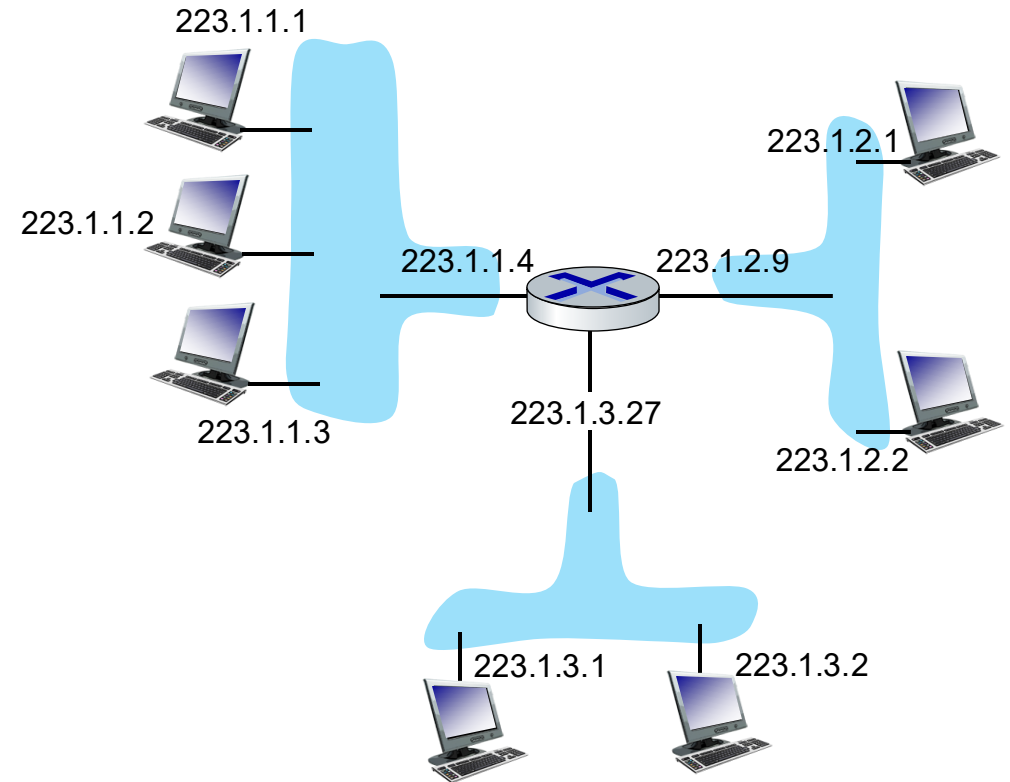
	length =1500	ID =x	fragflag =1	offset =0	
--	-----------------	----------	----------------	--------------	--

	length =1500	ID =x	fragflag =1	offset =185	
--	-----------------	----------	----------------	----------------	--

	length =1040	ID =x	fragflag =0	offset =370	
--	-----------------	----------	----------------	----------------	--

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)

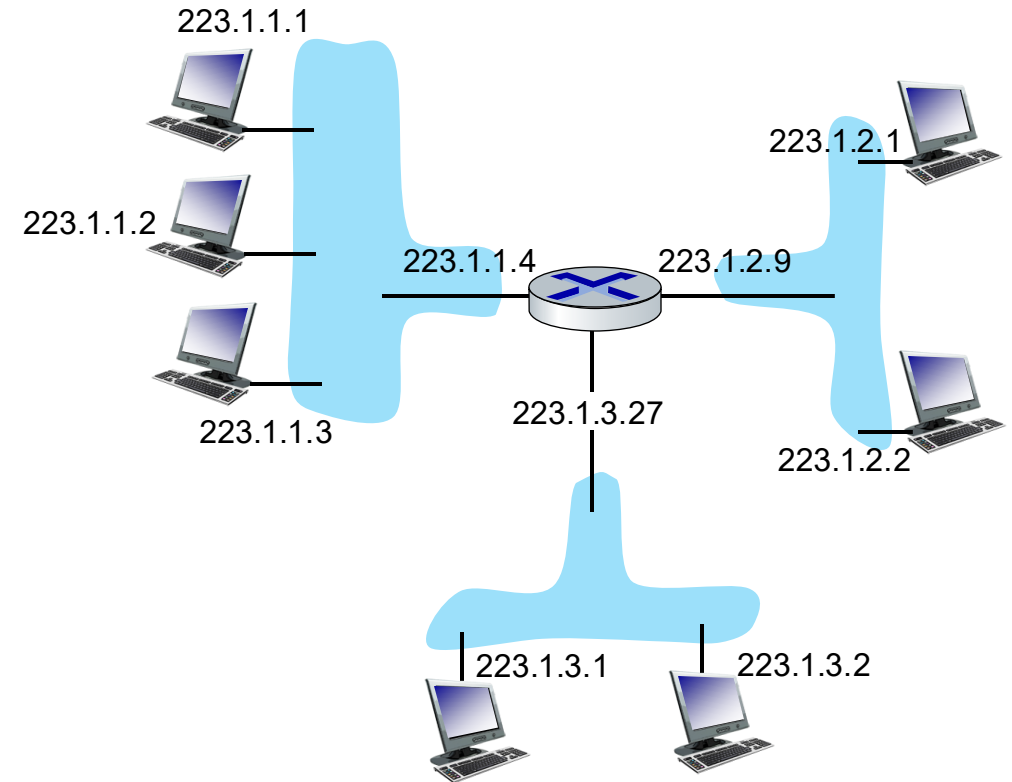


dotted-decimal IP address notation:

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

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

Network Layer: 4-15

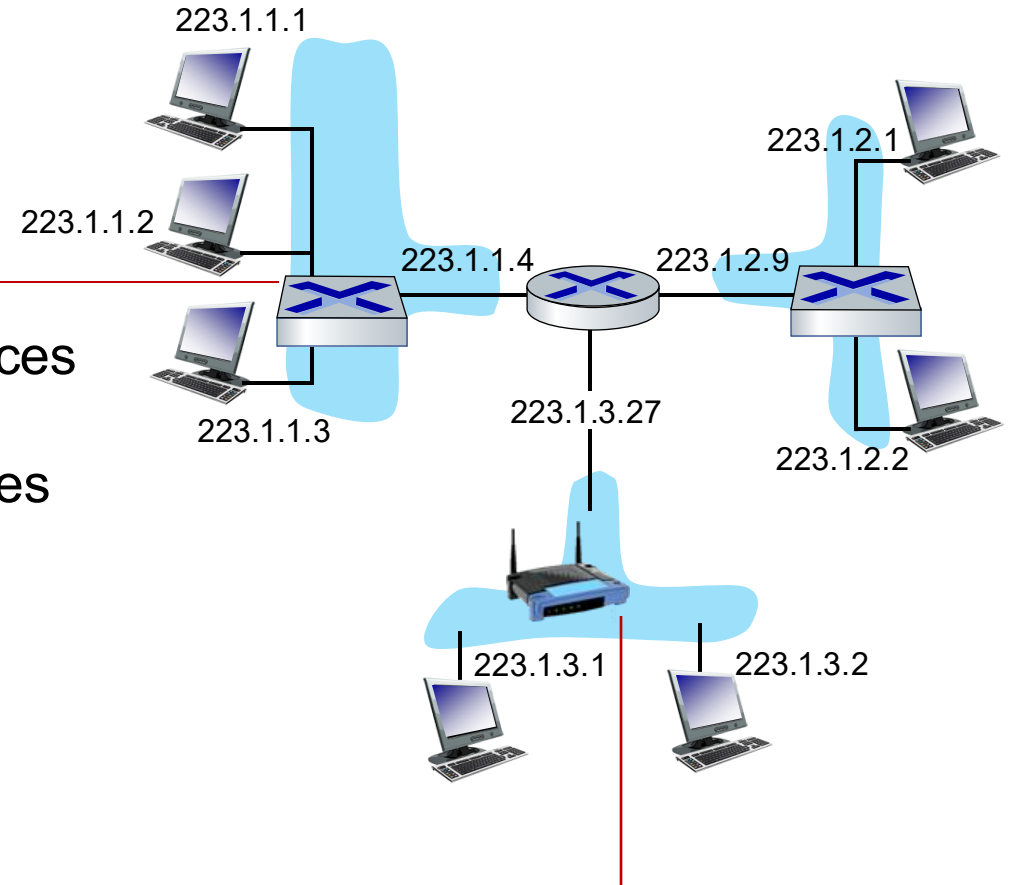
IP addressing: introduction

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)

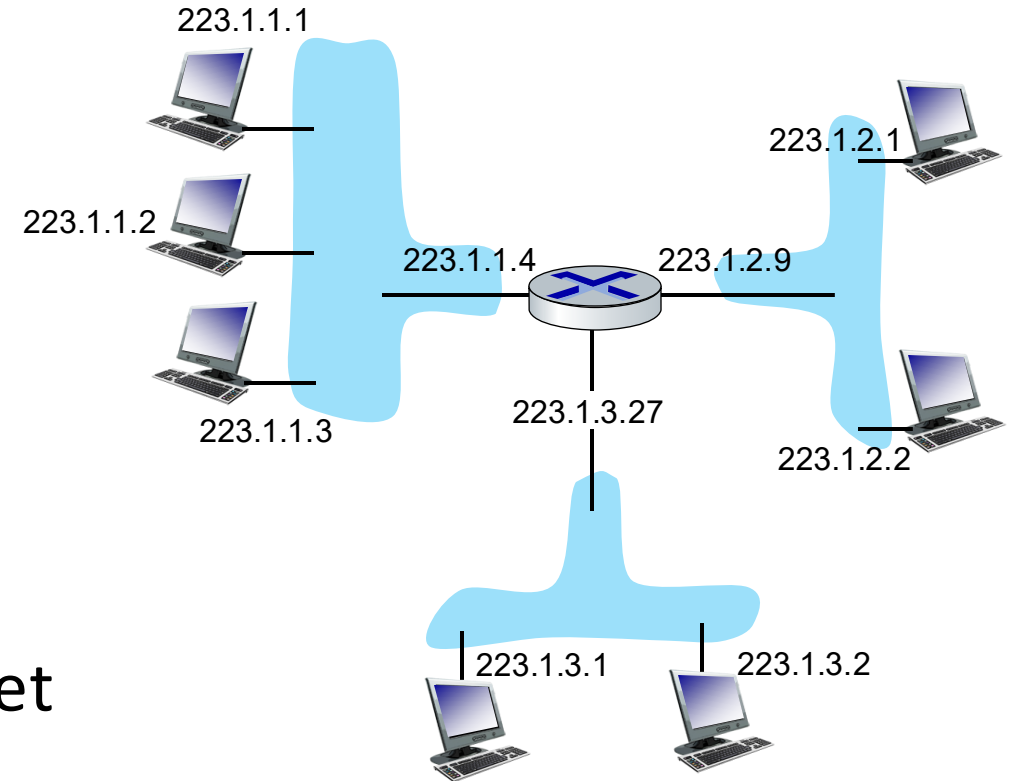
A: wired Ethernet interfaces connected by Ethernet switches



A: wireless WiFi interfaces connected by WiFi base station

Subnets

- *What's a subnet ?*
 - 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

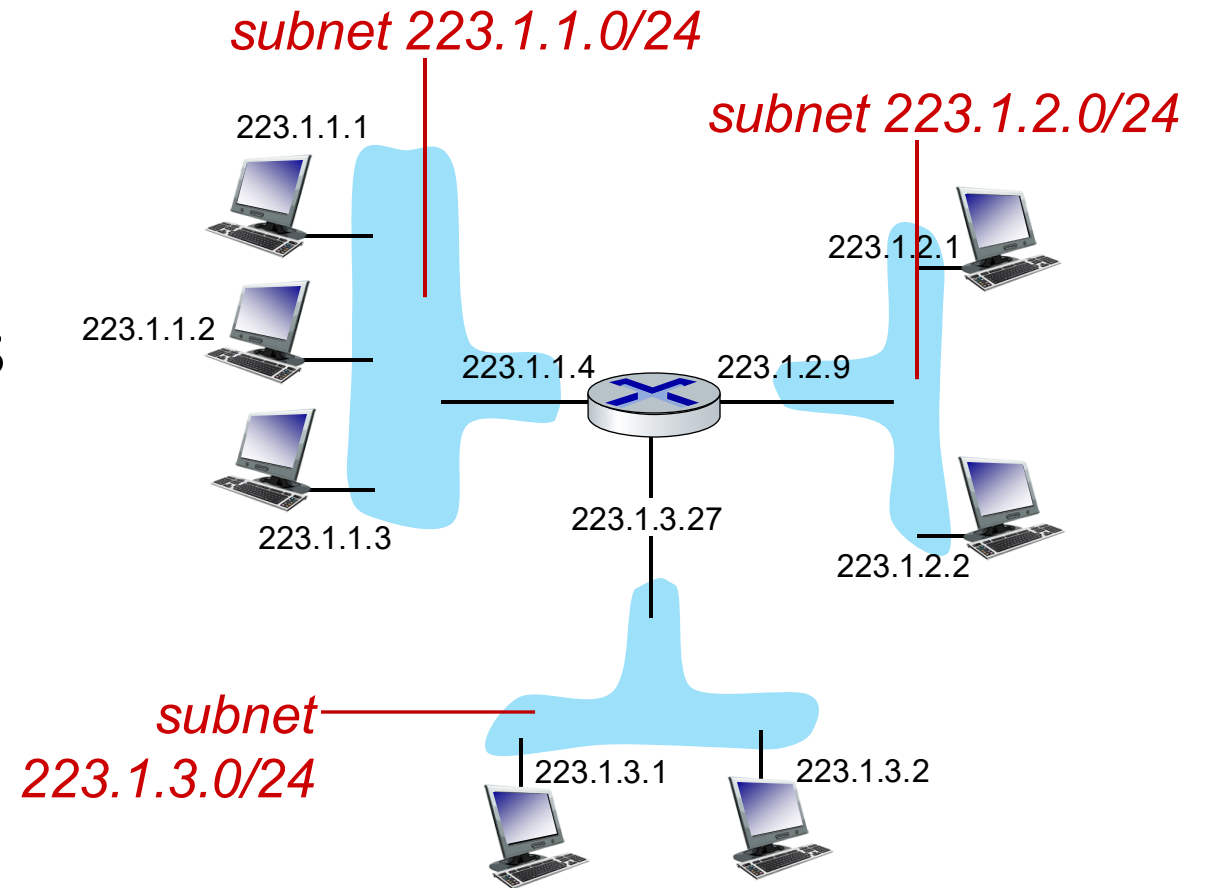


network consisting of 3 subnets

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*

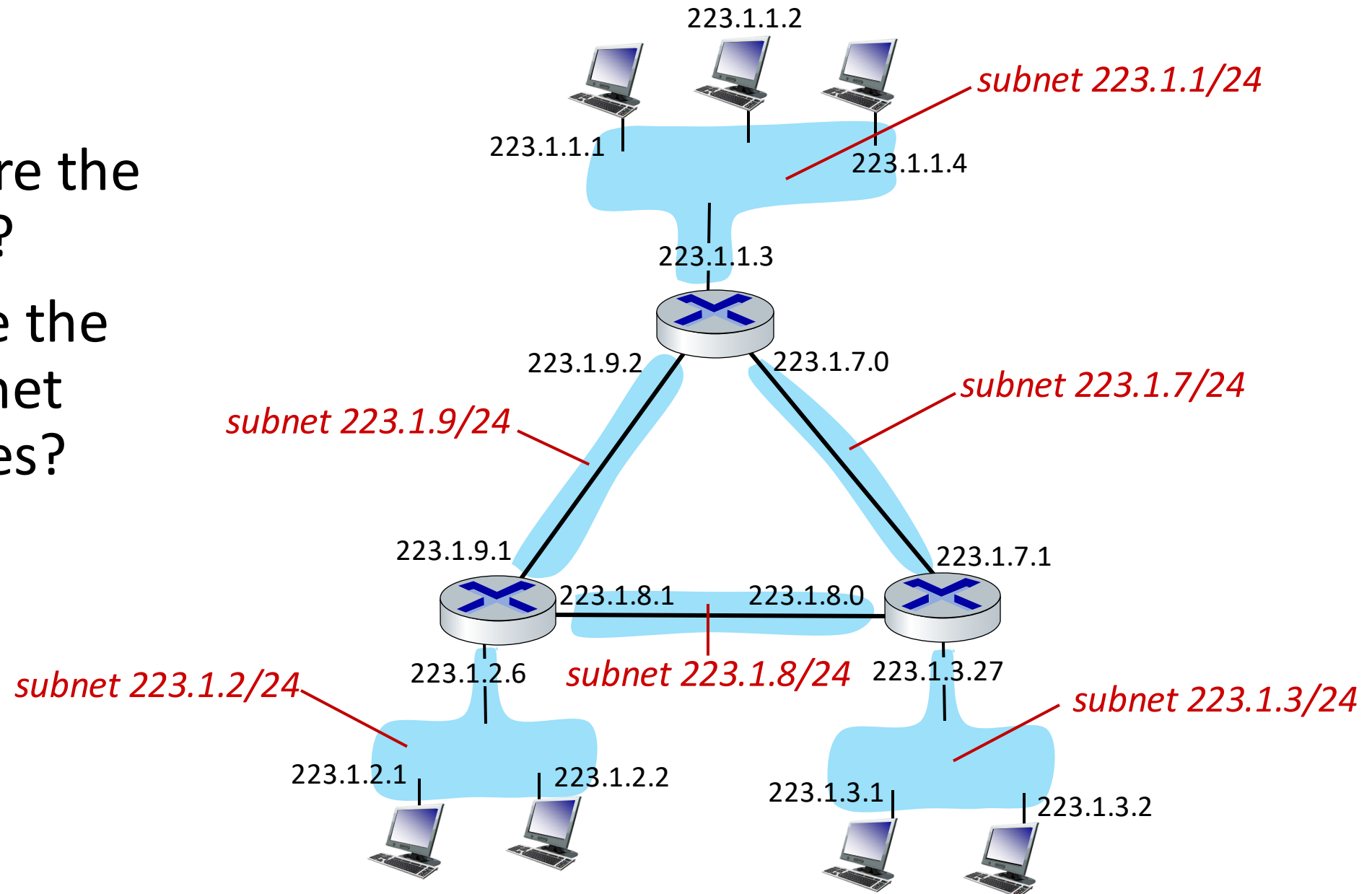


subnet mask: /24

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

Subnets

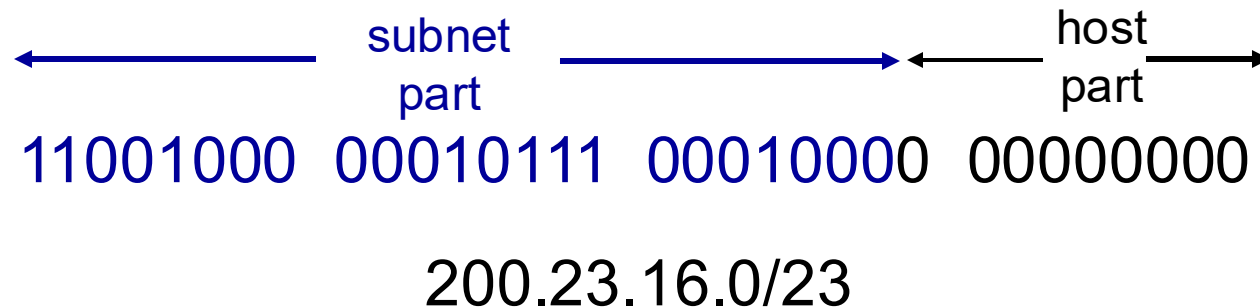
- where are the subnets?
- what are the /24 subnet addresses?



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



IP addresses: how to get one?

That's actually **two** questions:

1. Q: How does a *host* get IP address within its network (host part of address)?
2. Q: How does a *network* get IP address for itself (network part of address)

How does *host* get IP address?

- hard-coded by sysadmin in config file (e.g., /etc/rc.config in UNIX)
- **DHCP**: Dynamic Host Configuration Protocol: dynamically get address from as server
 - “plug-and-play”

DHCP: Dynamic Host Configuration Protocol

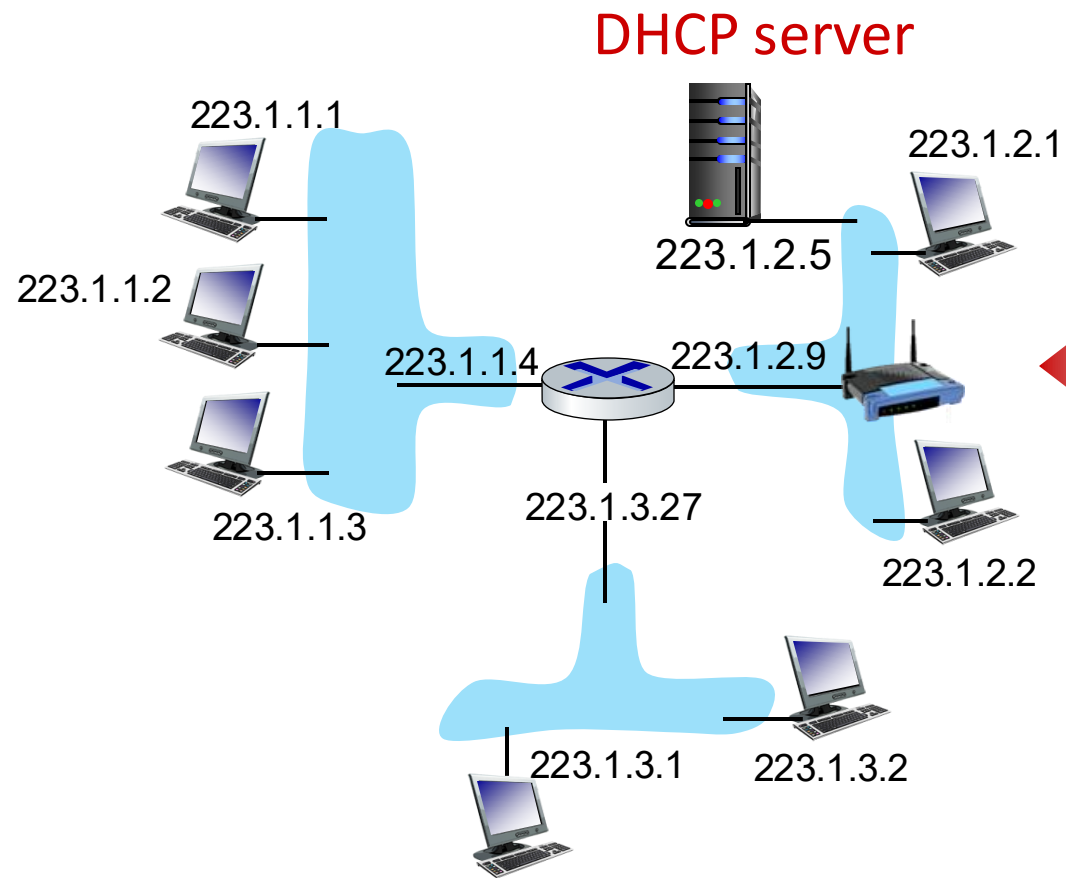
goal: host *dynamically* obtains IP address from network server when it “joins” network

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

DHCP overview:

- host broadcasts **DHCP discover** msg [optional]
- DHCP server responds with **DHCP offer** msg [optional]
- host requests IP address: **DHCP request** msg
- DHCP server sends address: **DHCP ack** msg

DHCP client-server scenario



Typically, DHCP server will be co-located in router, serving all subnets to which router is attached



arriving **DHCP client** needs address in this network

DHCP client-server scenario

DHCP server: 223.1.2.5



DHCP discover

Broadcast: is there a
DHCP server out there?

Arriving client



DHCP offer

Broadcast: I'm a DHCP
server! Here's an IP
address you can use

DHCP request

Broadcast: OK. I would
like to use this IP address!

DHCP ACK

Broadcast: OK. You've
got that IP address!

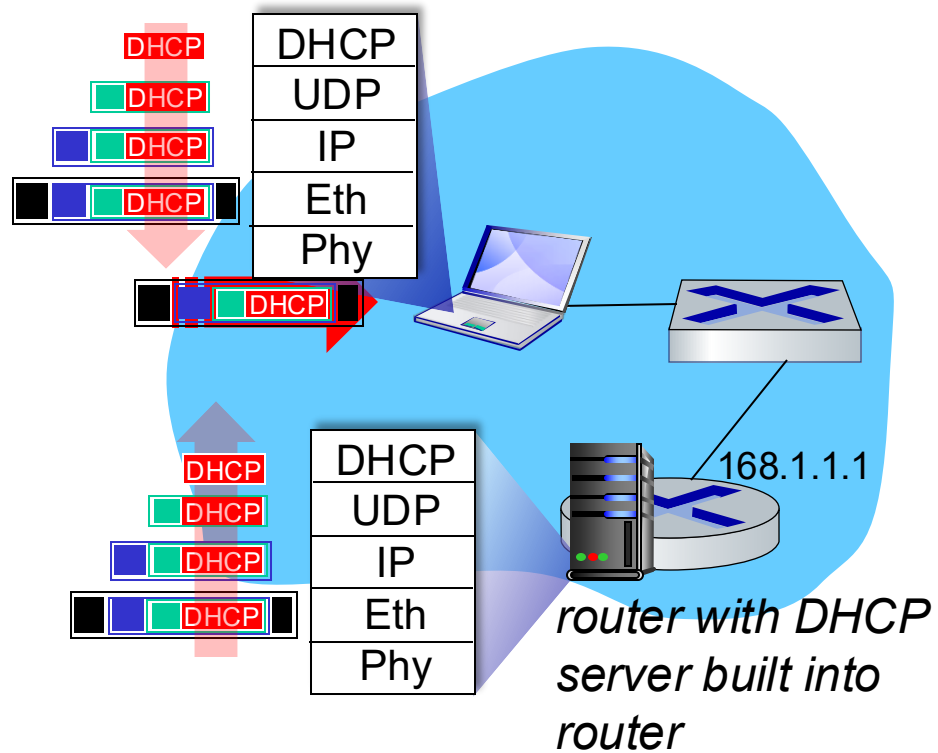
The two steps above can
be skipped "if a client
remembers and wishes to
reuse a previously
allocated network address"
[RFC 2131]

DHCP: more than IP addresses

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

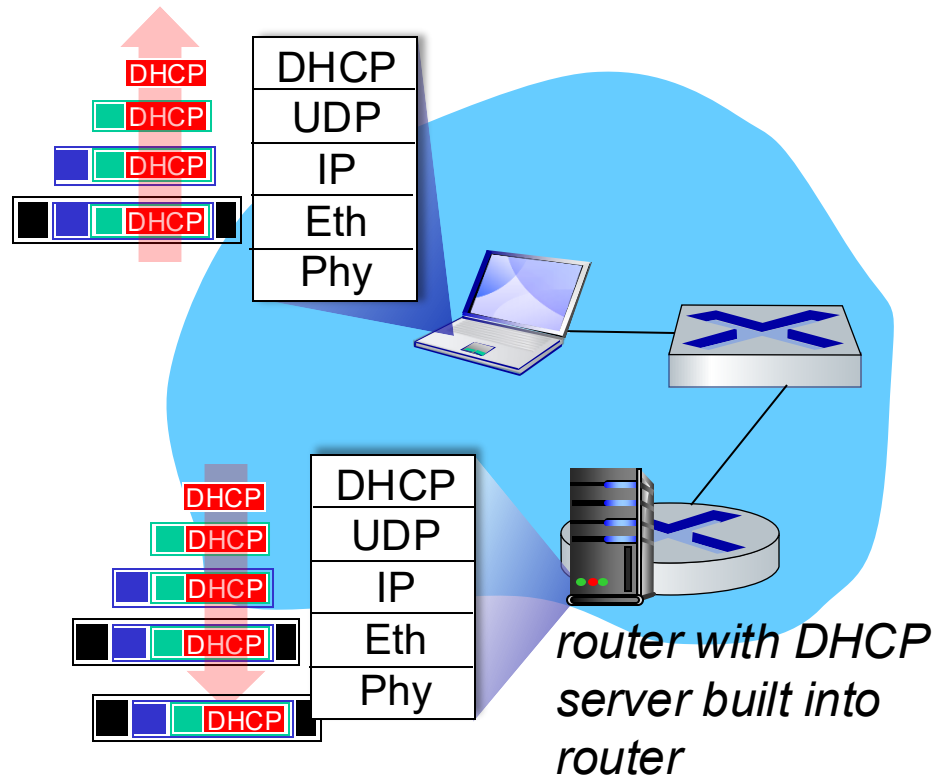
- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

DHCP: example



- Connecting laptop will use DHCP to get IP address, address of first-hop router, address of DNS server.
- DHCP REQUEST message encapsulated in UDP, encapsulated in IP, encapsulated in Ethernet
- Ethernet frame broadcast (dest: FFFFFFFF) on LAN, received at router running DHCP server
- Ethernet de-mux'ed to IP de-mux'ed, UDP de-mux'ed 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
- encapsulated DHCP server reply forwarded to client, de-muxing up to DHCP at client
- client now knows its IP address, name and IP address of DNS server, IP address of its first-hop router