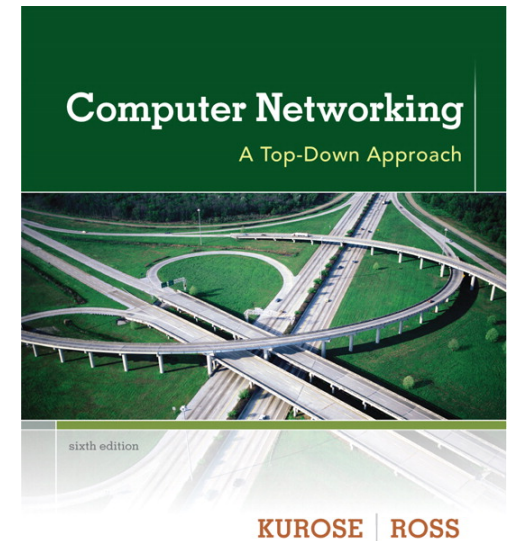


# Chapter 4

## Network Layer

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a.a. 2019/2020

We thank for the support material Prof. Kurose-Ross  
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*Computer  
Networking: A Top  
Down Approach*  
6<sup>th</sup> edition  
Jim Kurose, Keith Ross  
Addison-Wesley  
March 2012

# Chapter 4: outline

## 4.1 introduction

## 4.2 virtual circuit and datagram networks

## 4.3 what's inside a router

## 4.4 IP: Internet Protocol

- datagram format
- IPv4 addressing
- ICMP
- IPv6

## 4.5 routing algorithms

- link state
- distance vector
- hierarchical routing

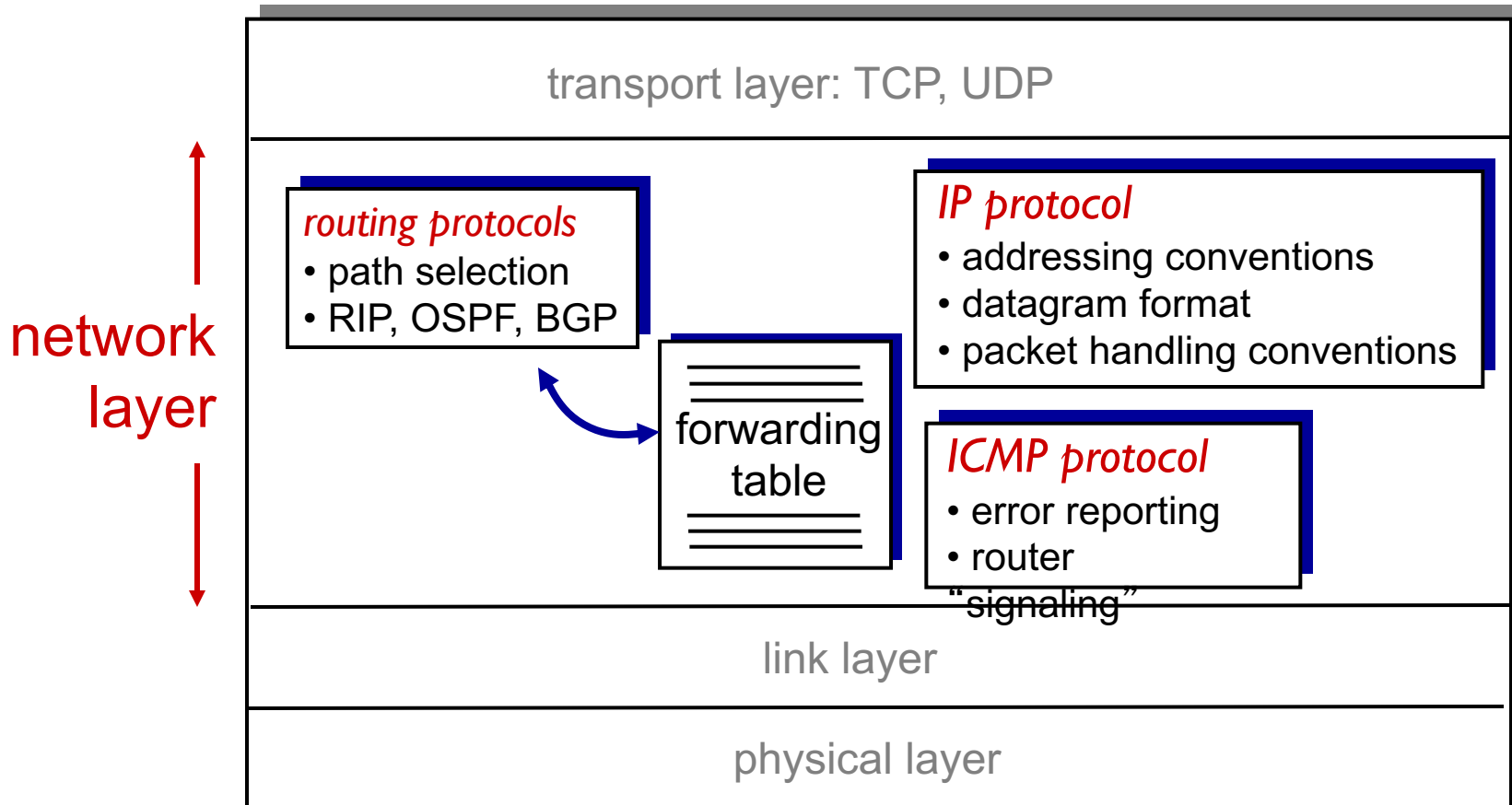
## 4.6 routing in the Internet

- RIP
- OSPF
- BGP

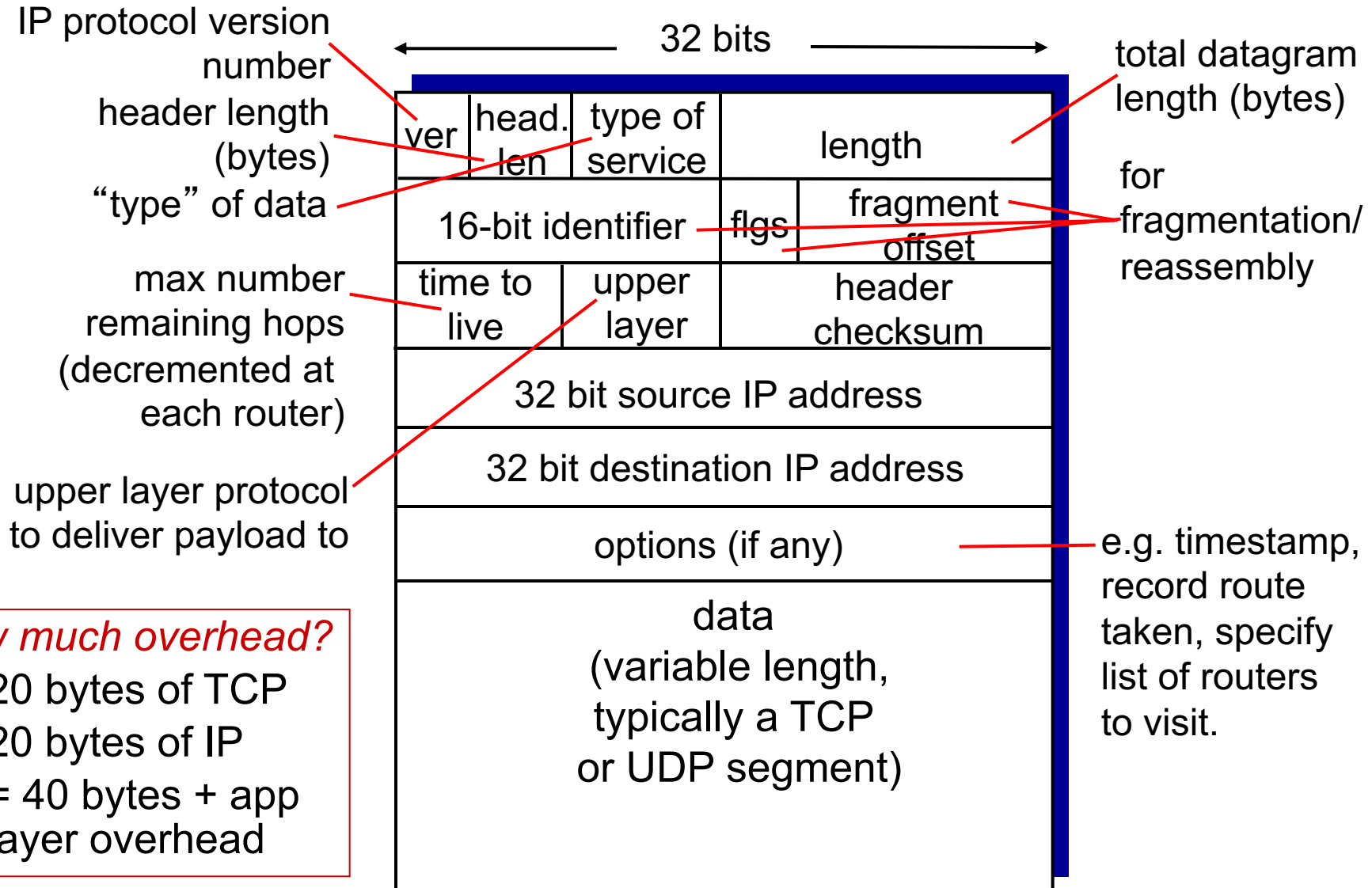
## 4.7 broadcast and multicast routing

# The Internet network layer

host, router network layer functions:

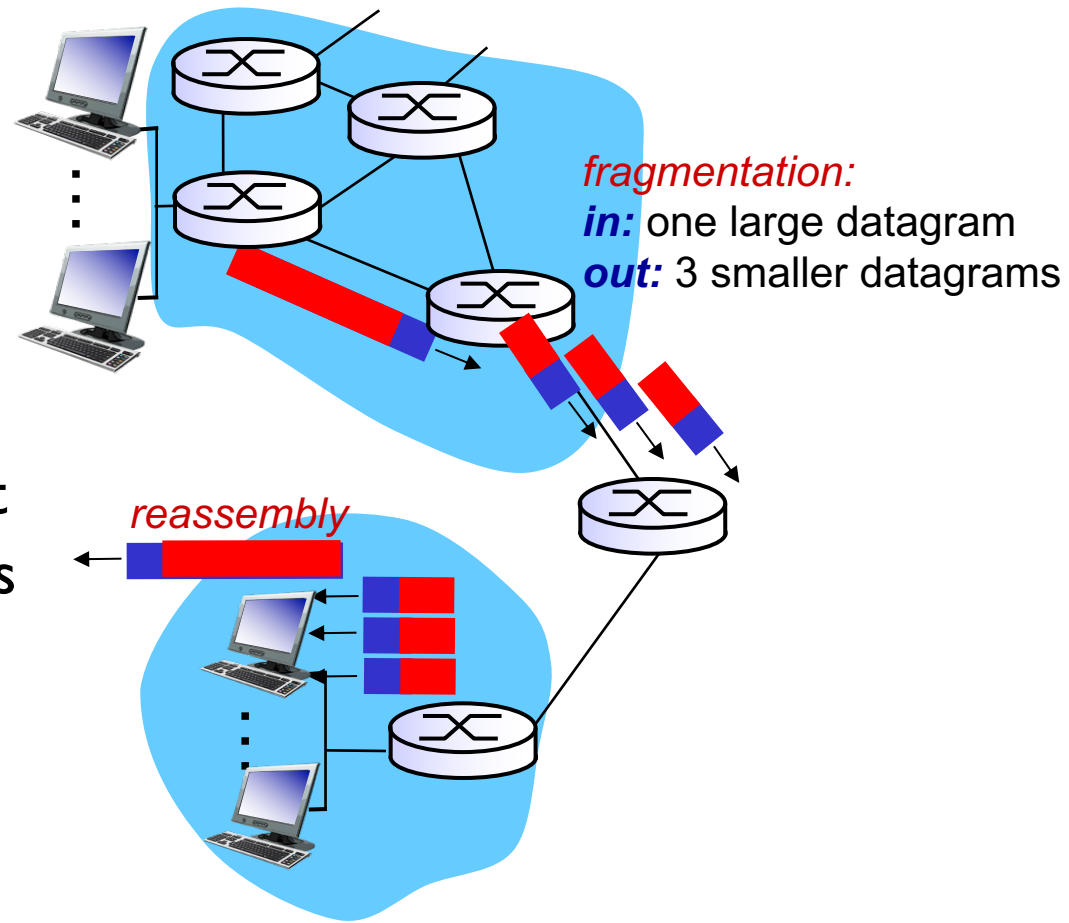


# IP datagram format



# 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<br>=4000 | ID<br>=x | fragflag<br>=0 | offset<br>=0 |  |
|--|-----------------|----------|----------------|--------------|--|

*one large datagram becomes  
several smaller datagrams*

1480 bytes in  
data field

offset =  
 $1480/8$

|  |                 |          |                |              |  |
|--|-----------------|----------|----------------|--------------|--|
|  | length<br>=1500 | ID<br>=x | fragflag<br>=1 | offset<br>=0 |  |
|--|-----------------|----------|----------------|--------------|--|

|  |                 |          |                |                |  |
|--|-----------------|----------|----------------|----------------|--|
|  | length<br>=1500 | ID<br>=x | fragflag<br>=1 | offset<br>=185 |  |
|--|-----------------|----------|----------------|----------------|--|

|  |                 |          |                |                |  |
|--|-----------------|----------|----------------|----------------|--|
|  | length<br>=1040 | ID<br>=x | fragflag<br>=0 | offset<br>=370 |  |
|--|-----------------|----------|----------------|----------------|--|

# Chapter 4: outline

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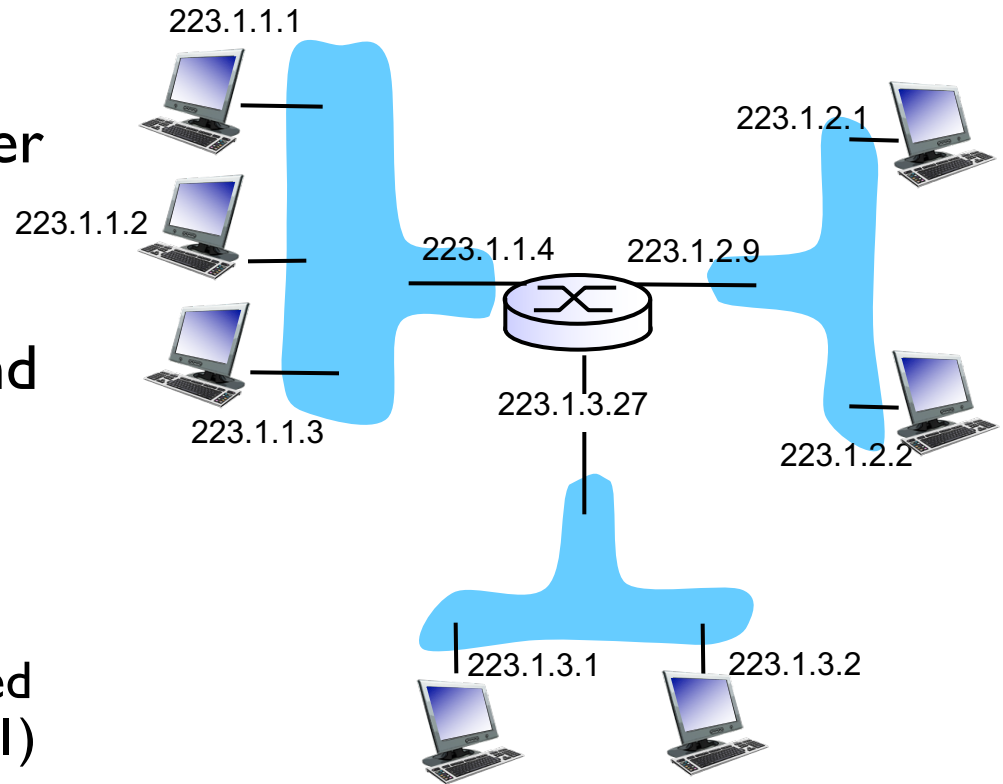
## 4.6 routing in the Internet

- RIP
- OSPF
- BGP

## 4.7 broadcast and multicast routing

# IP addressing: introduction

- ❖ **IP address:** 32-bit identifier for host, 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)
- ❖ **IP addresses associated with each interface**



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



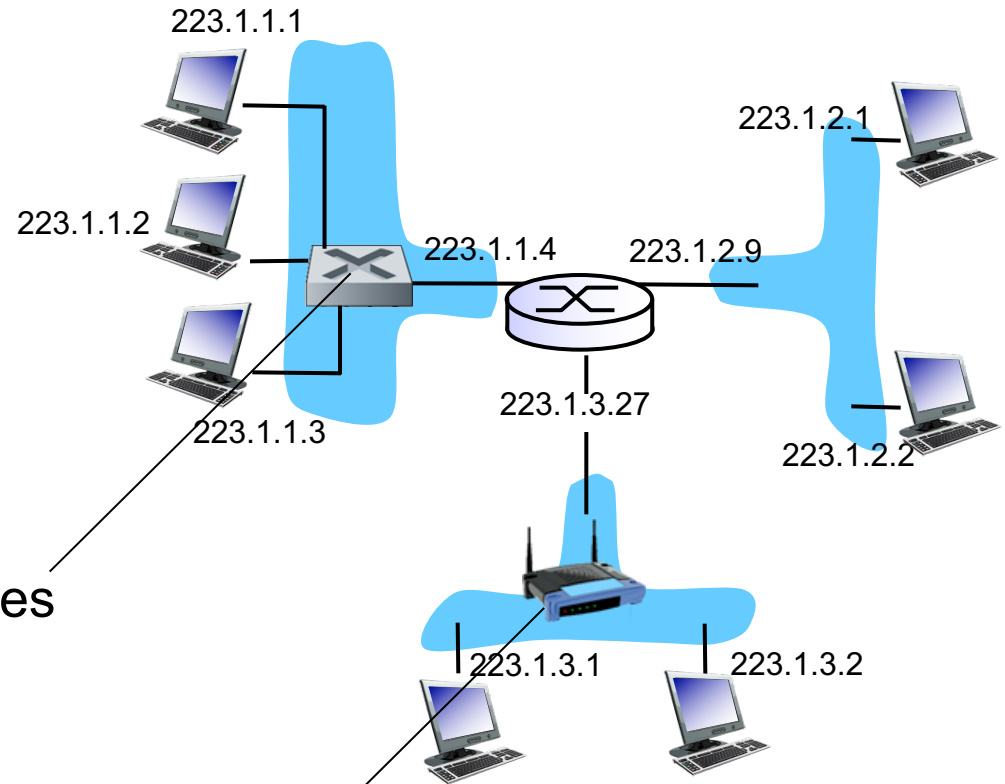
# IP addressing: introduction

*Q: how are interfaces actually connected?*

*A: we'll learn about that in chapter 5, 6.*

*A: wired Ethernet interfaces connected by Ethernet switches*

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



*A: wireless WiFi interfaces connected by WiFi base station*

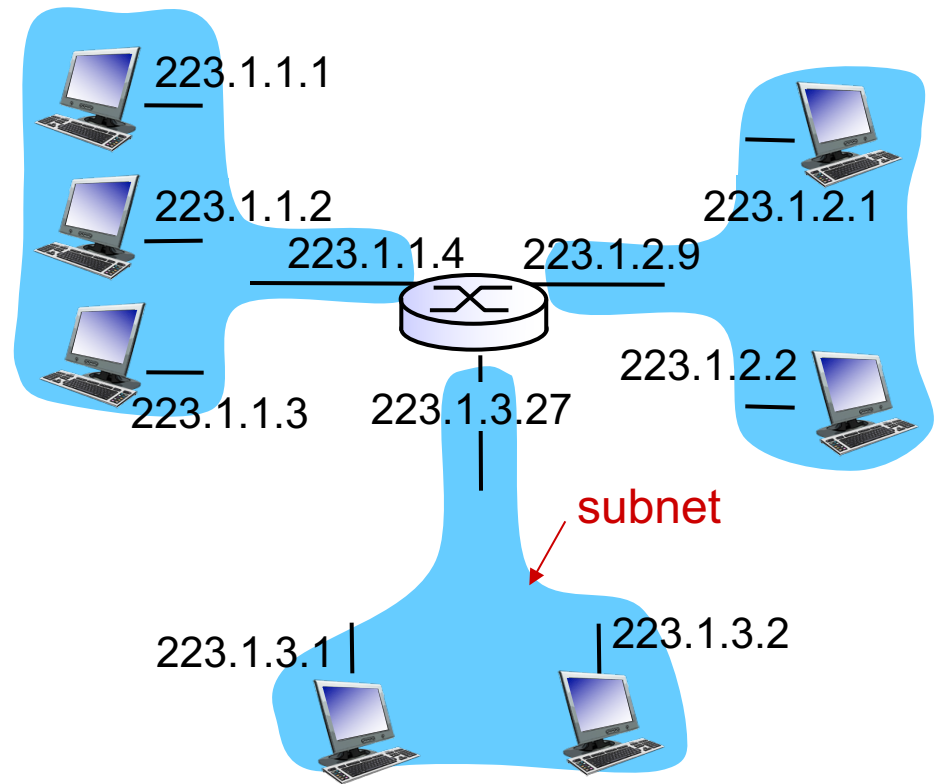
# Subnets

## ❖ IP address:

- subnet part - high order bits
- host part - low order bits

## ❖ *what 's a subnet ?*

- device interfaces with same subnet part of IP address
- can physically reach each other *without intervening router*

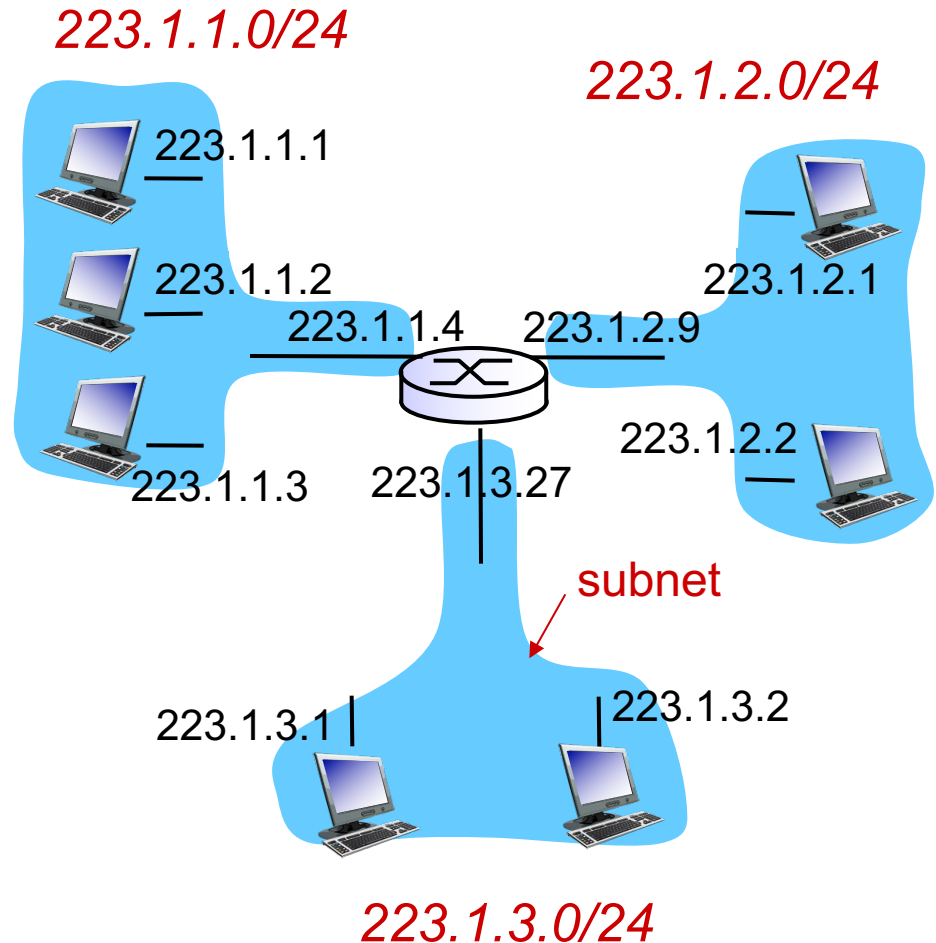


network consisting of 3 subnets

# Subnets

## *recipe*

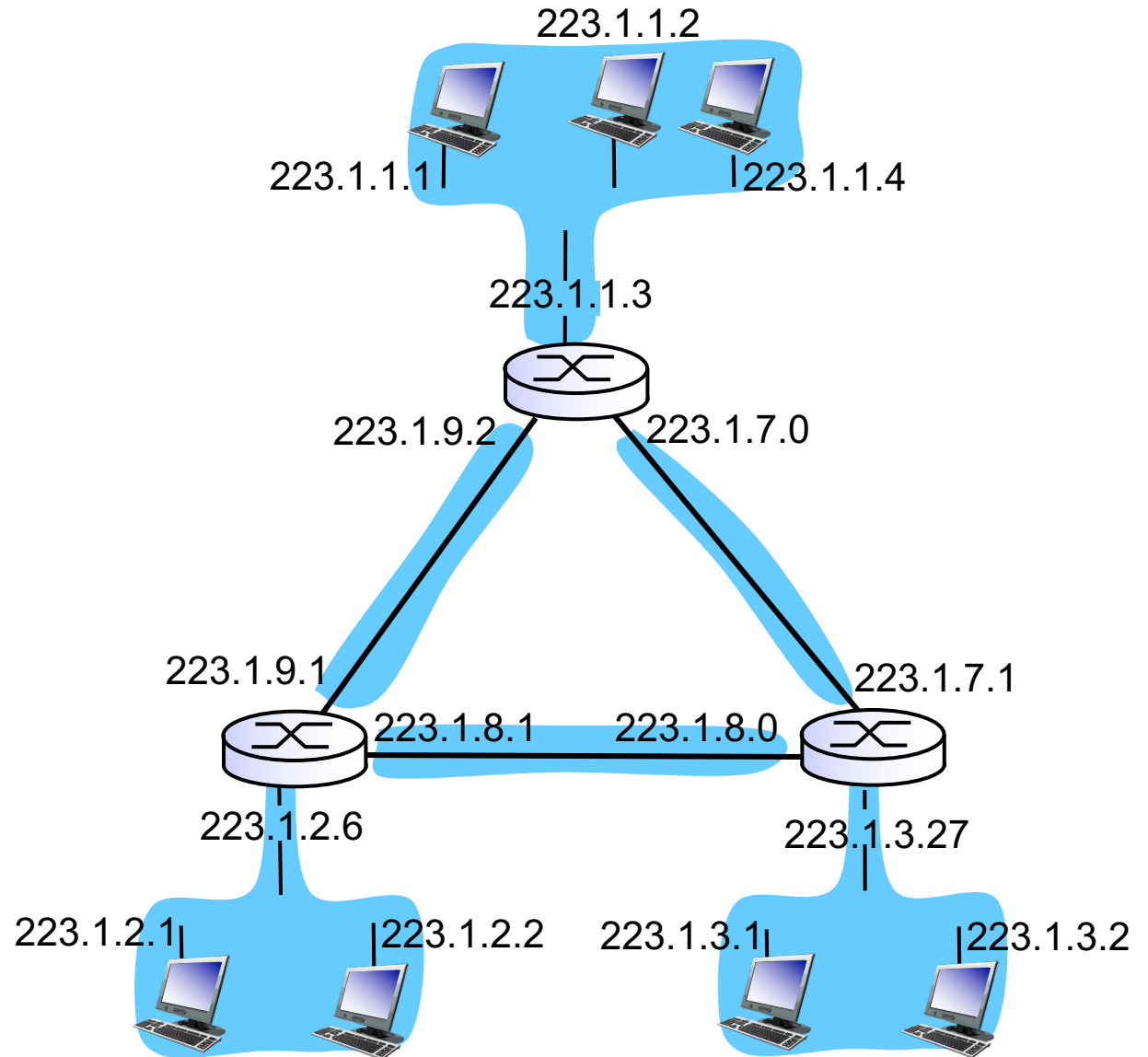
- ❖ to determine the subnets, detach each interface from its host or router, creating islands of isolated networks
- ❖ each isolated network is called a *subnet*



subnet mask: /24

# Subnets

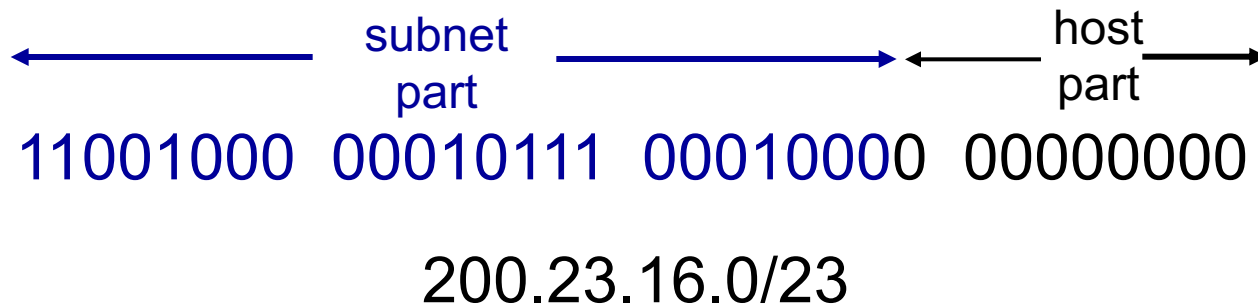
how many?



# IP addressing: CIDR

## CIDR: Classless InterDomain Routing

- 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?

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

- ❖ hard-coded by system admin in a file
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- ❖ **DHCP: Dynamic Host Configuration Protocol:** dynamically get address from as server
  - “plug-and-play”

# DHCP: Dynamic Host Configuration Protocol

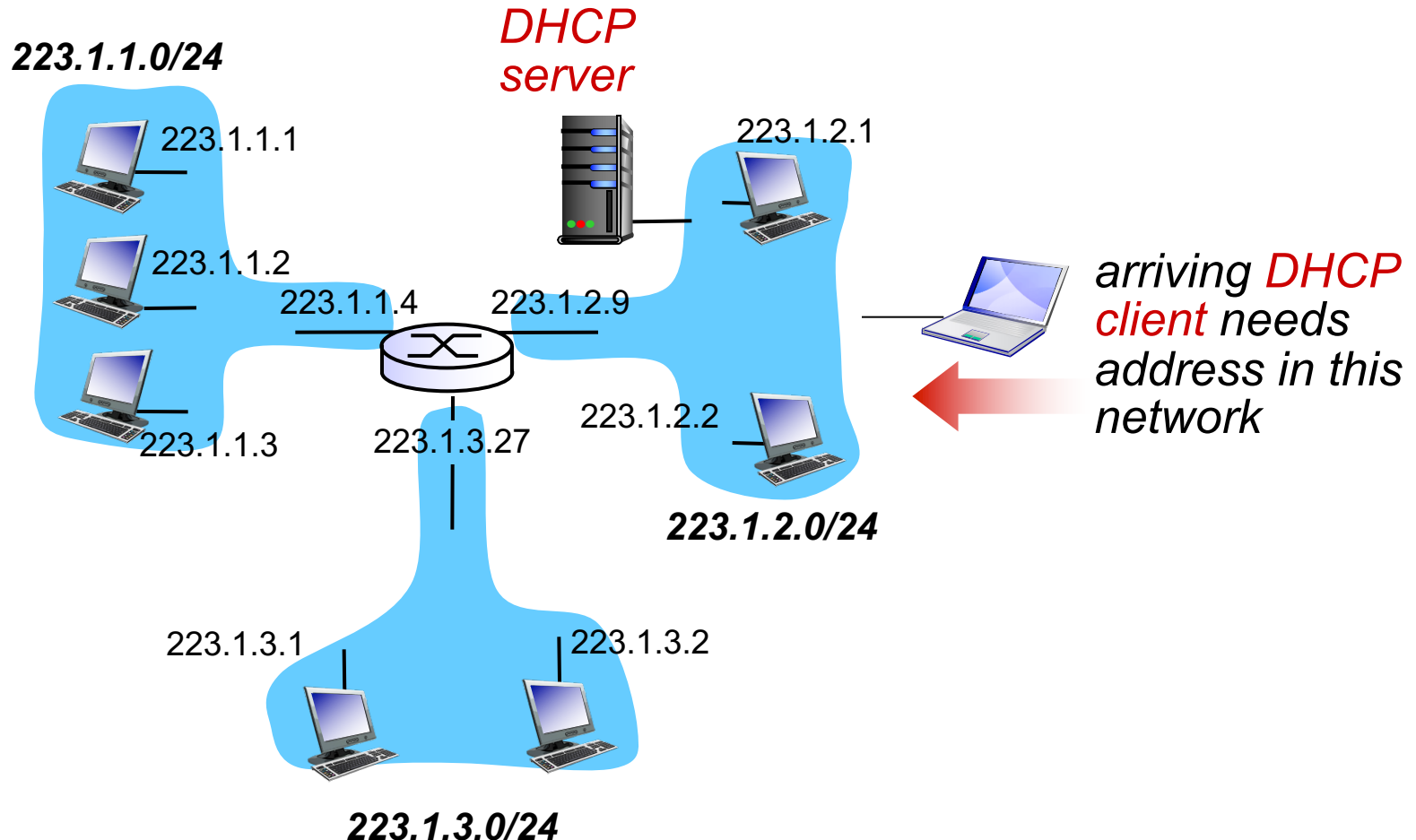
*goal:* allow host to *dynamically* obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/“on”)
- support for mobile users who want to join network (more shortly)

## *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





# DHCP client-server scenario

DHCP server: 223.1.2.5

**DHCP discover**

src : 0.0.0.0, 68  
dest.: 255.255.255.255,67  
yiaddr: 0.0.0.0  
transaction ID: 654

arriving  
client



**DHCP offer**

src: 223.1.2.5, 67  
dest: 255.255.255.255, 68  
yiaddr: 223.1.2.4  
transaction ID: 654  
lifetime: 3600 secs

**DHCP request**

src: 0.0.0.0, 68  
dest.: 255.255.255.255, 67  
yiaddr: 223.1.2.4  
transaction ID: 655  
lifetime: 3600 secs

**DHCP ACK**

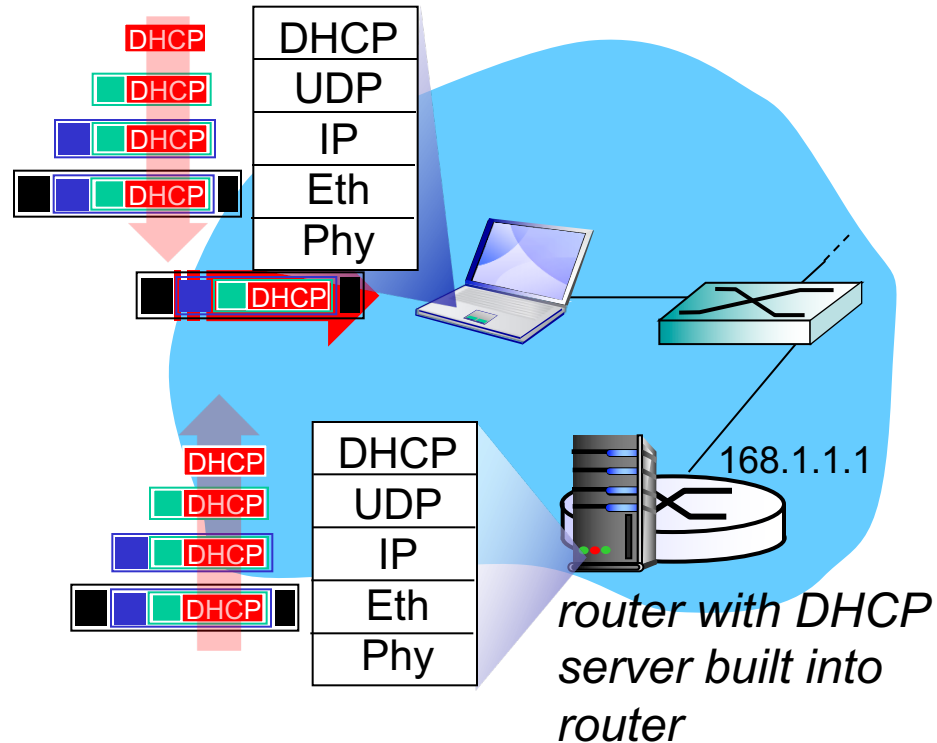
src: 223.1.2.5, 67  
dest: 255.255.255.255, 68  
yiaddr: 223.1.2.4  
transaction ID: 655  
lifetime: 3600 secs

# DHCP: more than IP addresses

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

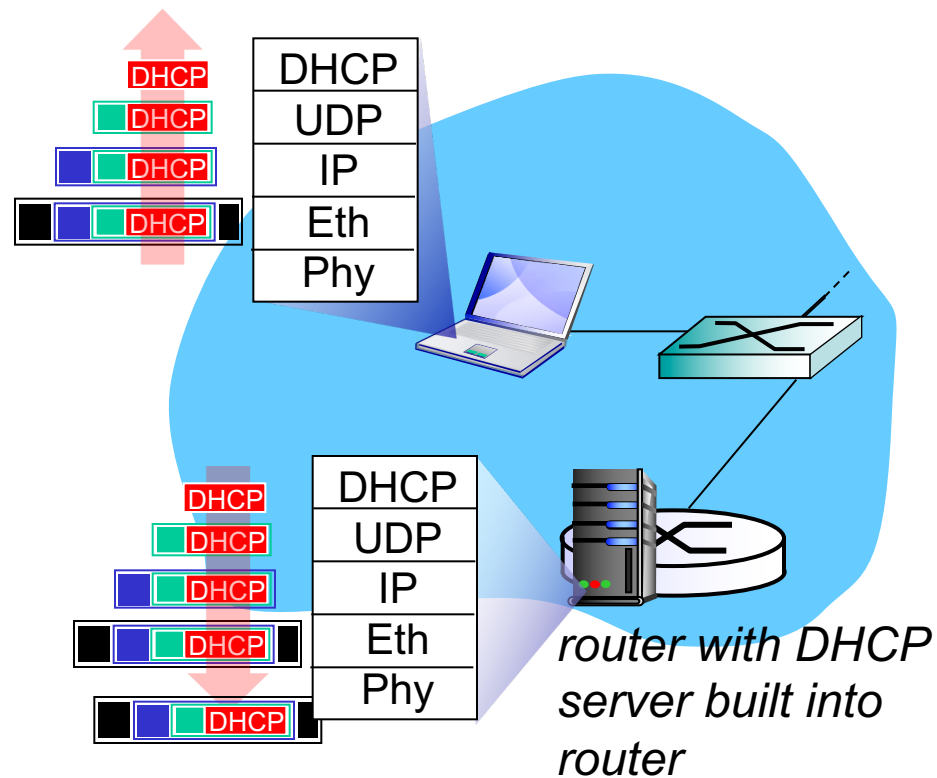
- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

# DHCP: example



- ❖ connecting laptop needs its IP address, addr of first-hop router, addr of DNS server: use DHCP
- ❖ DHCP request encapsulated in UDP, encapsulated in IP, encapsulated in 802.1 Ethernet
- ❖ Ethernet frame broadcast (dest: FFFFFFFF) on LAN, received at router running DHCP server
- ❖ Ethernet demuxed to IP demuxed, UDP demuxed 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
- ❖ encapsulation of DHCP server, frame forwarded to client, demuxing up to DHCP at client
- ❖ client now knows its IP address, name and IP address of DSN server, IP address of its first-hop router

# DHCP: Wireshark output (home LAN)

Message type: **Boot Request (1)**

Hardware type: Ethernet

Hardware address length: 6

Hops: 0

**Transaction ID: 0x6b3a11b7**

Seconds elapsed: 0

Bootp flags: 0x0000 (Unicast)

Client IP address: 0.0.0.0 (0.0.0.0)

Your (client) IP address: 0.0.0.0 (0.0.0.0)

Next server IP address: 0.0.0.0 (0.0.0.0)

Relay agent IP address: 0.0.0.0 (0.0.0.0)

**Client MAC address: Wistron\_23:68:8a (00:16:d3:23:68:8a)**

Server host name not given

Boot file name not given

Magic cookie: (OK)

Option: (t=53,l=1) **DHCP Message Type = DHCP Request**

Option: (61) Client identifier

Length: 7; Value: 010016D323688A;

Hardware type: Ethernet

Client MAC address: Wistron\_23:68:8a (00:16:d3:23:68:8a)

Option: (t=50,l=4) Requested IP Address = 192.168.1.101

Option: (t=12,l=5) Host Name = "nomad"

**Option: (55) Parameter Request List**

Length: 11; Value: 010F03062C2E2F1F21F92B

**1 = Subnet Mask; 15 = Domain Name**

**3 = Router; 6 = Domain Name Server**

44 = NetBIOS over TCP/IP Name Server

.....

request

Message type: **Boot Reply (2)**

Hardware type: Ethernet

Hardware address length: 6

Hops: 0

**Transaction ID: 0x6b3a11b7**

Seconds elapsed: 0

Bootp flags: 0x0000 (Unicast)

**Client IP address: 192.168.1.101 (192.168.1.101)**

Your (client) IP address: 0.0.0.0 (0.0.0.0)

**Next server IP address: 192.168.1.1 (192.168.1.1)**

Relay agent IP address: 0.0.0.0 (0.0.0.0)

Client MAC address: Wistron\_23:68:8a (00:16:d3:23:68:8a)

Server host name not given

Boot file name not given

Magic cookie: (OK)

**Option: (t=53,l=1) DHCP Message Type = DHCP ACK**

**Option: (t=54,l=4) Server Identifier = 192.168.1.1**

**Option: (t=1,l=4) Subnet Mask = 255.255.255.0**

**Option: (t=3,l=4) Router = 192.168.1.1**

**Option: (6) Domain Name Server**

Length: 12; Value: 445747E2445749F244574092;

IP Address: 68.87.71.226;

IP Address: 68.87.73.242;

IP Address: 68.87.64.146

**Option: (t=15,l=20) Domain Name = "hsd1.ma.comcast.net."**

reply

# IP addresses: how to get one?

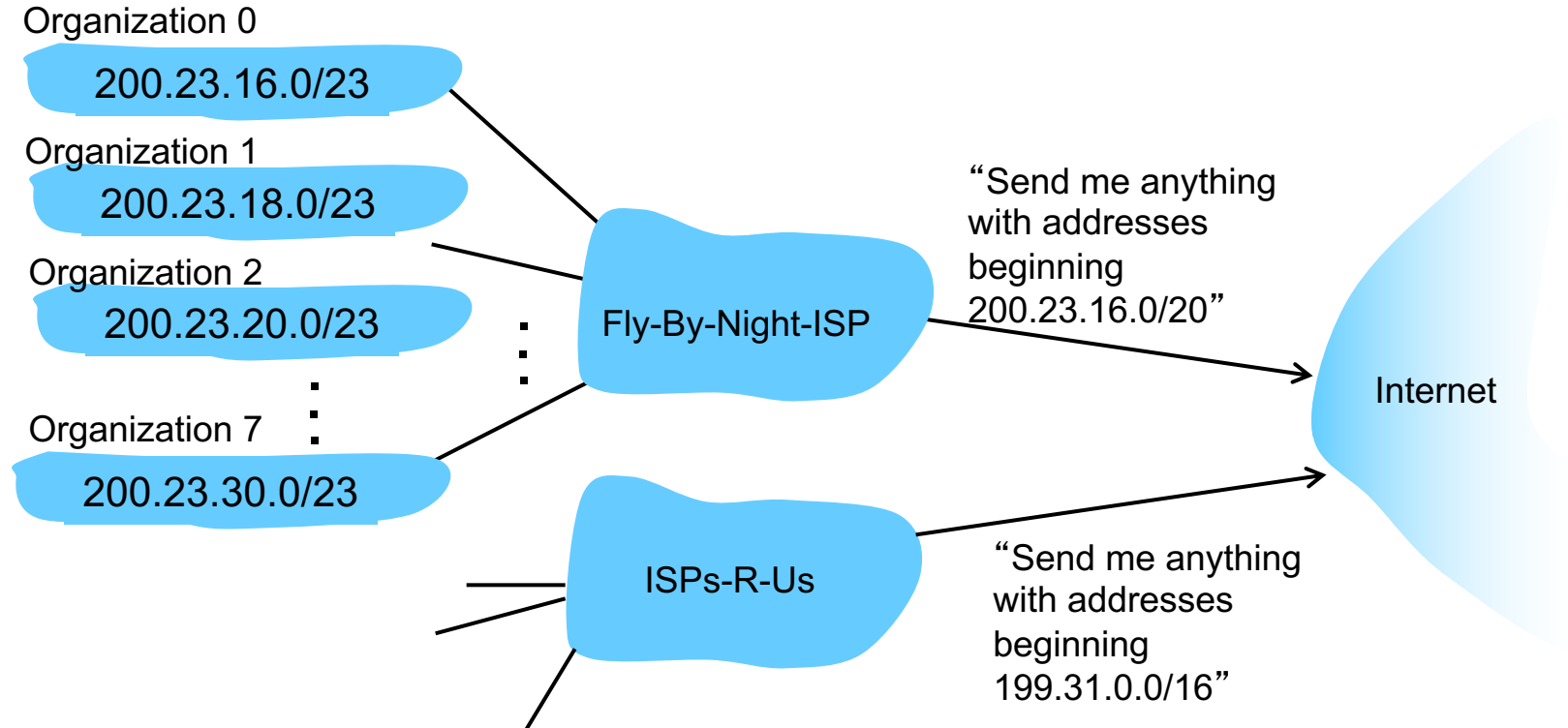
**Q:** how does *network* get subnet part of IP addr?

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

|                |  |                |
|----------------|--|----------------|
| ISP's block    | <u>11001000 00010111 00010000</u> 00000000 | 200.23.16.0/20 |
| Organization 0 | <u>11001000 00010111 00010000</u> 00000000 | 200.23.16.0/23 |
| Organization 1 | <u>11001000 00010111 00010010</u> 00000000 | 200.23.18.0/23 |
| Organization 2 | <u>11001000 00010111 00010100</u> 00000000 | 200.23.20.0/23 |
| ...            | .....                                      | ....           |
| Organization 7 | <u>11001000 00010111 00011110</u> 00000000 | 200.23.30.0/23 |

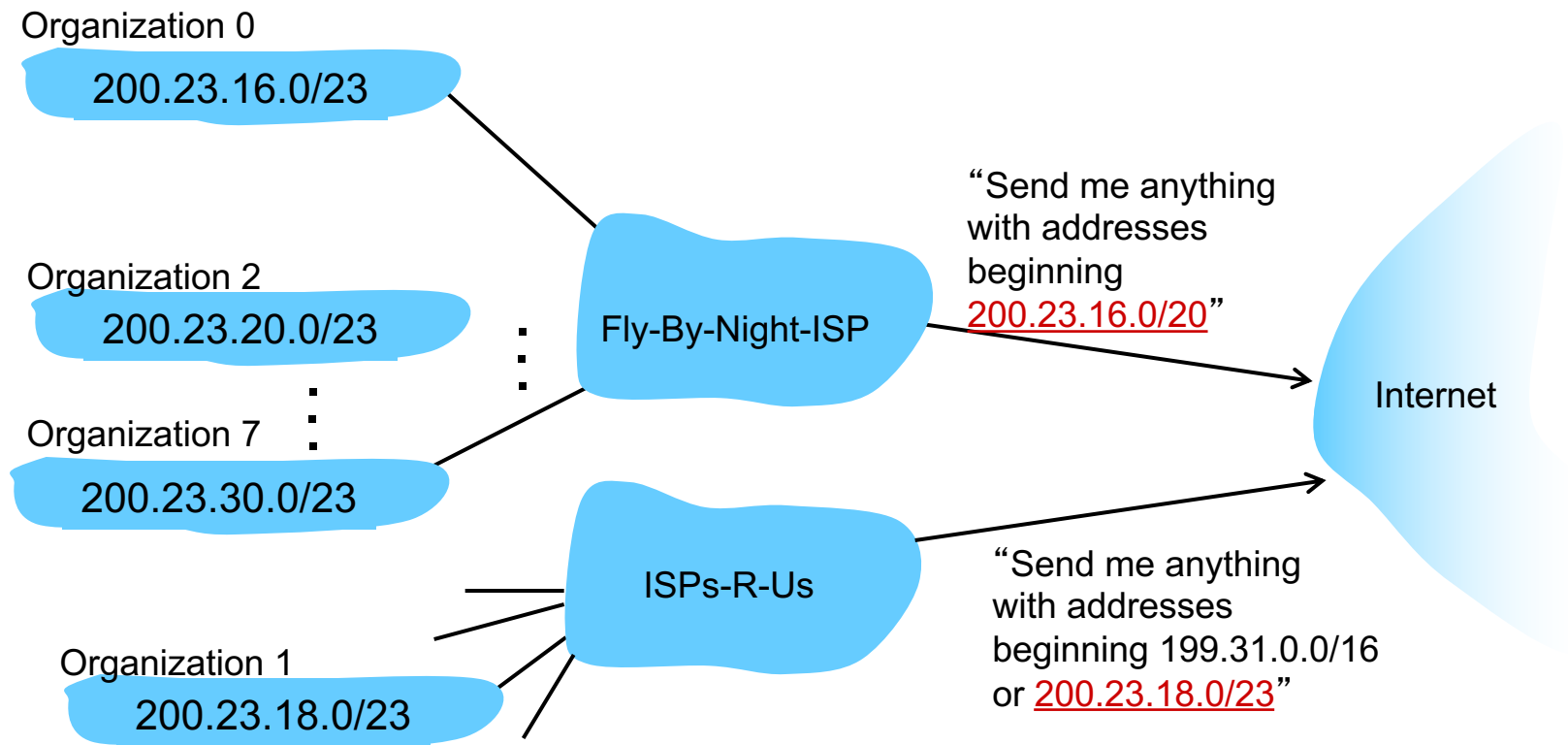
# Hierarchical addressing: route aggregation

hierarchical addressing allows efficient advertisement of routing information:



# Hierarchical addressing: more specific routes

ISPs-R-Us has a more specific route to Organization 1





# IP addressing: the last word...

**Q:** how does an ISP get block of addresses?

**A: ICANN:** Internet Corporation for Assigned Names and Numbers <http://www.icann.org/>

- allocates addresses
- manages DNS
- assigns domain names, resolves disputes