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
- NAT

4.5 routing algorithms

- link state
- distance vector
- hierarchical routing

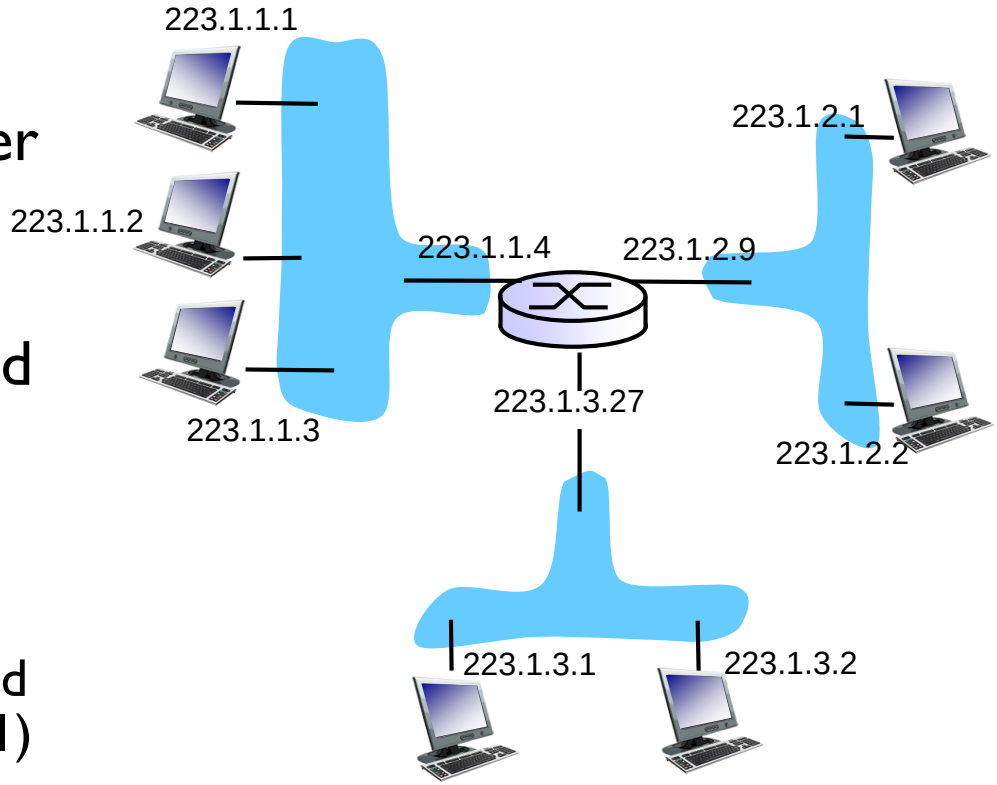
4.6 routing in the Internet

- RIP
- OSPF
- BGP

4.7 broadcast and multicast routing

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*



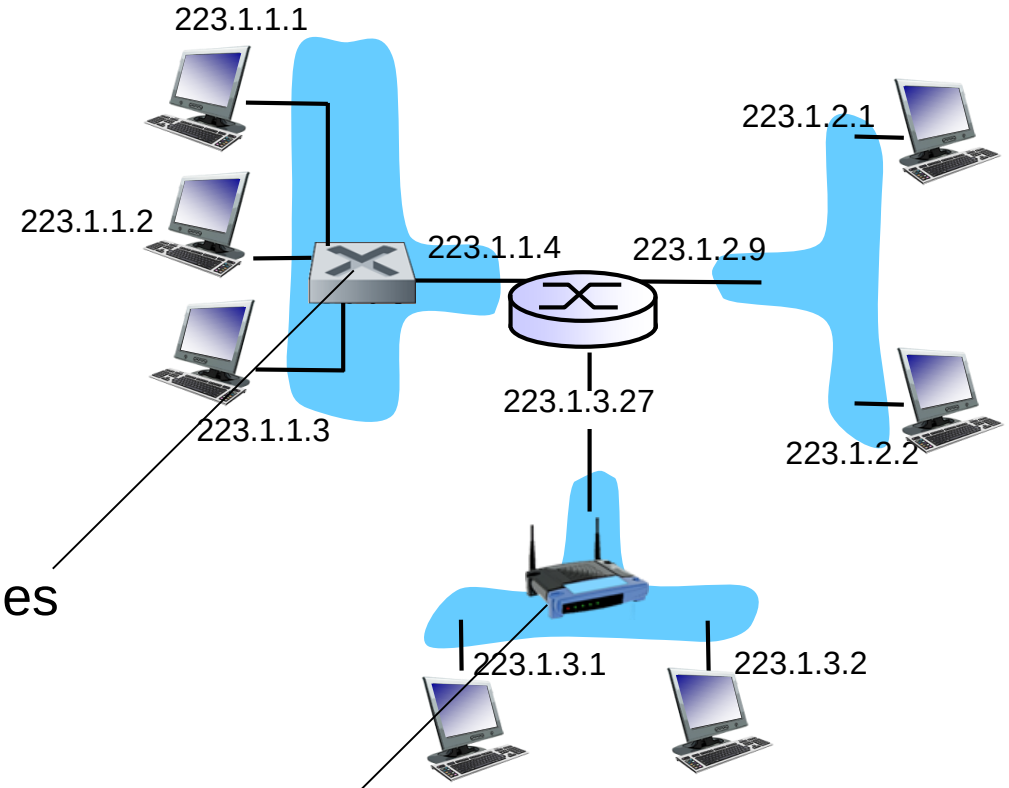
223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

IP addressing: introduction

Q: how are interfaces actually connected?

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



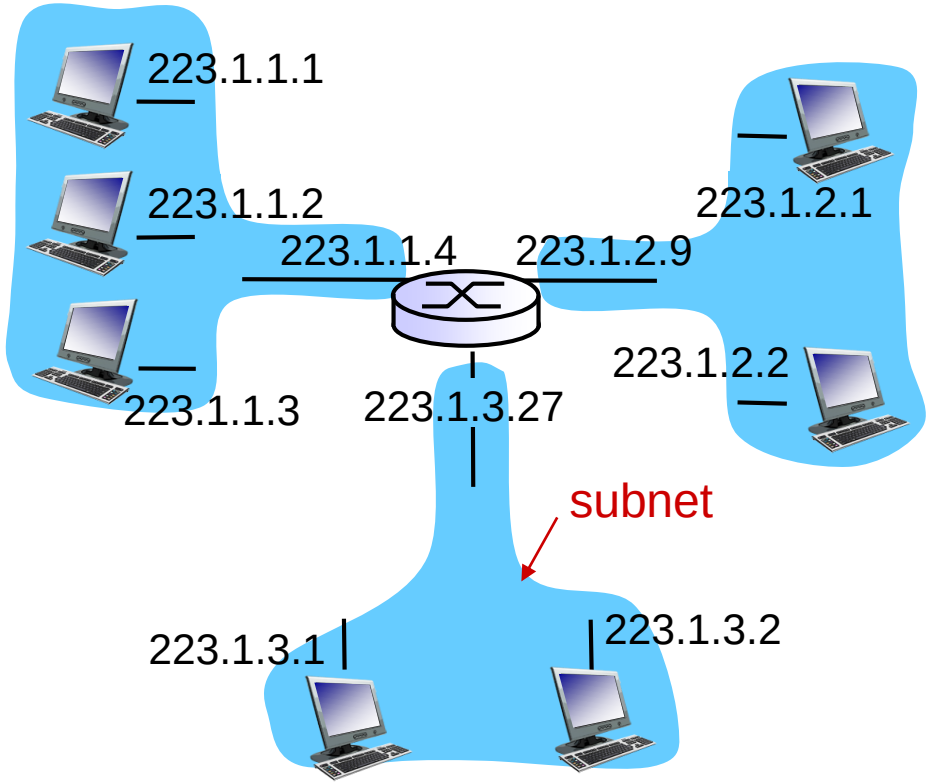
A: wired Ethernet interfaces connected by Ethernet switches

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*

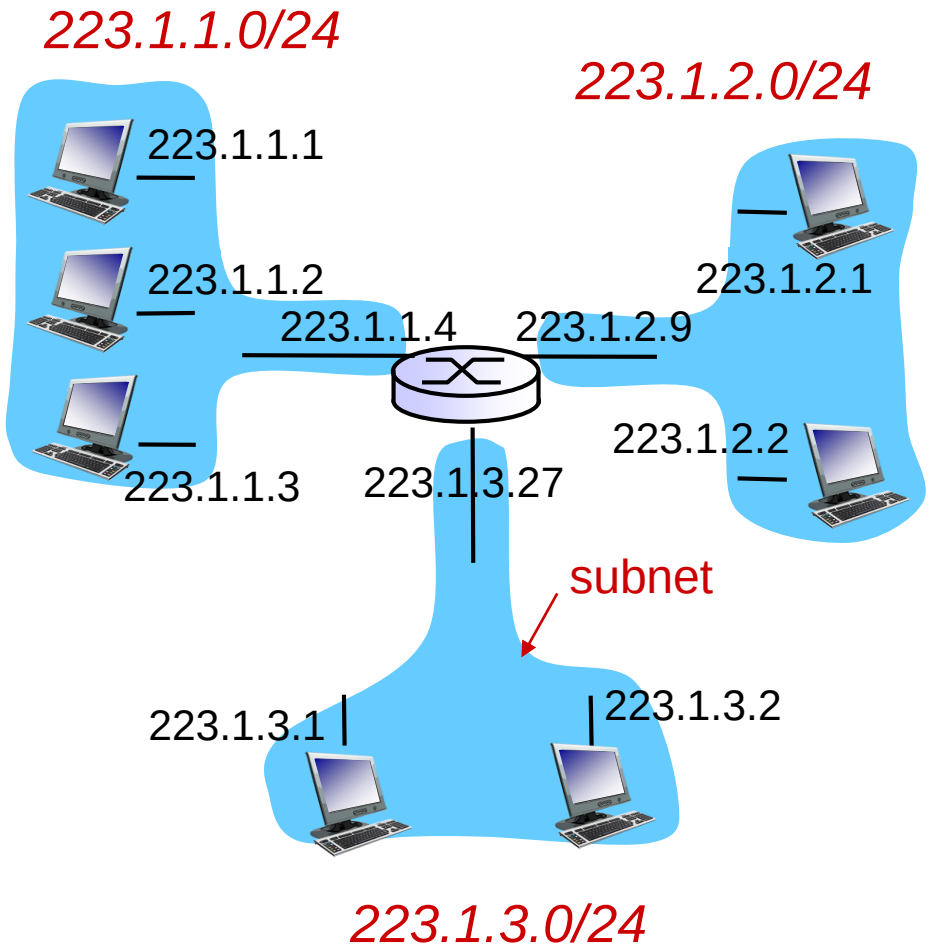


network consisting of 3 subnets

Subnets

recipe

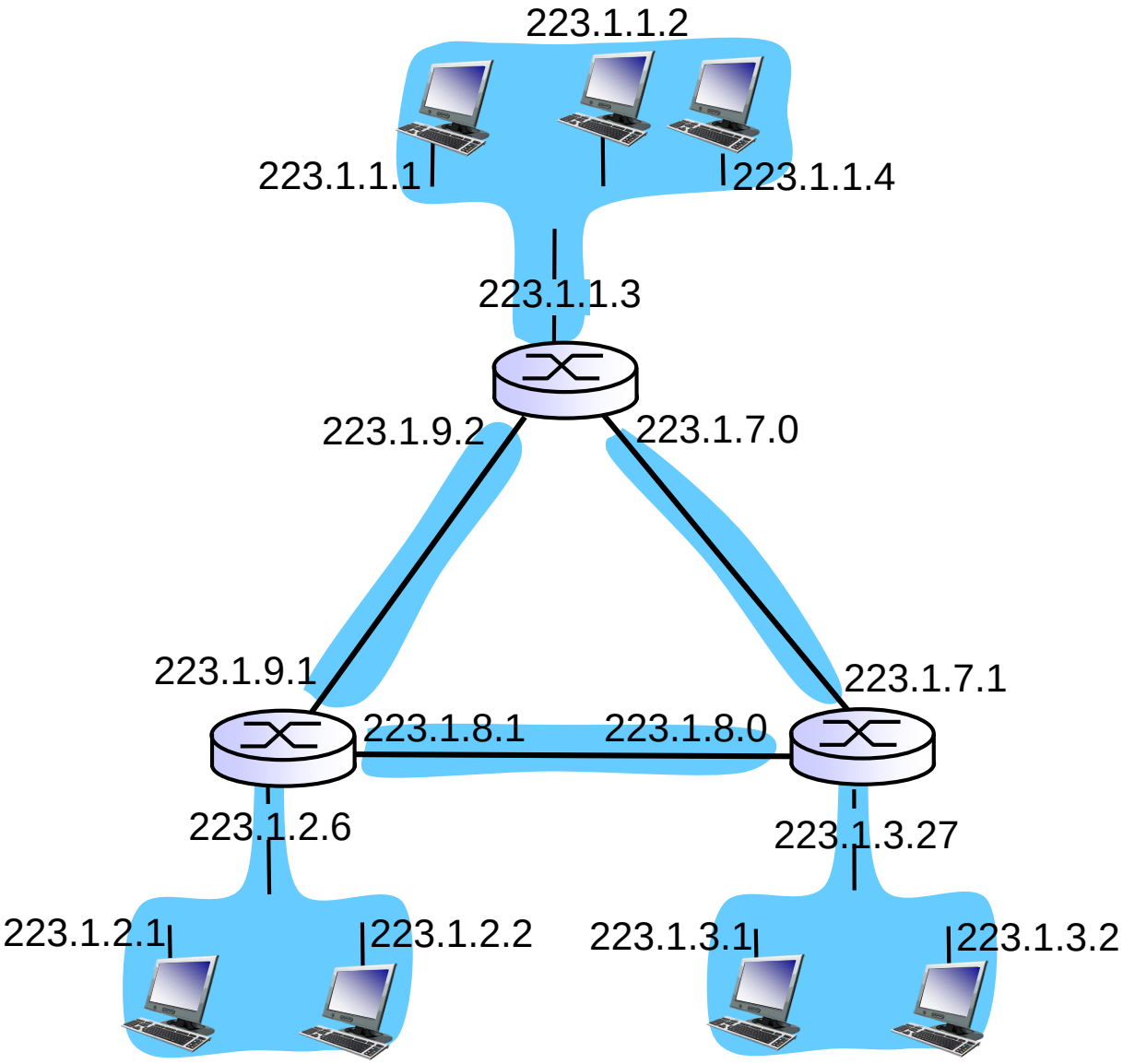
- to determine the subnets, detach each interface from its host or router, creating islands of isolated networks
- each isolated network is called a *subnet*



subnet mask: /24

Subnets

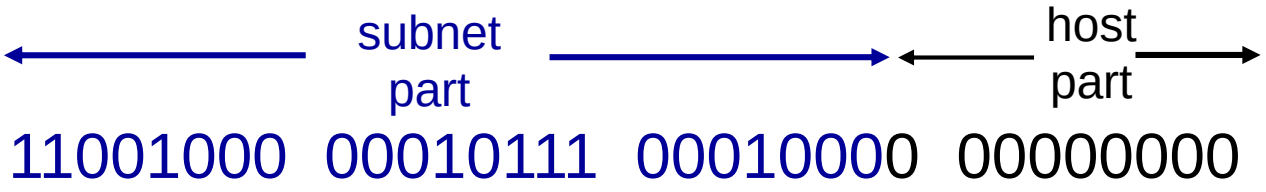
how many?



IP addressing: CIDR

CIDR: Classless InterDomain Routing

- Replaces older "class" based system (A, B, C, D)
- subnet portion of address of *arbitrary length*
- address format: a.b.c.d/x, where x is # bits in subnet portion of address



200.23.16.0/23

CIDR Subnets and masks

192.168.1.0/24

- For this particular address, the first 24 bits are the network prefix used for routing:
  - 192.168.1 =
    11000000 10101000 00000001
- We write this prefix like this:
  - 192.168.1.0 =
    11000000 10101000 00000001 00000000
- The remaining 8 bits are used for *host addressing*:
  - 192.168.1.1 - 192.168.1.254
  - .0 and .255 are special reserved addresses.

CIDR Subnets and masks

- The subnet mask is a binary number that, when applied by a bitwise AND operation to *any* IP address in the network, yields the routing prefix.
- 192.168.1.0/24 Network prefix has the corresponding subnet mask of 255.255.255.0.
- Example:
  - 192 . 168 . 1 . 10
    11000000 10101000 00000001 00001010
  - 255 . 255 . 255 . 0
    11111111 11111111 11111111 00000000
  - AND
    11000000 10101000 00000001 00001010
    11111111 11111111 11111111 00000000

    11000000 10101000 00000001 00000000 = 192.168.1.0

Subnets and masks

255.255.255.255	11111111.11111111.11111111.11111111	/32	**Host (single addr)**
255.255.255.254	11111111.11111111.11111111.11111110	/31	**Unuseable**
255.255.255.252	11111111.11111111.11111111.11111100	/30	2 useable
255.255.255.248	11111111.11111111.11111111.11111000	/29	6 useable
255.255.255.240	11111111.11111111.11111111.11110000	/28	14 useable
255.255.255.224	11111111.11111111.11111111.11100000	/27	30 useable
255.255.255.192	11111111.11111111.11111111.11000000	/26	62 useable
255.255.255.128	11111111.11111111.11111111.10000000	/25	126 useable
255.255.255.0	11111111.11111111.11111111.00000000	/24	"Class C" **254 useable**
255.255.254.0	11111111.11111111.11111110.00000000	/23	2 Class C's
255.255.252.0	11111111.11111111.11111100.00000000	/22	4 Class C's
255.255.248.0	11111111.11111111.11111000.00000000	/21	8 Class C's
255.255.240.0	11111111.11111111.11110000.00000000	/20	16 Class C's
255.255.224.0	11111111.11111111.11100000.00000000	/19	32 Class C's
255.255.192.0	11111111.11111111.11000000.00000000	/18	64 Class C's
255.255.128.0	11111111.11111111.10000000.00000000	/17	128 Class C's
255.255.0.0	11111111.11111111.00000000.00000000	/16	"Class B"
255.254.0.0	11111111.11111110.00000000.00000000	/15	2 Class B's
255.252.0.0	11111111.11111100.00000000.00000000	/14	4 Class B's
255.248.0.0	11111111.11111000.00000000.00000000	/13	8 Class B's
255.240.0.0	11111111.11110000.00000000.00000000	/12	16 Class B's
255.224.0.0	11111111.11100000.00000000.00000000	/11	32 Class B's
255.192.0.0	11111111.11000000.00000000.00000000	/10	64 Class B's
255.128.0.0	11111111.10000000.00000000.00000000	/9	128 Class B's
255.0.0.0	11111111.00000000.00000000.00000000	/8	"Class A"
254.0.0.0	11111110.00000000.00000000.00000000	/7	
252.0.0.0	11111100.00000000.00000000.00000000	/6	
248.0.0.0	11111000.00000000.00000000.00000000	/5	
240.0.0.0	11110000.00000000.00000000.00000000	/4	
224.0.0.0	11100000.00000000.00000000.00000000	/3	
192.0.0.0	11000000.00000000.00000000.00000000	/2	
128.0.0.0	10000000.00000000.00000000.00000000	/1	
0.0.0.0	00000000.00000000.00000000.00000000	/0	**IP space**

IP addresses: how to get one?

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

- Statically assigned - hard-coded by system admin:
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- Dynamically assigned:
  - DHCP: Dynamic Host Configuration Protocol: dynamically get address from a server
  - "plug-and-play"

DHCP: Dynamic Host Configuration Protocol

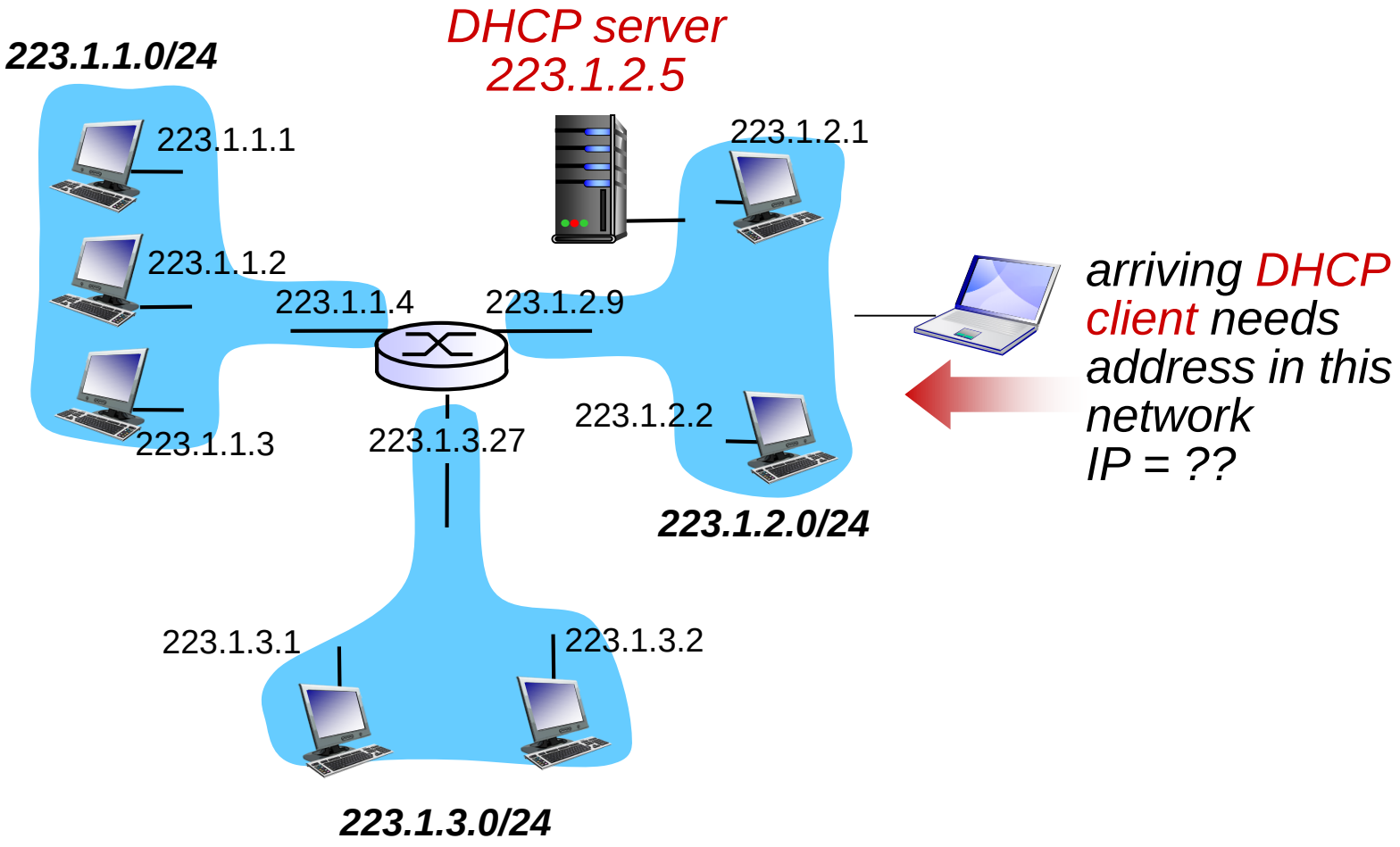
goal: allow host to *dynamically* obtain its IP address from network server when it joins network, and keep it for a time (a "lease")

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected or "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

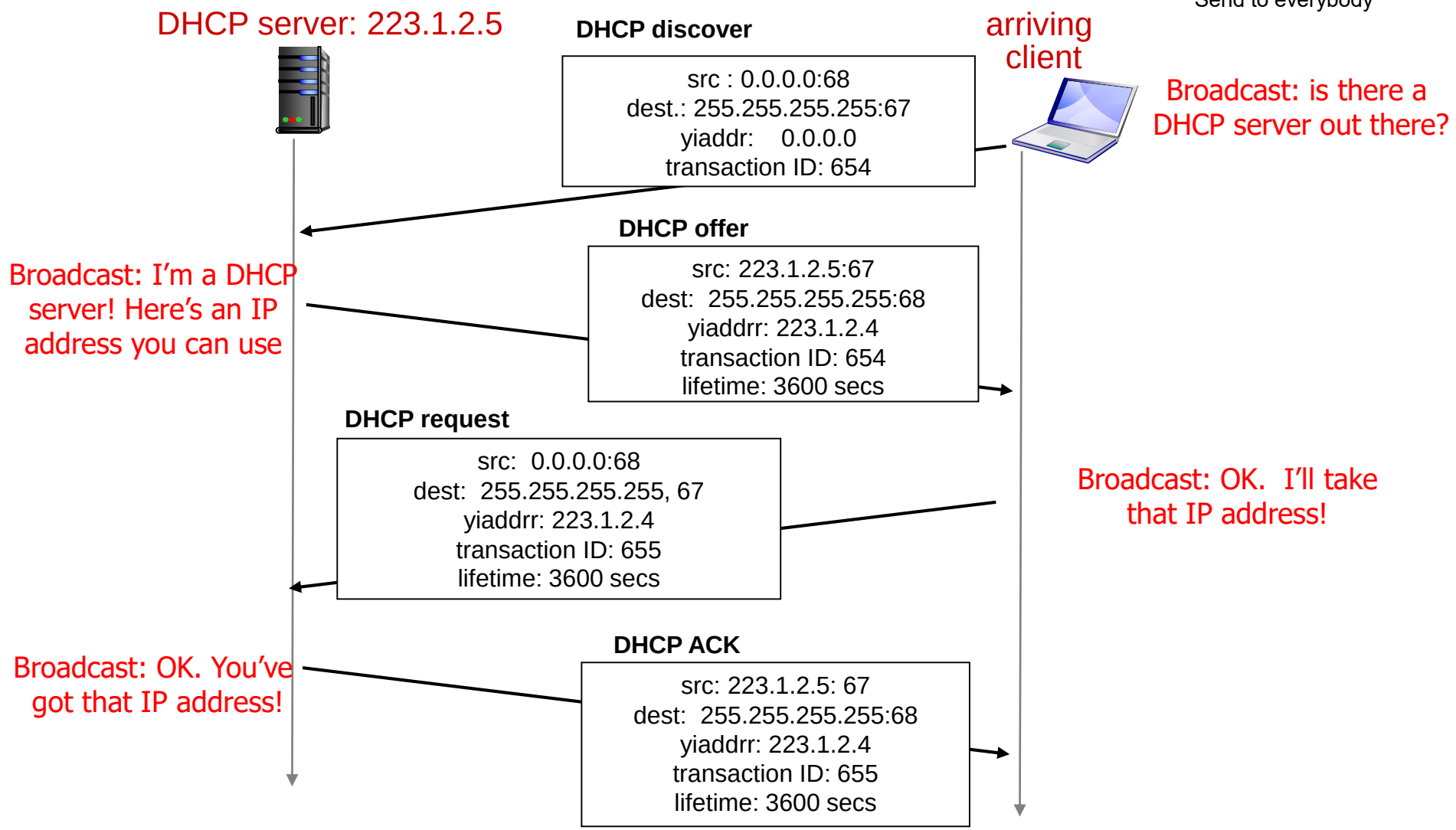
DHCP client-server scenario



DHCP client-server scenario

0.0.0.0 =
"I don't have an address"

255.255.255.255 =
"Send to everybody"



DHCP: Dynamic Host Configuration Protocol

Homework note:

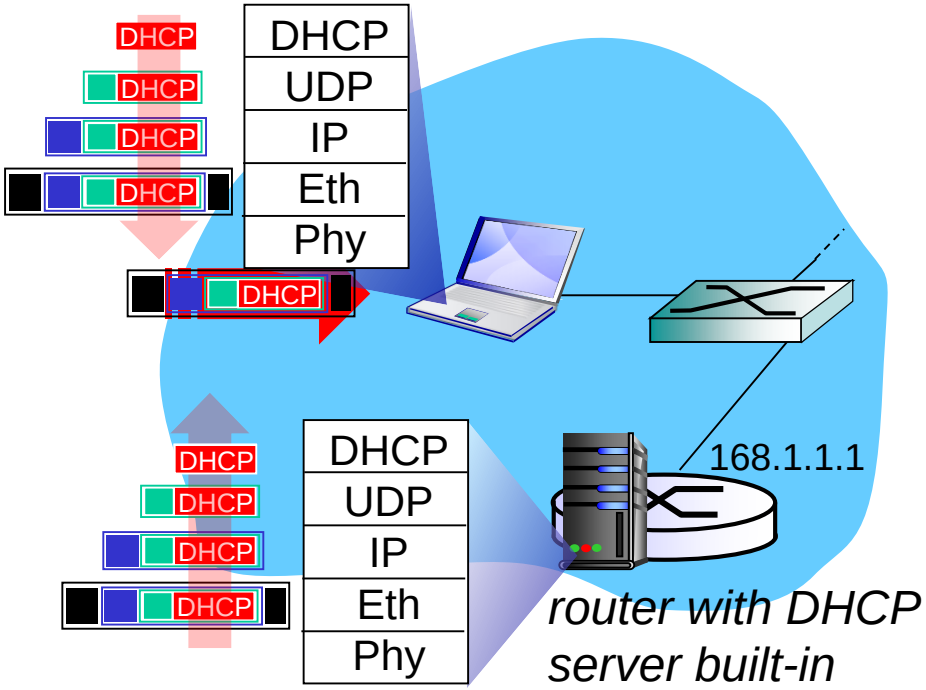
- Normallis, the server's HDCP Offer packet is a broadcast packet
- However, it might be unicast addressed to the client IP address offered in the selfsame packet (as well as the MAC address of the requesting client), even though the client hasn't accepted the IP address yet
- Happens if the DHCP Discover packet (sent by the client) has the broadcast flag set to off

DHCP: more than IP addresses

DHCP can return more than just allocated IPv4 address on subnet:

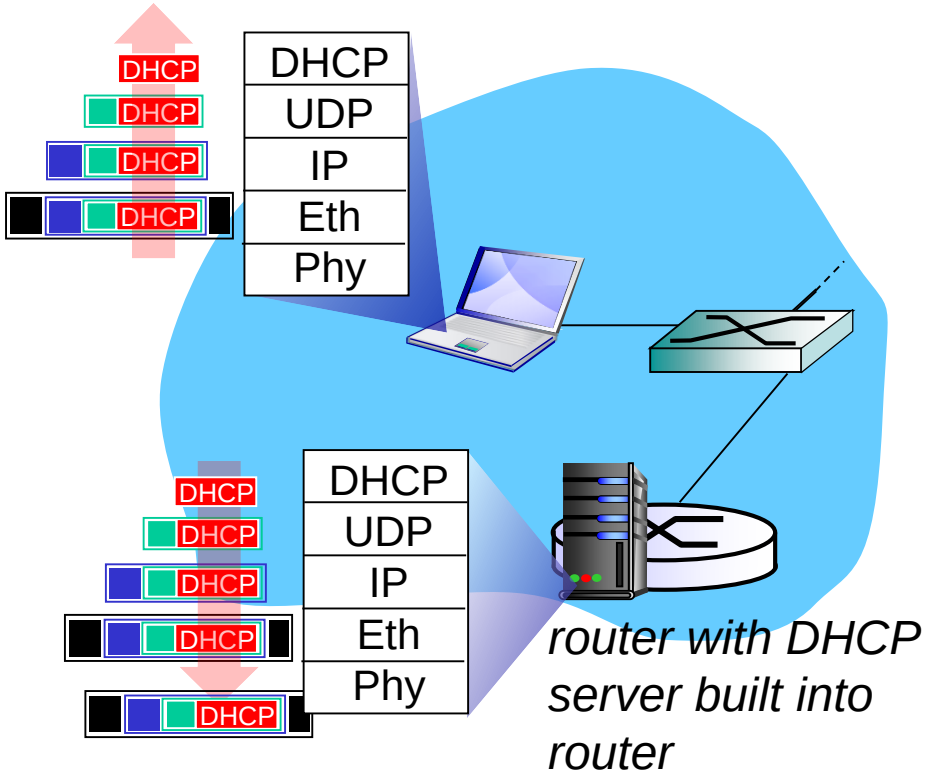
- address of first-hop router for client (default gateway)
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)
- Windows Domain name
- IPv6 addressing information

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: FFFFFFFFFFFF) 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)

request

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
    ……

reply

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."

IP addresses: how to get one?

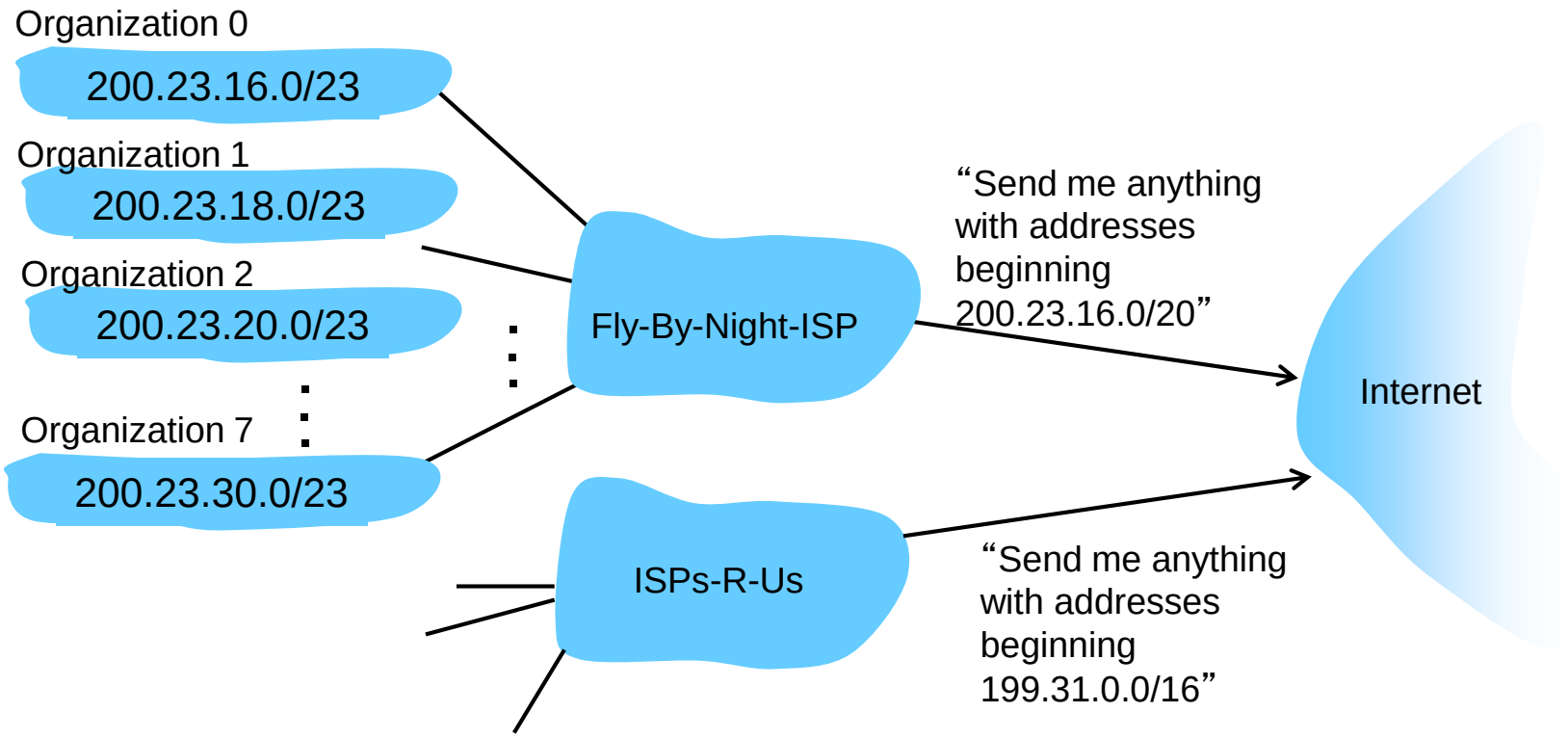
Q: how does *network* get subnet part of IP addr?

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

ISP's block	11001000 00010111 00010000	00000000	200.23.16.0/20
Organization 0	11001000 00010111 0001000**0**	00000000	200.23.16.0/23
Organization 1	11001000 00010111 0001001**0**	00000000	200.23.18.0/23
Organization 2	11001000 00010111 0001010**0**	00000000	200.23.20.0/23
...	.....	....	....
Organization 7	11001000 00010111 0001111**0**	00000000	200.23.30.0/23

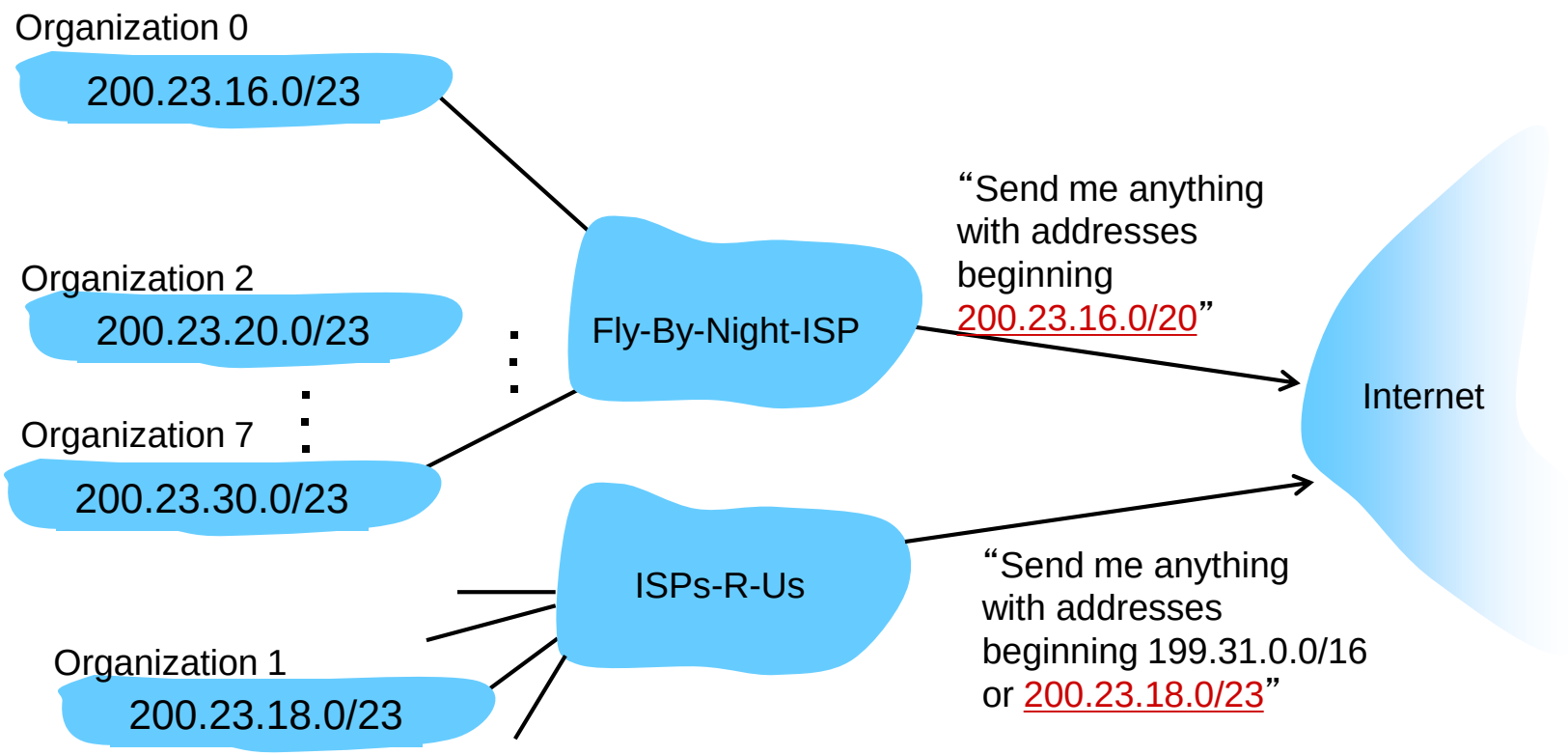
Hierarchical addressing: route aggregation

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
- There are no more IPv4 addresses to give out!

Who's got them…

Companies orgs with IPv4 /8 blocks from IANA – Internet Assigned Numbers Authority (a dept. of ICANN)

Owner	/8 Blocks	~IP addresses
US Military (Department of Defense etc.)	12	201 million
Level 3 Communications, Inc.	2	33 million
Hewlett-Packard	2	33 million
AT&T Bell Laboratories (Alcatel-Lucent)	1	16 million
AT&T Global Network Services	1	16 million
Bell-Northern Research (Nortel Networks)	1	16 million
Amateur Radio Digital Communications	1	16 million
Apple Computer Inc.	1	16 million
Cap Debis CCS (Mercedes-Benz)	1	16 million
Computer Sciences Corporation	1	16 million
Deparment of Social Security of UK	1	16 million
E.I. duPont de Nemours and Co., Inc.	1	16 million
Eli Lily and Company	1	16 million
Ford Motor Company	1	16 million
General Electric Company	1	16 million
Halliburton Company	1	16 million
IBM	1	16 million
Interop Show Network	1	16 million
Merck and Co., Inc.	1	16 million
MERIT Computer Network	1	16 million
Massachusetts Institute of Technology	1	16 million
Performance Systems International (Cogent)	1	16 million
Prudential Equity Group, LLC	1	16 million
Société Internationale De Telecommunications Aero.	1	16 million
U.S. Postal Service	1	16 million
UK Ministry of Defence	1	16 million
Xerox Corporation	1	16 million

http://royal.pingdom.com/2008/02/13/where-did-all-the-ip-numbers-go-the-us-department-of-defense-has-them/