CS 43: Computer Networks

The Network Layer

November 11, 2026



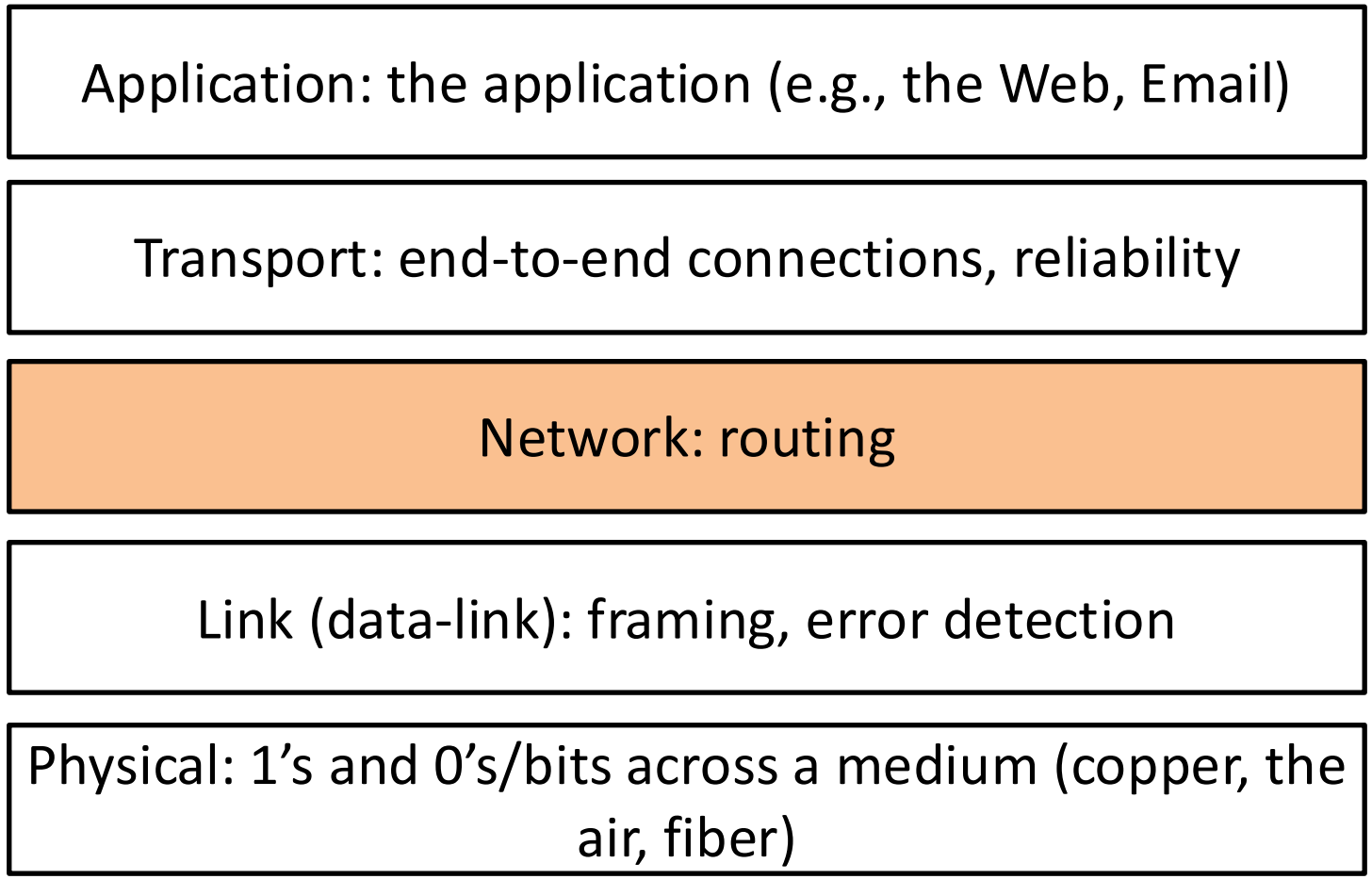
Reading Quiz
(graded for correctness)

Put devices away

Note: Reading quiz slides will have an orange border.

End of Reading Quiz!

The Network Layer!

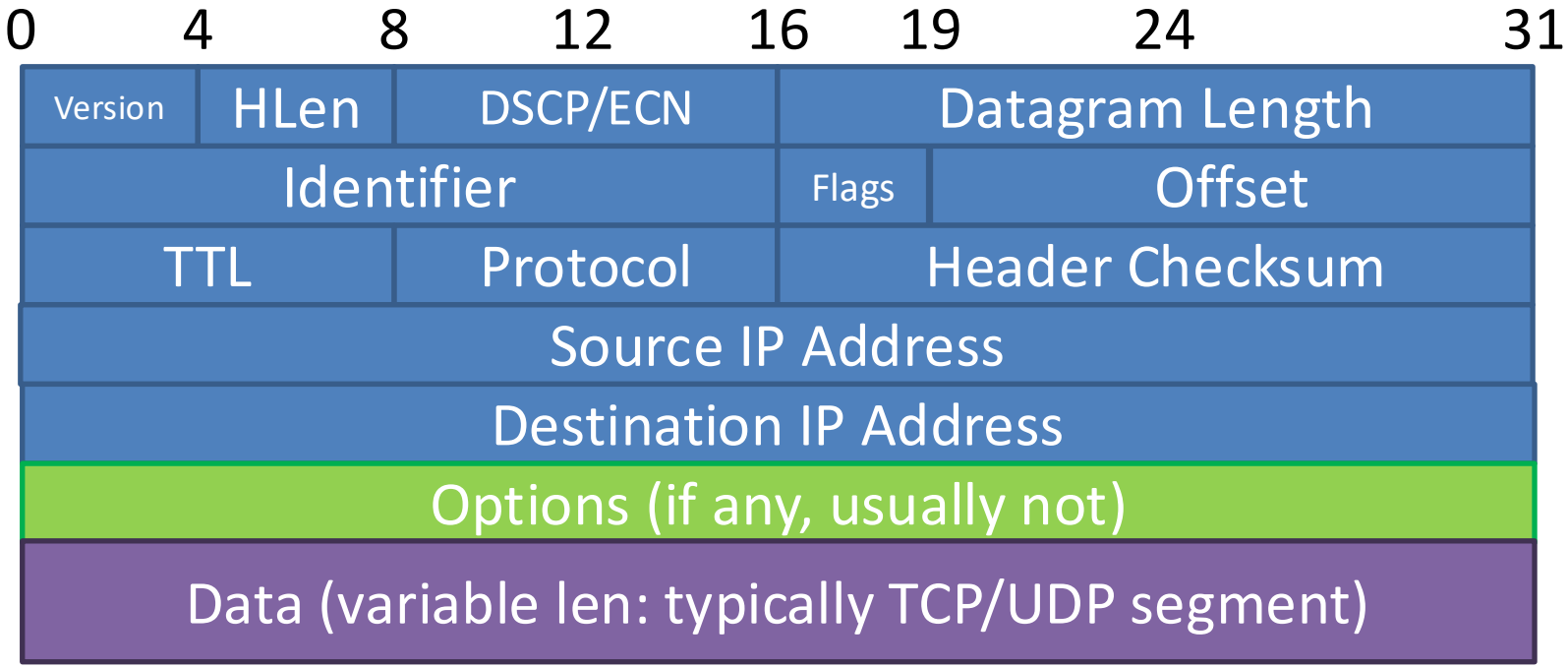


Today

- What is a subnet?
- How to organizations get assigned blocks of IP addresses?
- DHCP: How does a computer joining a network get assigned an IP address?
- How does hierarchical IP addressing allow for efficient routing?

IP Datagrams

- IP Datagrams are like a letter
  - Totally self-contained
  - Include all necessary addressing information
  - No advanced setup of connections or circuits

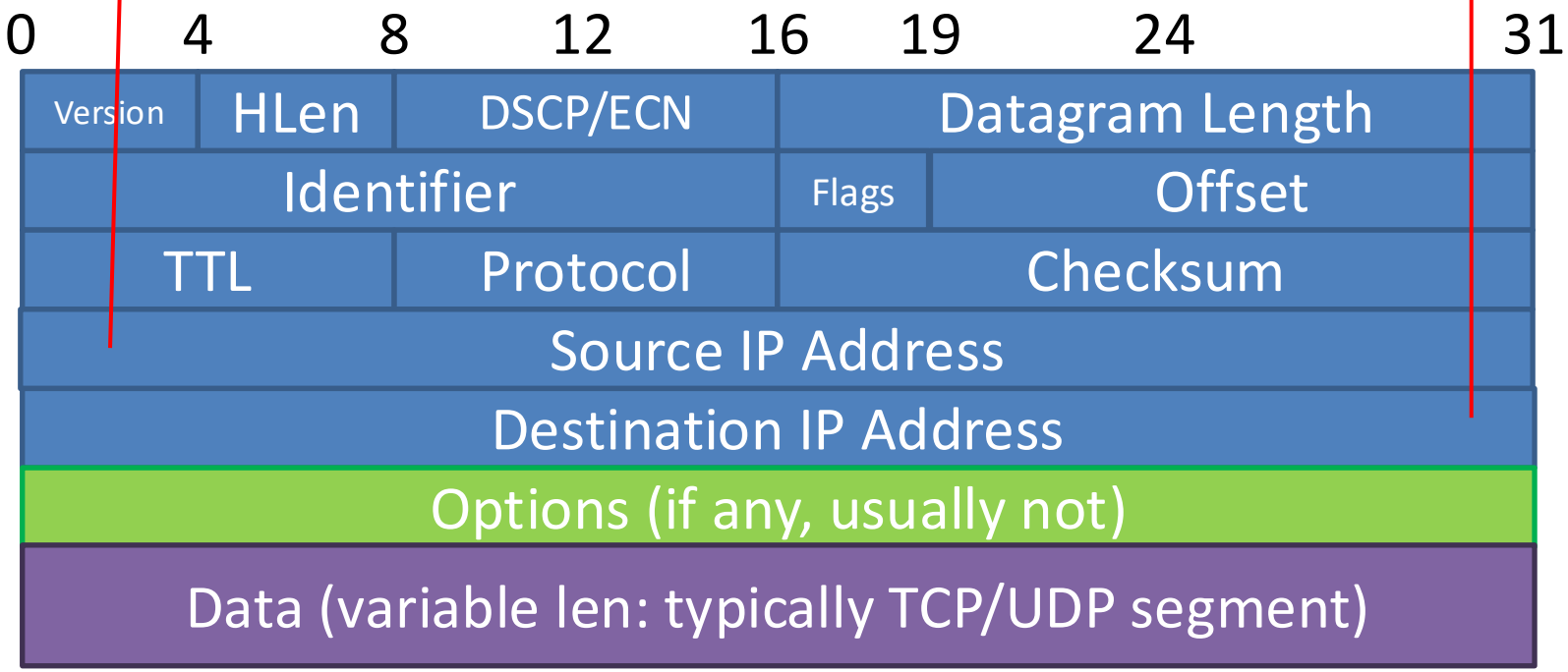


IP Datagrams

Source endpoint.

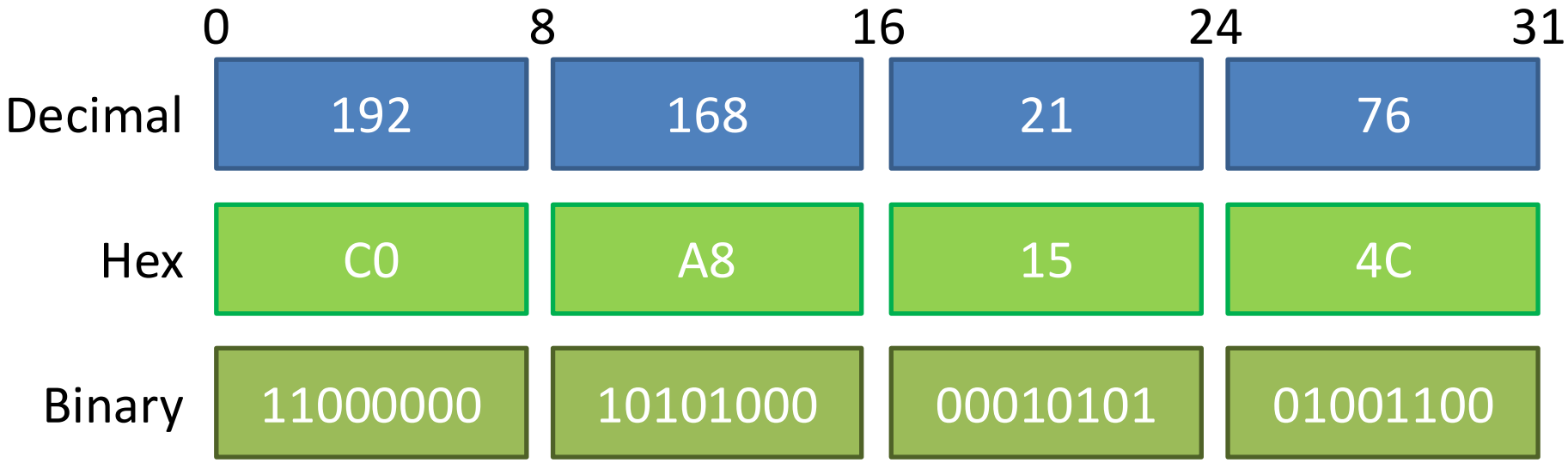
Addresses must be unique on the network!

Final destination endpoint.



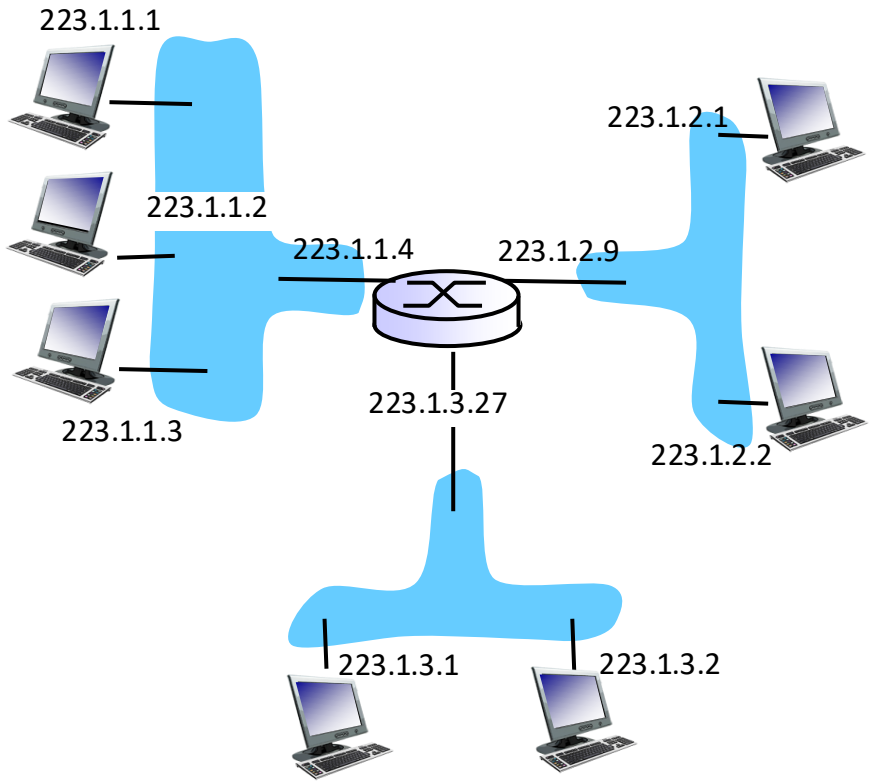
IP Addressing

- IP: 32-bit addresses
  - Usually written in dotted notation, e.g. 192.168.21.76
  - Each number is a byte
  - Stored in Big Endian order (network byte order)



Network Interfaces

- 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

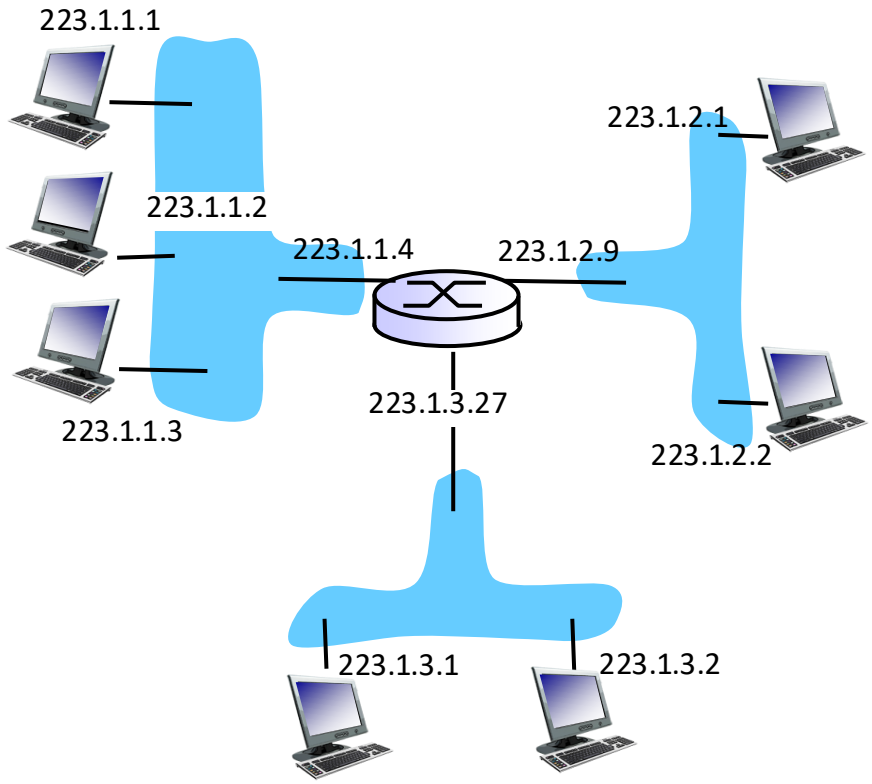


223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

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
  - On the same link layer



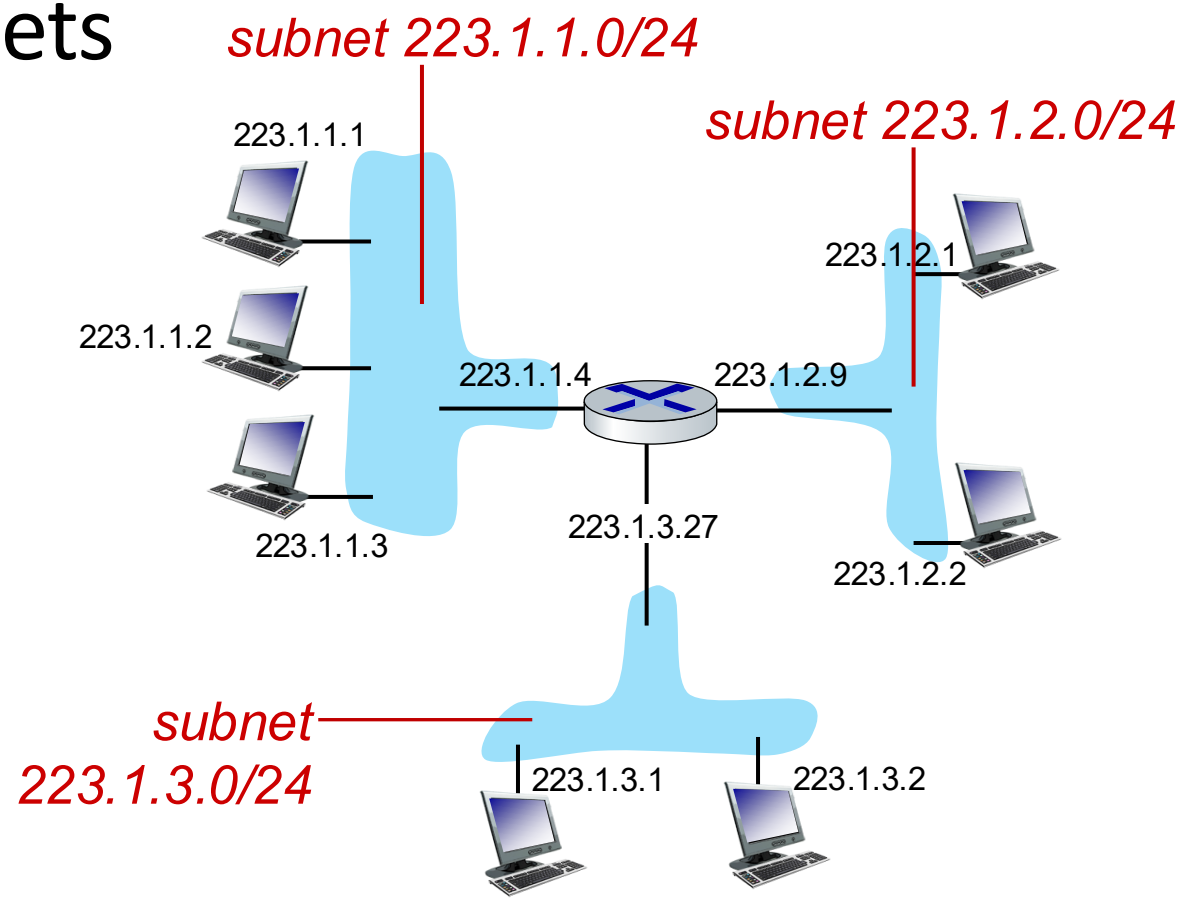
223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

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*



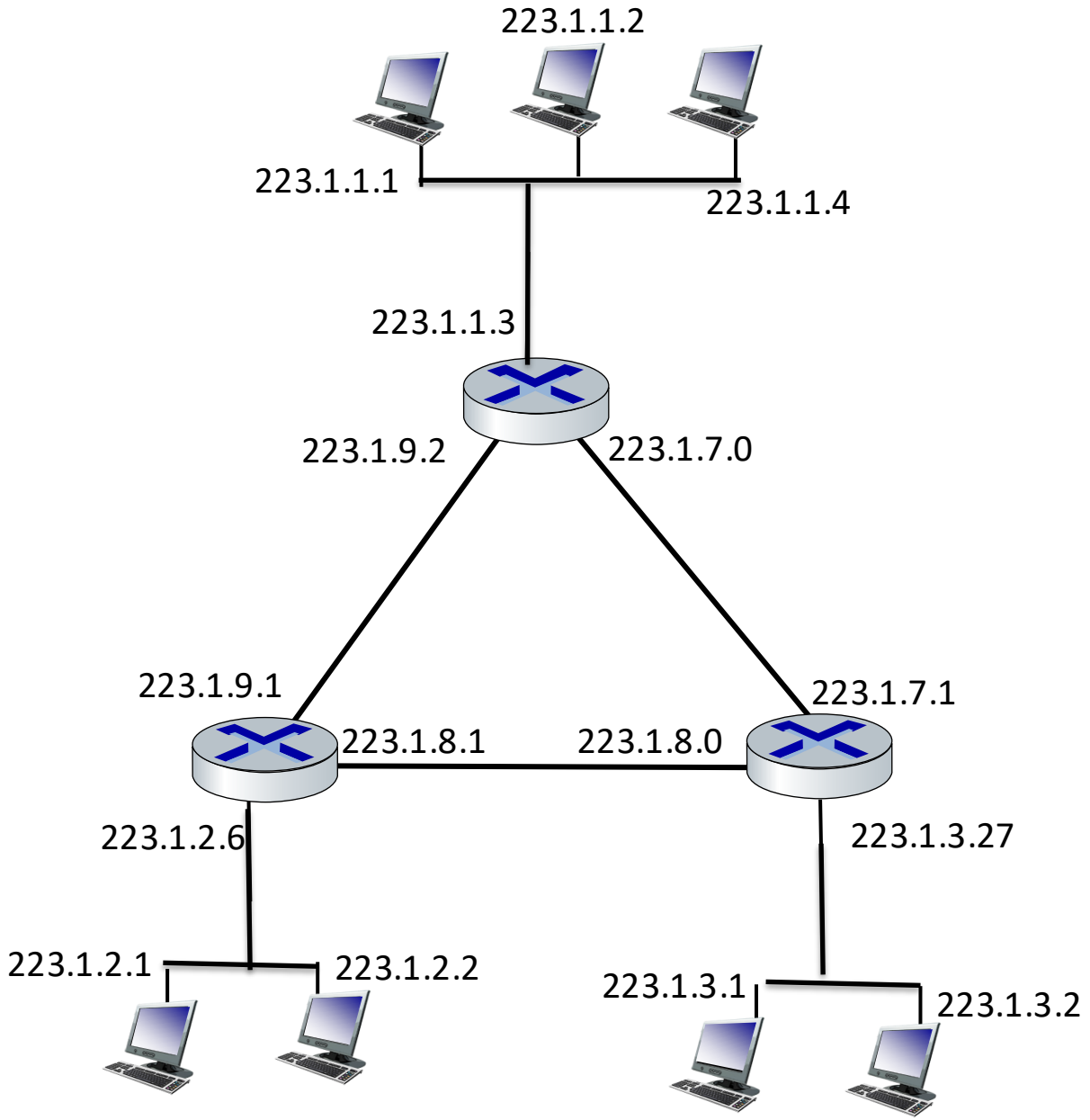
subnet mask: /24

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

Subnets

How many subnets are in the network?

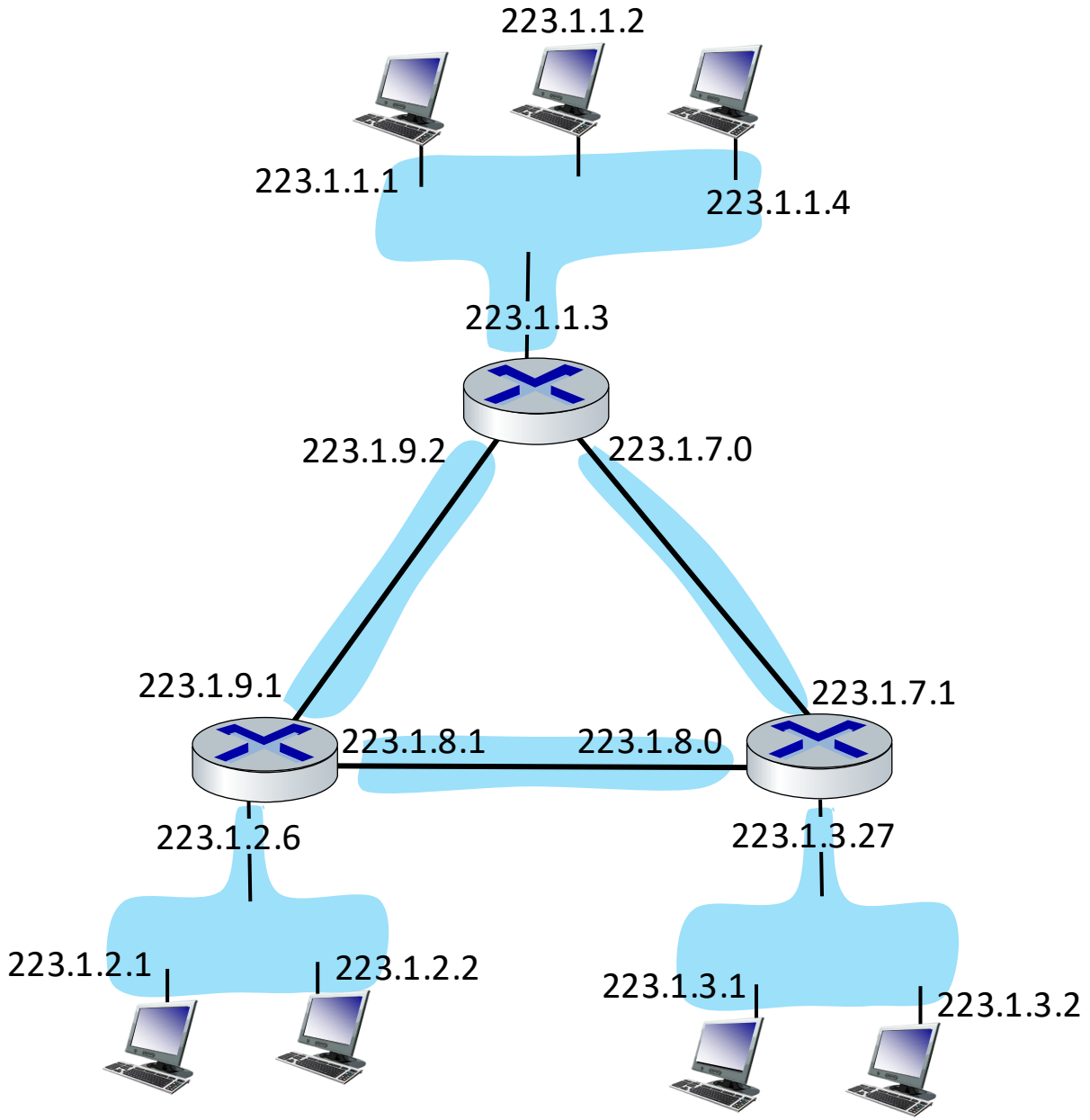
A. 3
B. 4
C. 6
D. 9
E. I don't know



Subnets

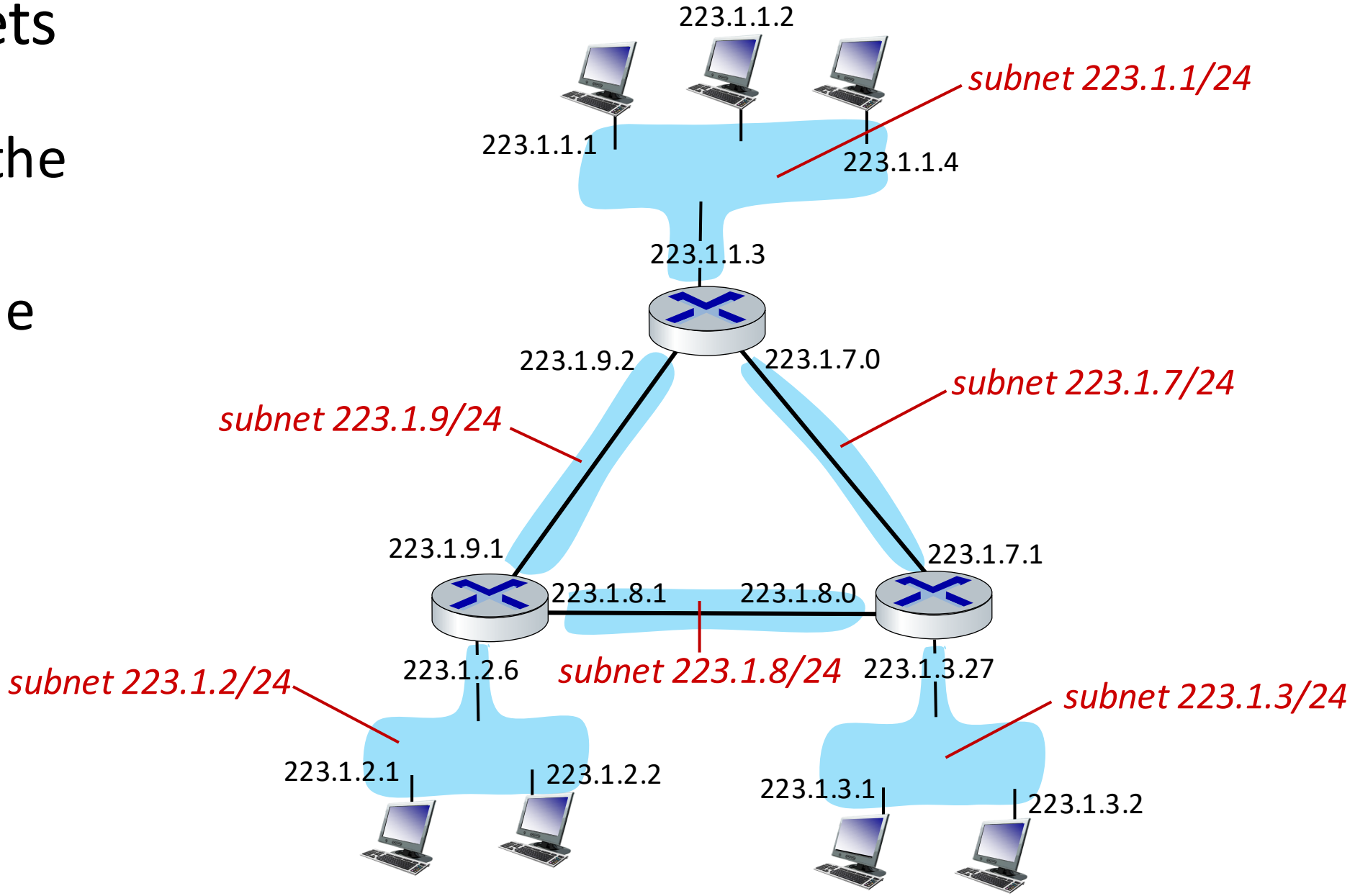
How many subnets are in the network?

A. 3
B. 4
C. 6
D. 9
E. I don't know



Subnets

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

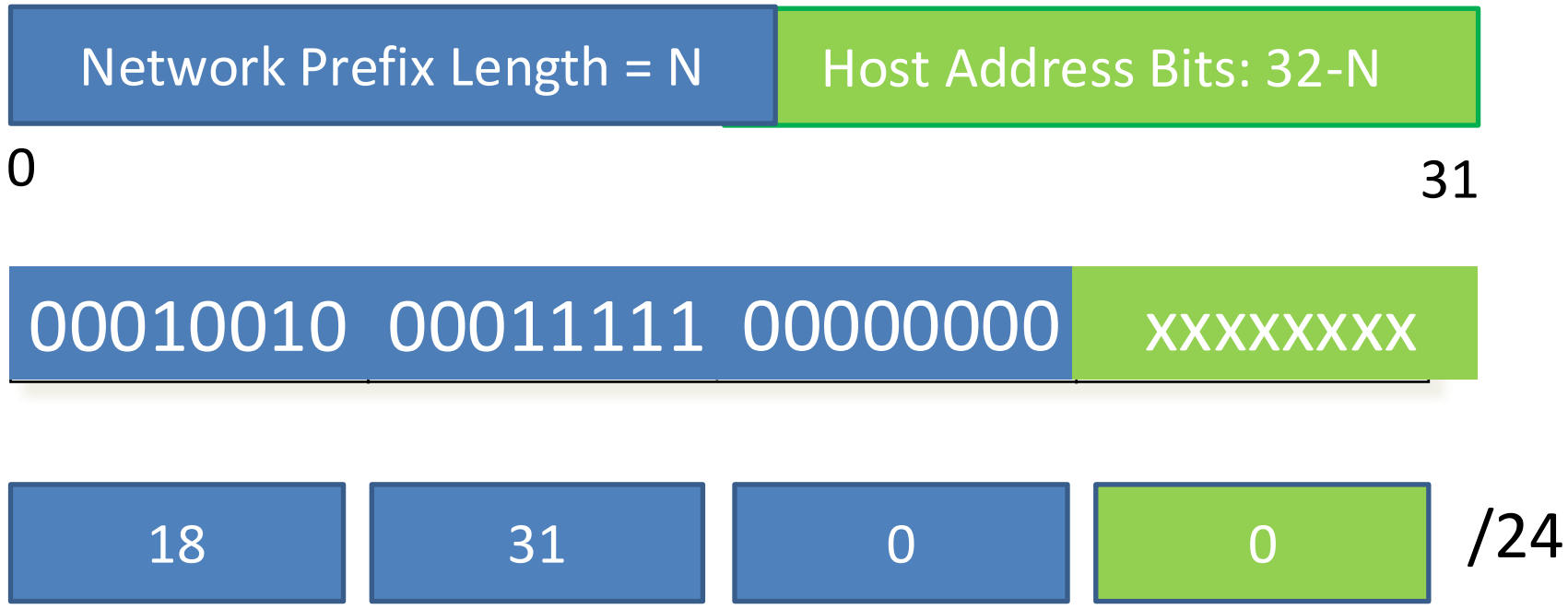


CIDR

- Classless Interdomain Routing
  - Prefix (subnet) length is no longer fixed
  - Address blocks come with a **subnet mask**

IP Prefixes

How would we express the following prefix?



How would we express the following prefix?

130 . 58 . 0100xxxx xxxxxxxx

A. 130.58.4.0/20
B. 130.58.64.0/20
C. 130.58.64.0/12
D. 130.58.0.0/16
E. I don’t know

How would we express the following prefix?

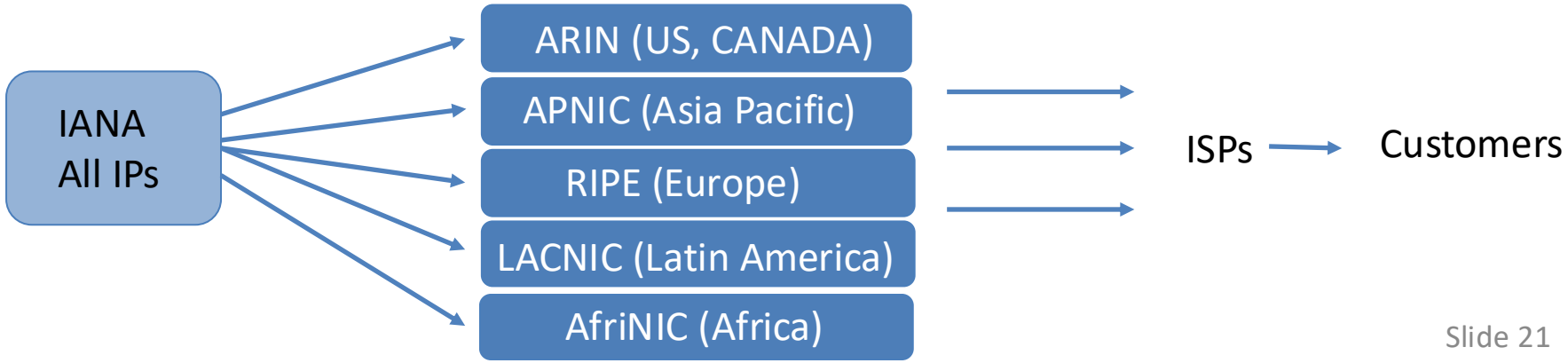
```
130 . 58 . 0100xxxx xxxxxxxx
```

A. 130.58.4.0/20
B. 130.58.64.0/20
C. 130.58.64.0/12
D. 130.58.0.0/16
E. I don’t know

Assigning Addresses

- IANA – Internet Assigned Numbers Authority
  - (Run by Jon Postel until 1988)
  - Now a part of ICANN

- ICANN: Internet Corporation for Assigned Names and Numbers
  - Manages IP addresses, DNS, resolves disputes



How many hosts can we have in one subnet?

- **Network address:** The first address in the subnet block
- **Broadcast address:** The last address in the subnet block
- So a /24 subnet has 256 total addresses, but only 254 usable host addresses

Example: 130.58.68.0/24 subnet
Network address: 130.58.68.0

Broadcast address: 130.58.68.255

Usable hosts: 130.58.68.1 to 130.58.68.254

How does a new host joining a network get an IP address?

DHCP: Dynamic Host Configuration Protocol

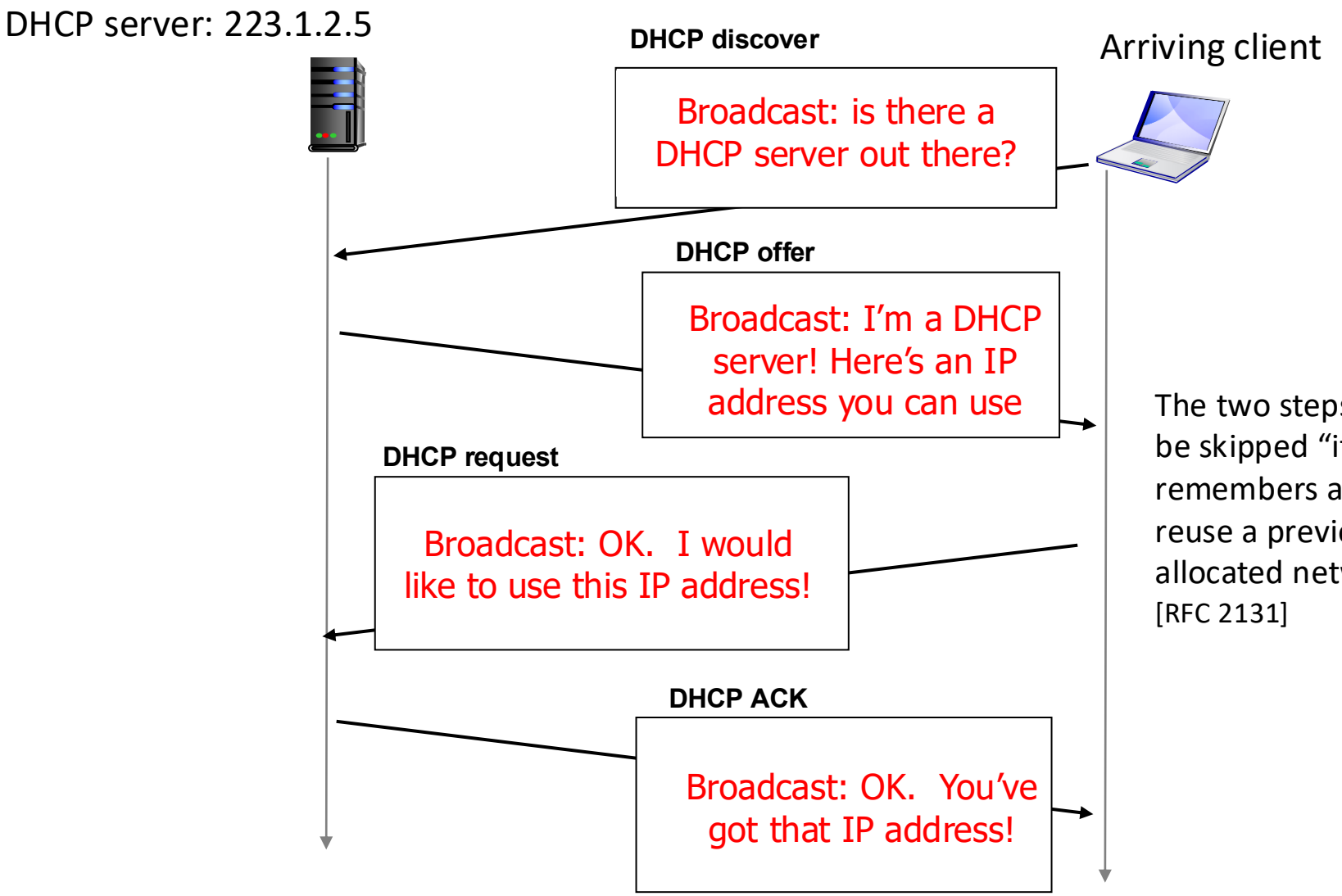
Goal: allow host to dynamically obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses
- support for mobile users who want to join 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



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

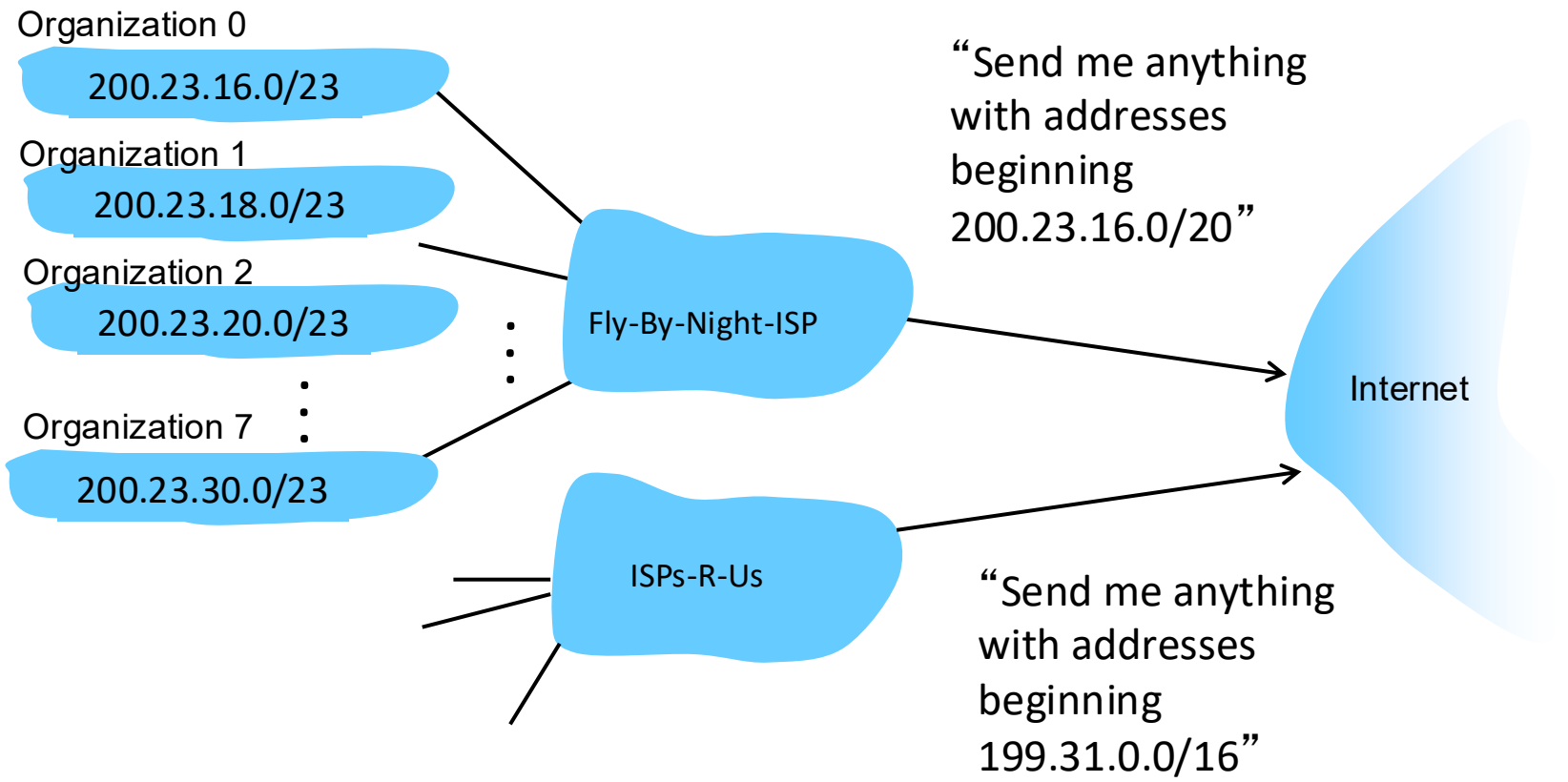
DHCP: More than IP Addresses

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

- address of first-hop router for client (default GW)
- name and IP address of DNS server(s)
- subnet mask

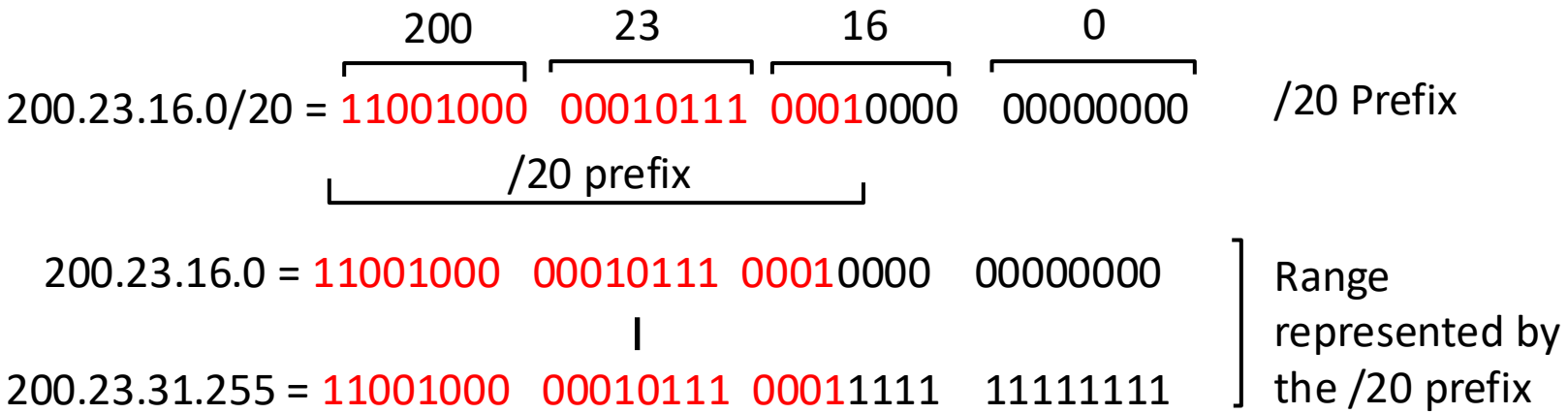
Hierarchical Addressing: Route Aggregation

Hierarchical addressing allows efficient advertisement of routing information:



Hierarchical Addressing: Route Aggregation

"Send me anything with addresses beginning 200.23.16.0/20" translates to the following:



/20 prefix contains the range of IP addresses that match the the first 20 bits, and can have any value for the remaining 12 bits in the range of :

[first 20 bits] 0000 00000000

[first 20 bits] 1111 11111111

A total of 2^12 = 4,096 IP addresses

Route aggregation in Fly-By-Night ISP

Fly-By-Night-ISP

200.23.16.0/20 = 11001000 00010111 00010000 00000000

Individual Organizations: All of these organizations IP addresses lie withinFly-by-Night's /20 prefix (first 20 bits are the same)

- they more specifically match on the three more bits to form a /23 prefix (first 23 bits of all IP addresses within their organization are the same).
- The last 9 (32-23) bits provide 2^9 = 512 unique IP addresses within each organization.

/23 prefixes

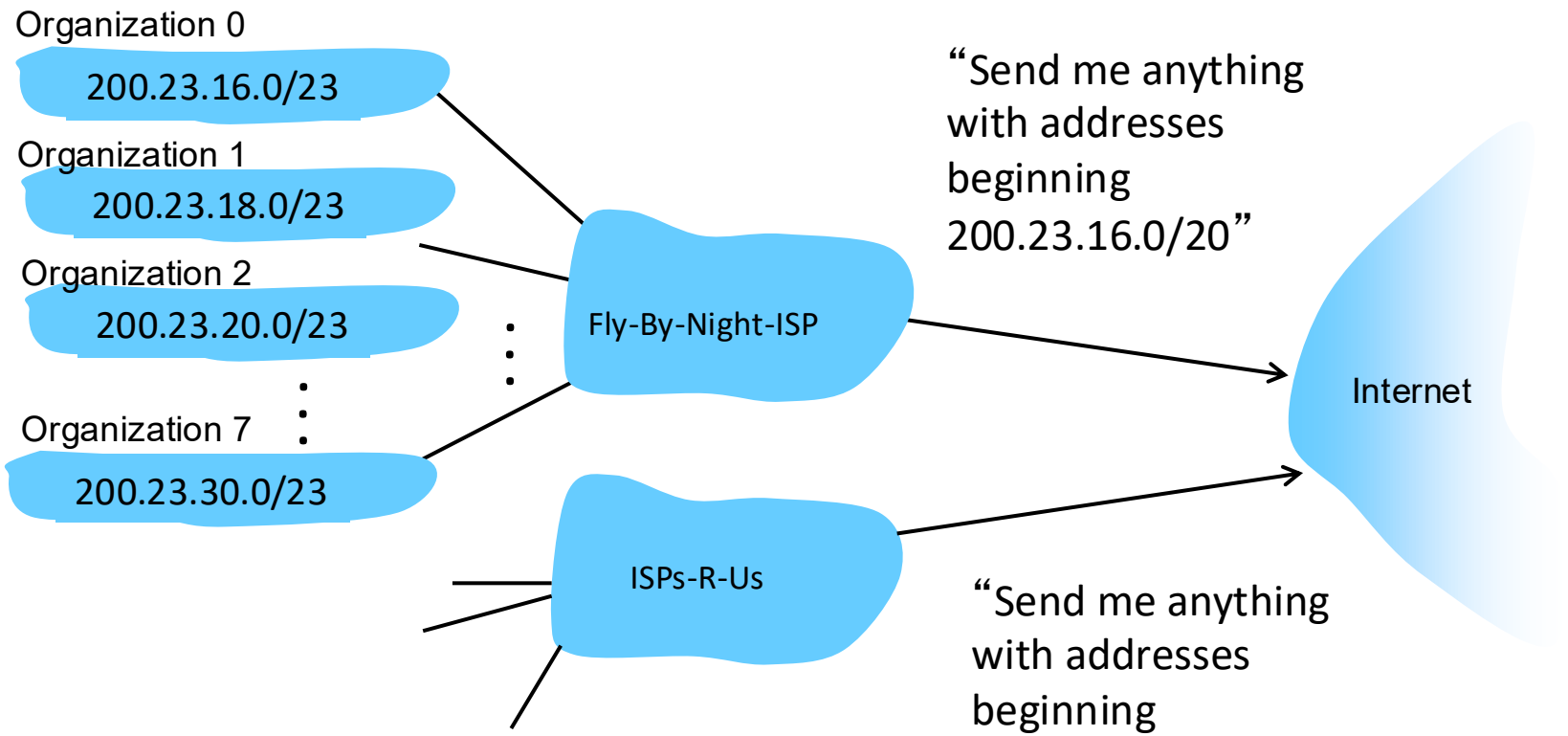
200.23.16.0/23 = 11001000 00010111 00010000 00000000

200.23.18.0/23 = 11001000 00010111 00010010 00000000

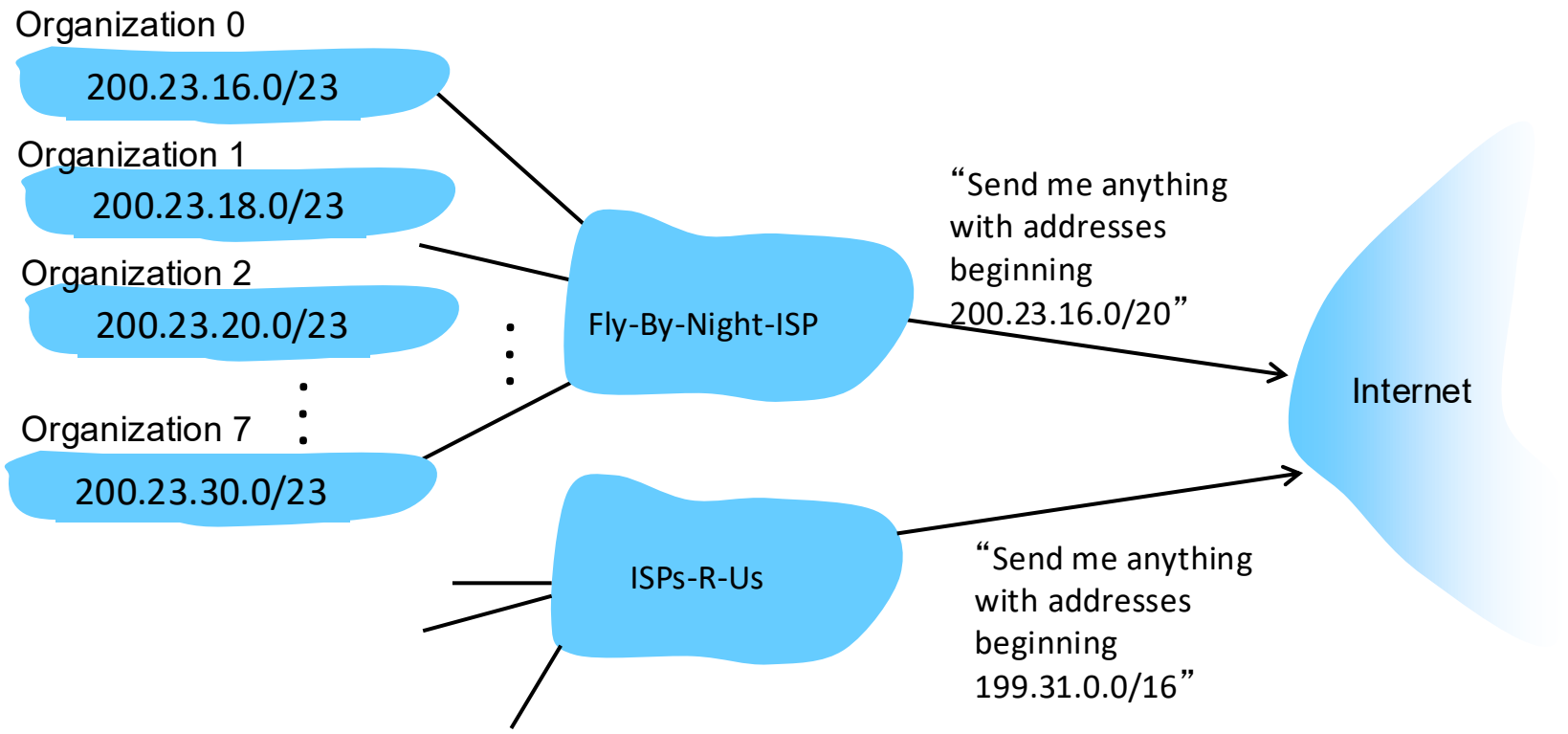
200.23.20.0/23 = 11001000 00010111 00010100 00000000

200.23.30.0/23 = 11001000 00010111 00011110 00000000

What should we do if organization 1 decides to switch to ISPs-R-Us?



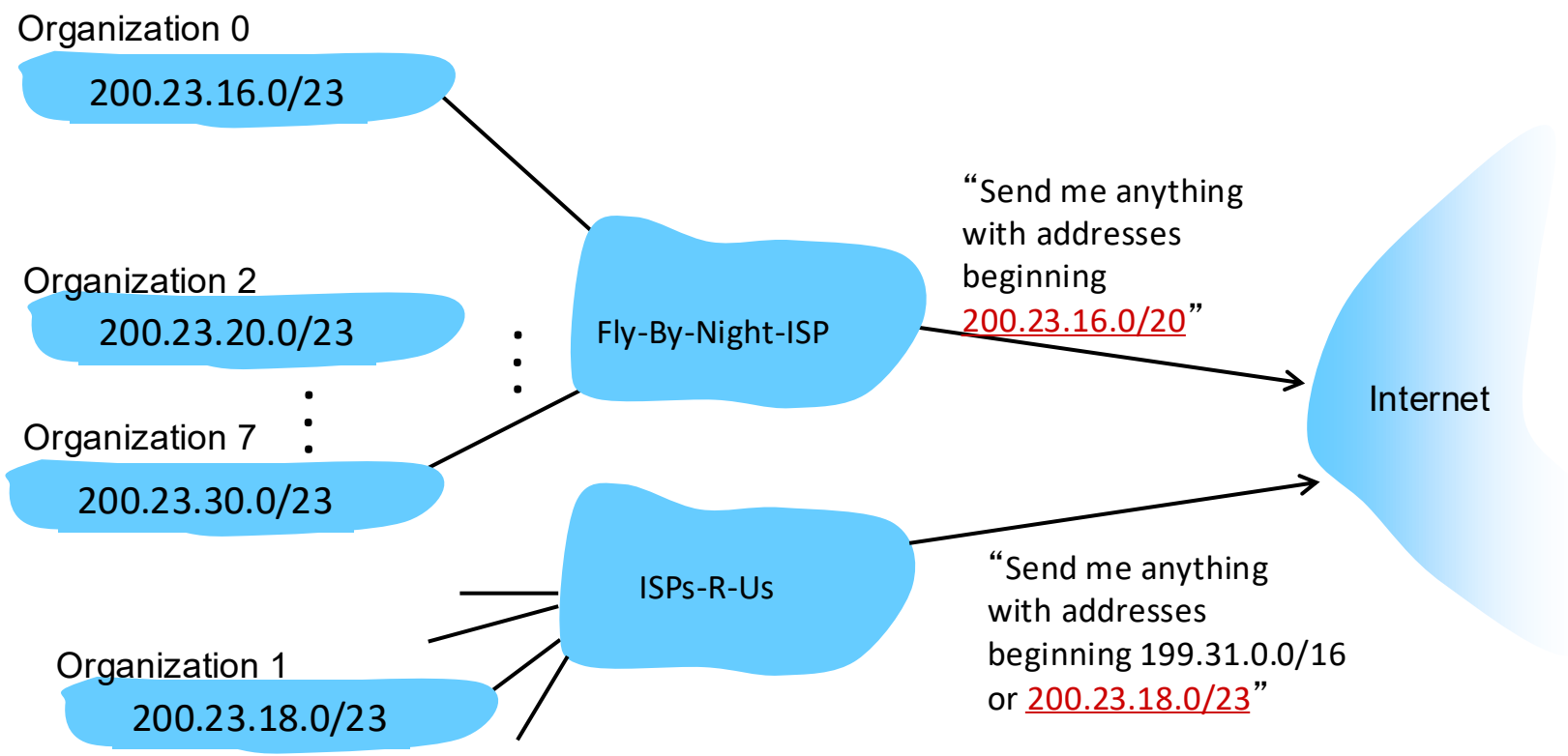
What should we do if organization 1 decides to switch to ISPs-R-Us?



A. Move 200.23.18.0/23 to ISPs-R-Us (and break up Fly-By-Night's /20 block).
B. Give new addresses to Organization 1 (and force them to change all their addresses).
C. Some other solution.

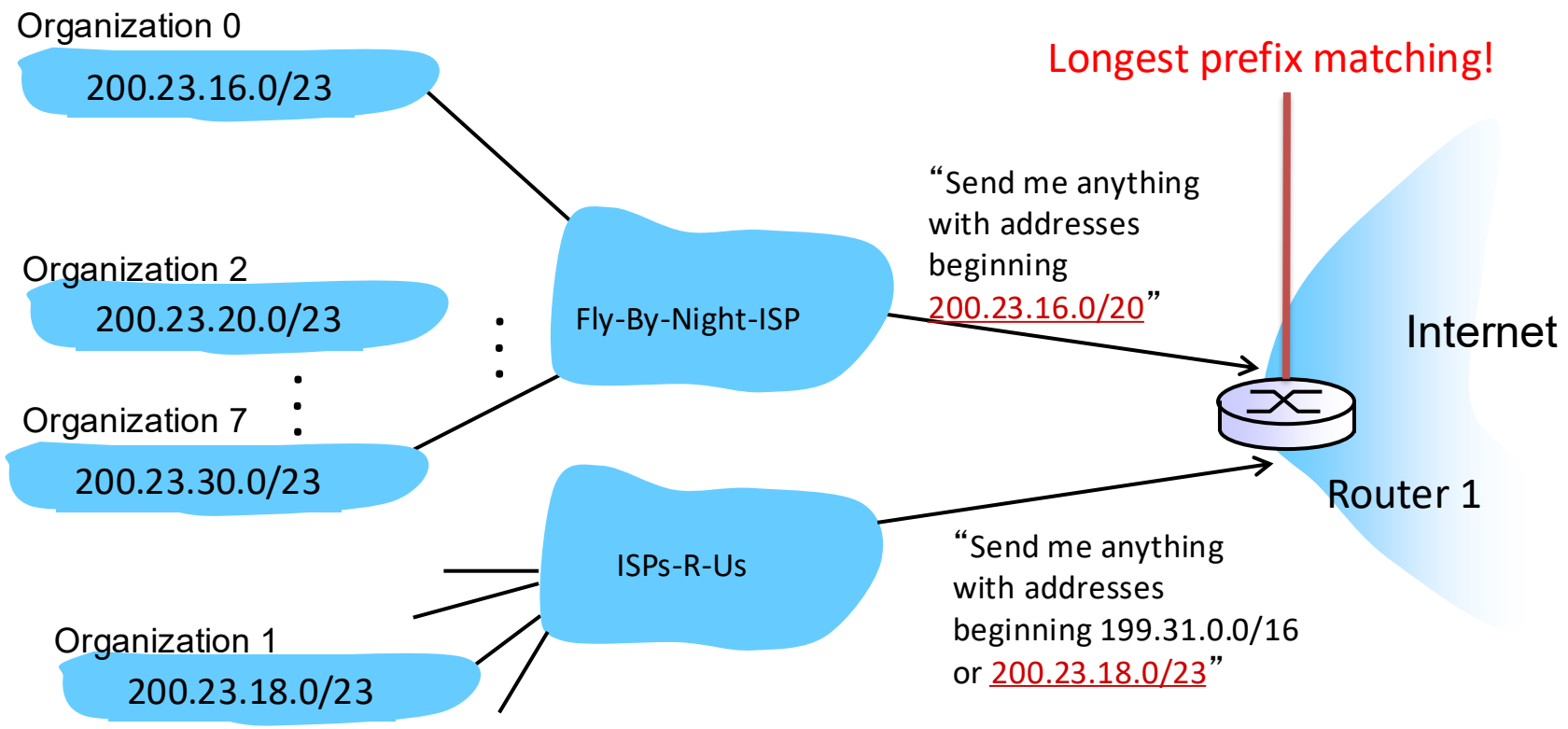
Hierarchical addressing: More Specific Routes

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

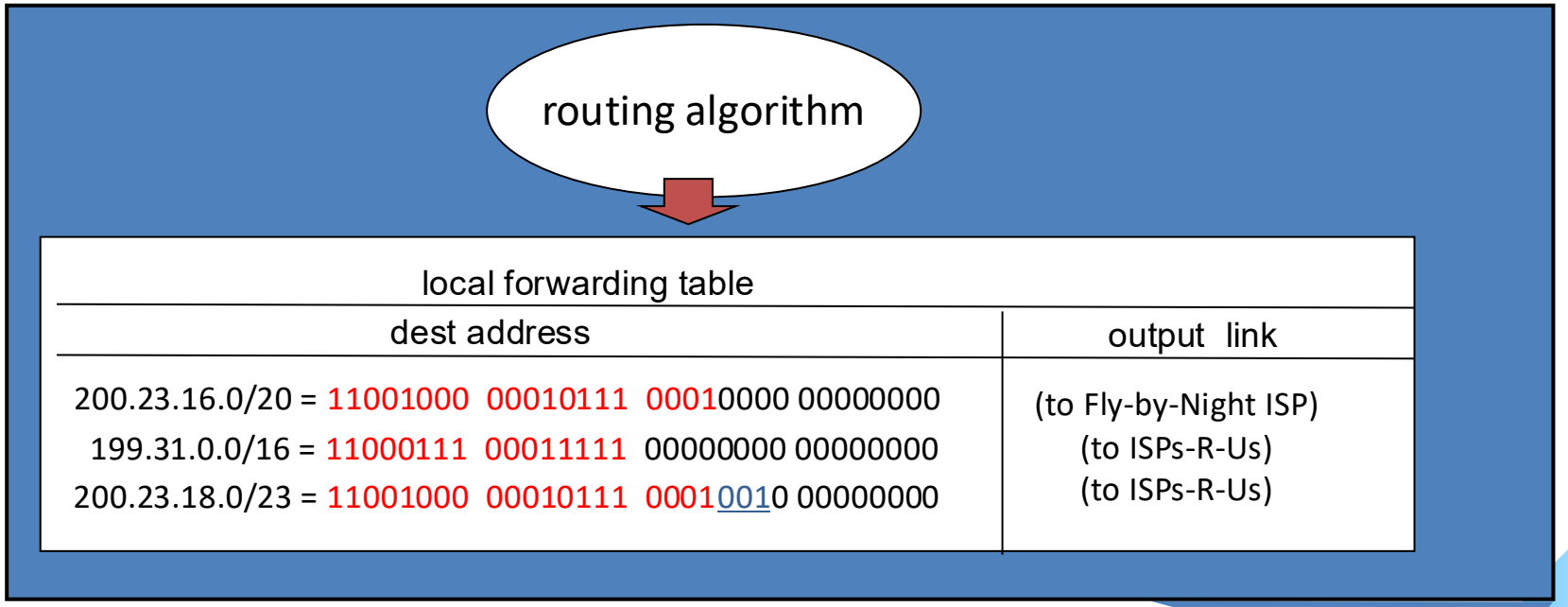


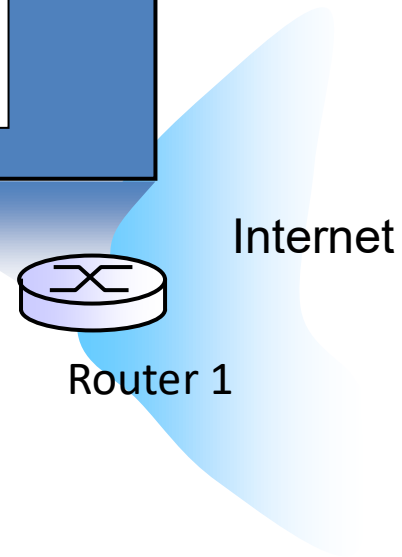
Hierarchical addressing: More Specific Routes

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



Longest Prefix Matching at Router 1





Now, when an incoming packet addressed with destination address 200.23.18.5 arrives – this address belongs to Organization 1 and the packet will be matched using longest prefix matching and will be routed to ISPs-R-Us rather than the Fly-by-Night ISP.

IP Addresses

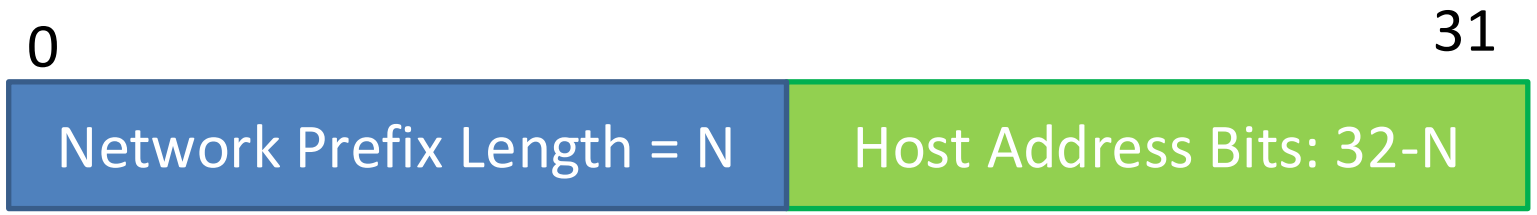
- 2^{32} => 4,294,967,296 possible addresses.
- In the early 80's, that's a lot!
  - Population was ~4.5 billion.
- Now…not so much.
  - Population > 7 billion.

Reference Slides

IP Prefixes

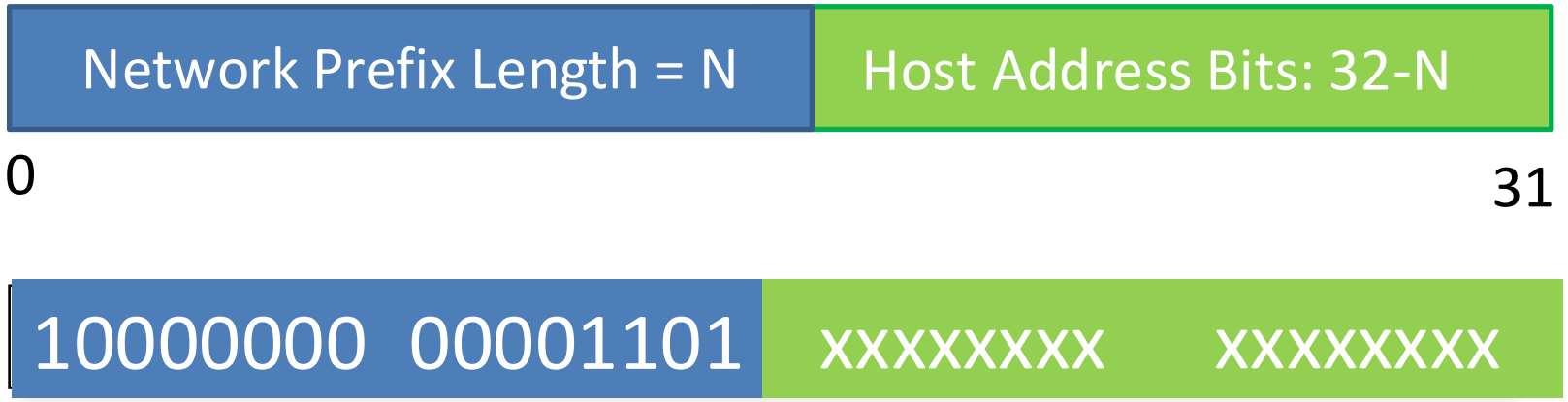
- Addresses are allocated in blocks called prefixes to organizations
- Addresses in an N-bit prefix have the same top N bits.

- If an organization has an IP/N prefix, it can allocate 2^32-N addresses to end hosts on its network



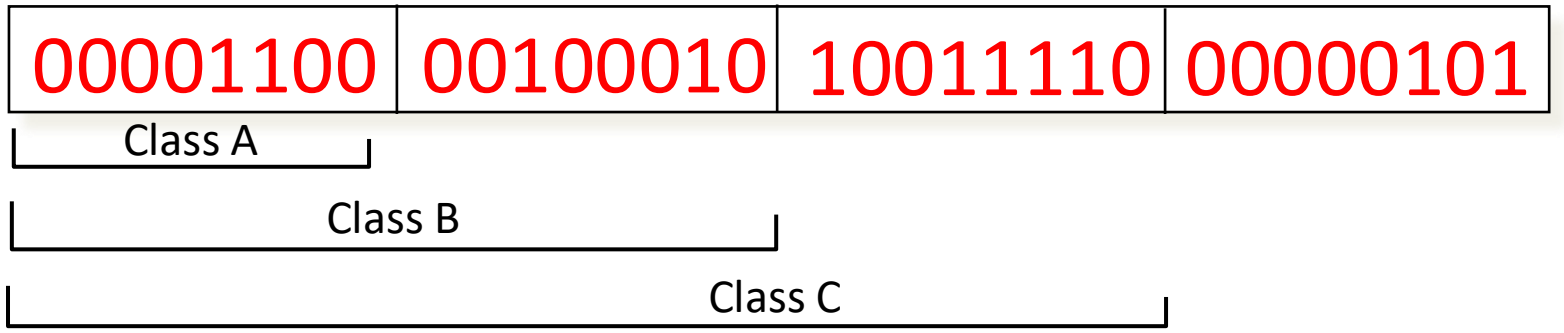
IP Prefixes

- Written in IP address/length notation
- Address is the lowest address in the allocated block. Length is prefix in bits.
- E.g. 128.13.0.0/16 is 128.13.0.0 to 128.13.255.255
  Read as: ”128.13.0.0 slash 16” prefix.



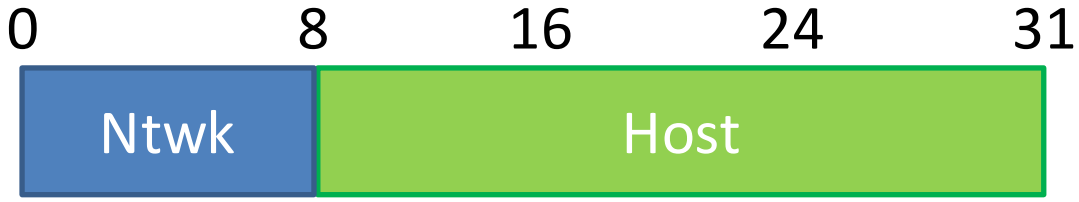
Who gets an address? How many?

- Classful Addressing
  - Class A: 8-bit prefix, 24 bits for hosts (16,777,216)
  - Class B: 16-bit prefix, 16 bits for hosts (65,536)
  - Class C: 24-bit prefix, 8 bits for hosts (256)



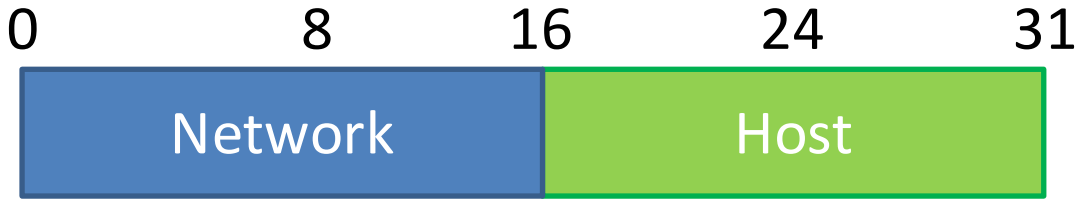
Classes of IP Addresses

Class A



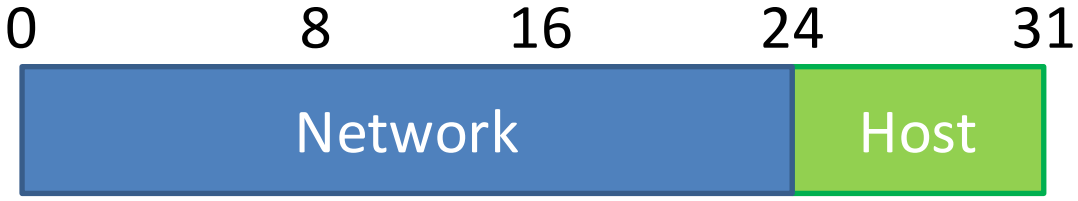
Example: MIT
18.*.*.*

Class B



Example: NEU
129.10.*.*

Class C



Example:
216.63.78.*

CIDR

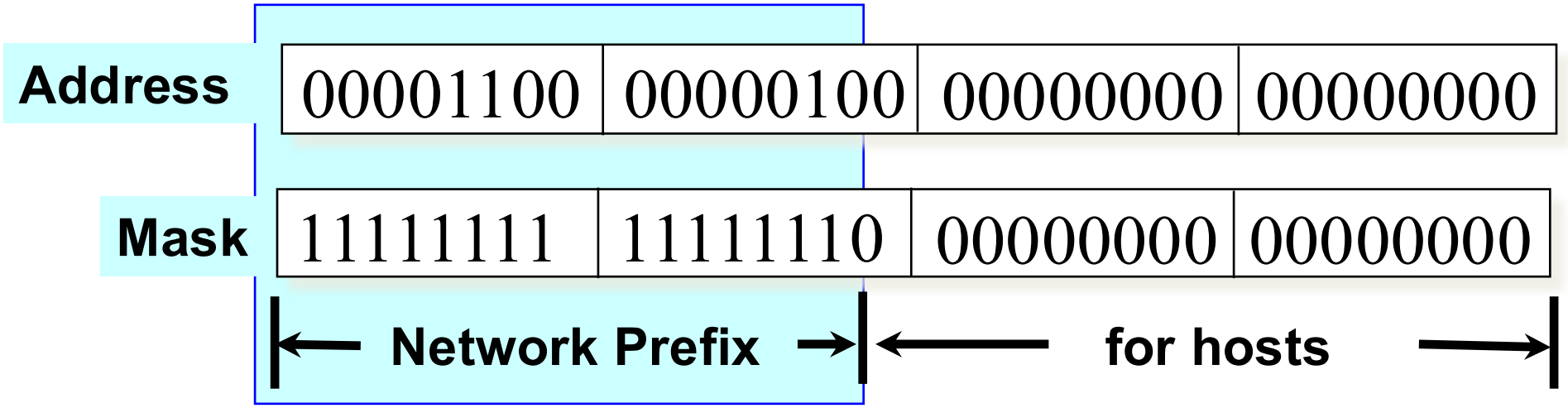
- Classless Inter-Domain Routing
  - Prefix (subnet) length is no longer fixed
  - (Can be division of bits rather than just 8/24, 16/16, and 24/8)

CIDR

- Classless Inter-Domain Routing
  - Prefix (subnet) length is no longer fixed
  - Address blocks come with a **subnet mask**

Classless Inter-Domain Routing (CIDR)

IP Address : 12.4.0.0 IP Mask: 255.254.0.0



Written as 12.4.0.0/15

Use two 32-bit numbers to represent a network.
Network number = IP address + Mask

CIDR

- Classless Interdomain Routing
  - Prefix (subnet) length is no longer fixed
  - Address blocks come with a **subnet mask**

- Subnet mask written in two ways:
  - Dotted decimal: 255.255.240.0
  - /20
  - Both mean:
    11111111 11111111 11110000 00000000



/20

CIDR

- Addresses divided into two pieces:
  - Prefix portion (network address)
  - Host portion

- Given an IP address and mask,
  we can determine:
  - The prefix (network address) by ANDing
  - The broadcast address by ORing inverted mask

Why might a device care about its “Network or Subet Address”?

- Answers the question: is the destination on the same subnet as me?

- Address + subnet mask -> Network address

- If destination is on same network:
  - Send directly to them
- Else:
  - Send to gateway router

Network Address (Subnet Address)

IP Address & subnet mask -> Network Address

- E.g., 230.8.1.3/18 /18 => mask is 255.255.192.0

11100110	**00001000**	**00000001**	**00000011**
11111111	**11111111**	**11000000**	**00000000**

IP address

/18 Subnet mask

Network Address (Subnet Address)

- E.g., 230.8.1.3/18 /18 => mask is 255.255.192.0

11100110	00001000	00000001	00000011	IP address
11111111	11111111	11000000	00000000	/18 Subnet mask
11100110	00001000	00000000	00000000	& the two

Network address advertised by router: 230.8.0.0

Broadcast Address

- E.g., 230.8.1.3/18

11100110	00001000	00000001	00000011	IP address
~~11111111~~	~~11111111~~	~~11000000~~	~~00000000~~	/18 Subnet mask
00000000	00000000	00111111	11111111	complement of the subnet mask

Broadcast Address

- E.g., 230.8.1.3/18

11100110	00001000	00000001	00000011	IP address
00000000	00000000	00111111	11111111	complement of the subnet mask

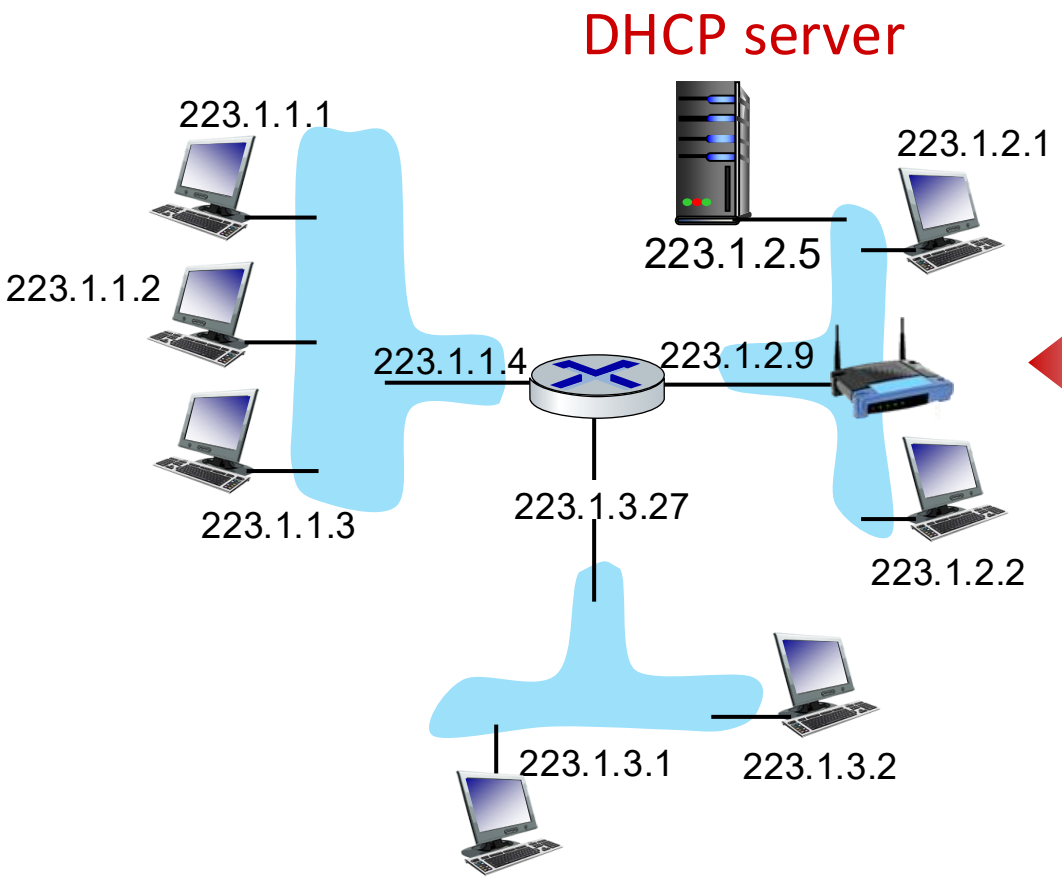
Broadcast Address

- E.g., 230.8.1.3/18

11100110	00001000	00000001	00000011	IP address
00000000	00000000	00111111	11111111	complement of the subnet mask
11100110	00001000	00111111	11111111	OR of the IP address and the complement of the subnet mask

Broadcast address: 230.8.63.255

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