Introduction to Computer Networks

CS640

Efficient Addressing

https://pages.cs.wisc.edu/~mgliu/CS640/S26/index.html

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Outline

- Last
  - IP Introduction
- Today
  - Efficient Addressing
- Announcements
  - Lab2 due on 03/03/2026

Recap

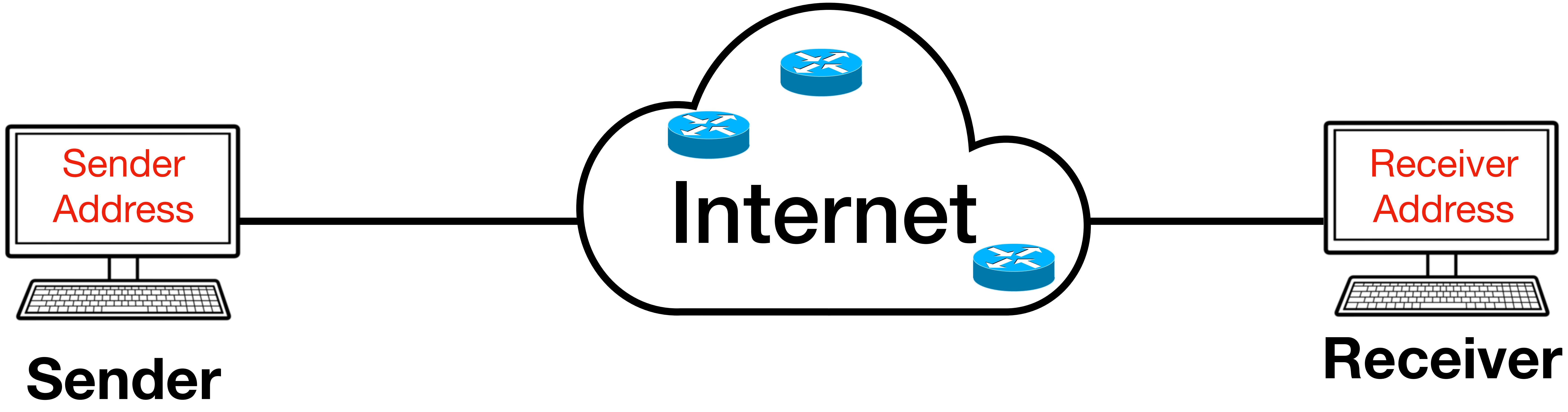
- Key Questions
  - Why is IP so powerful?

- Terminology
  - Best-effort host-to-host service model
  - IP header and its fields
  - ICMP
  - Router and routing

Why do we care about IP addressing?

IP — A Single Logical Network

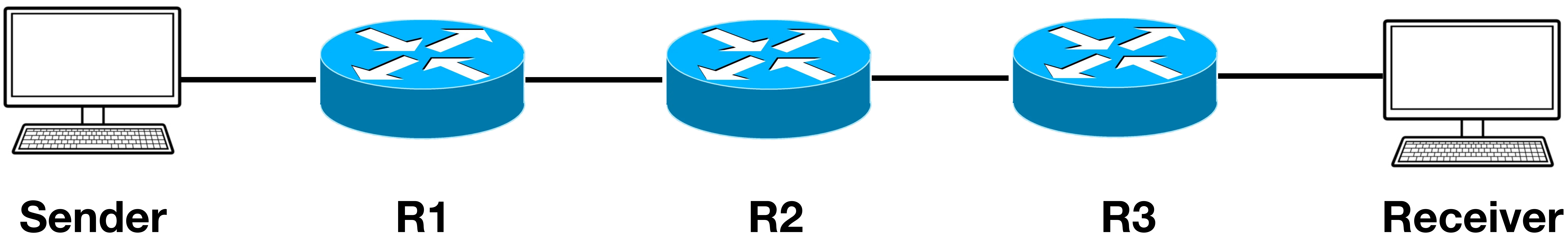
- IP addresses differentiate different communication entities
- IP addresses determine how data is transmitted
- IP addresses impact the network scalability



How do we allocate IP addresses?

IP Address Owner

- Interface: the communication port connects hosts and links
  - A host might contain one or several interfaces
  - A router encloses multiple interfaces



IP Address Owner

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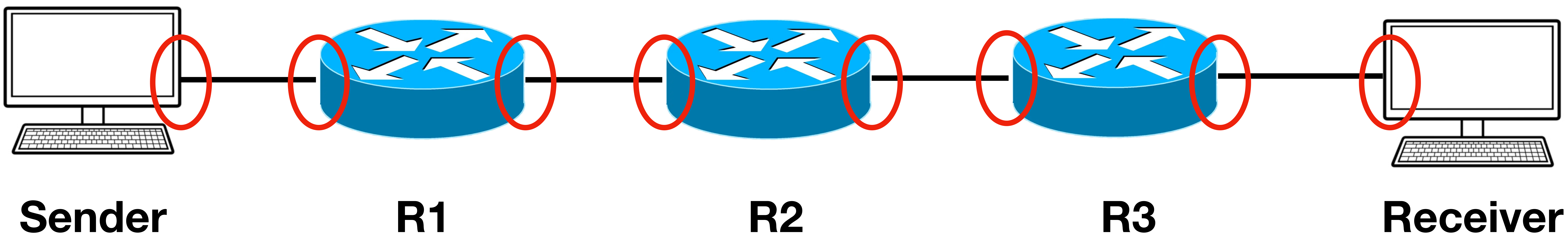

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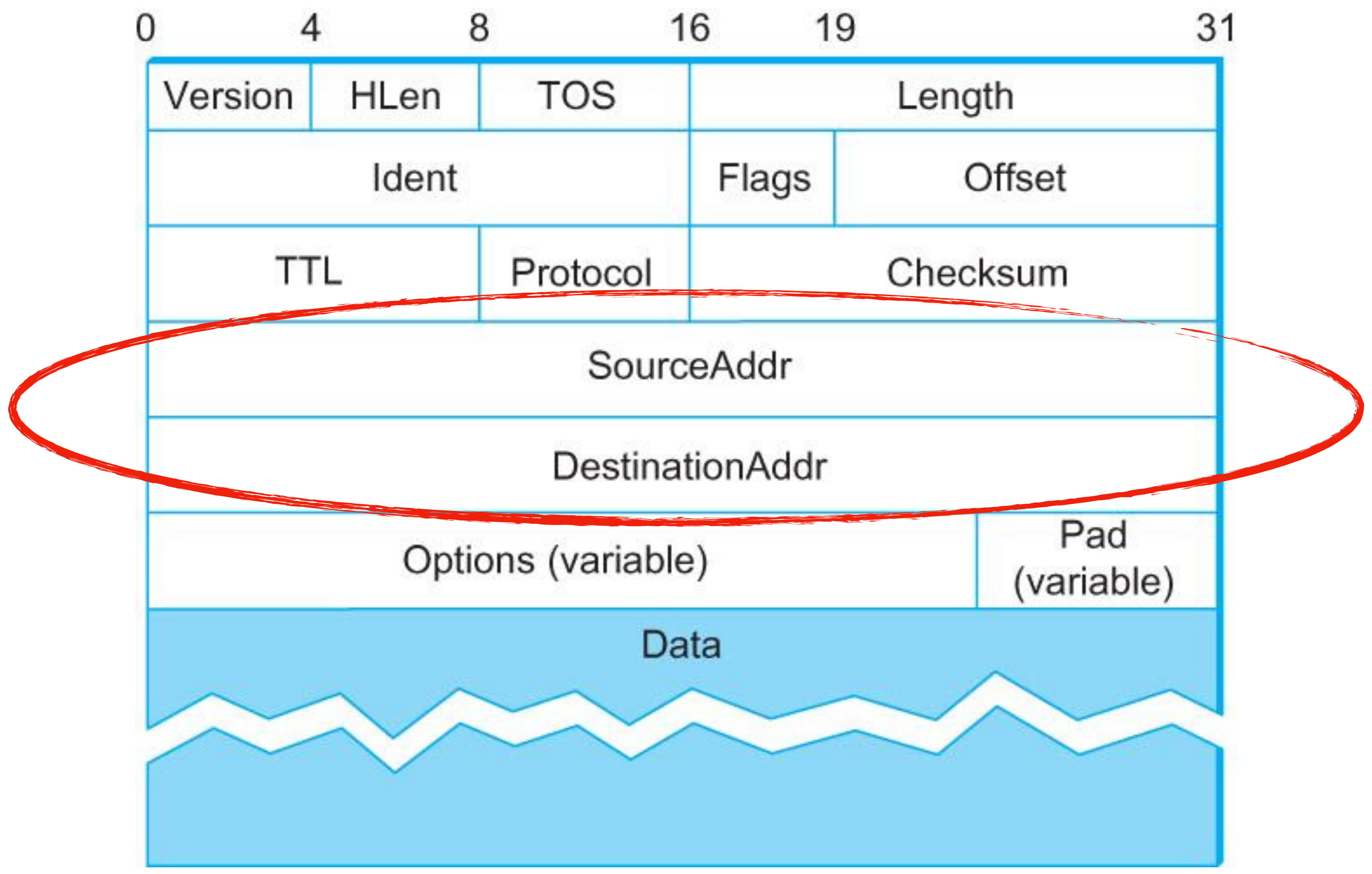
Hosts use IP addresses to differentiate communication entities.
Routers use IP addresses to route communication traffic.

IP address allocation must consider:

- The scale of your network => The number of hosts
- The efficiency of address lookup in the router => Hosts from the same network should have address locality

The Classful Addressing Scheme

- Hierarchical addresses
  - ICANN (Internet Corporation for Assigned Names and Numbers)
- Divide the 32-bit address space into network and host
  - <Network, Host>



Dotted-decimal Notation

- An IPv4 address is 32 bits long (4 bytes) => 2^32 addresses
  - Each byte of the address is written in its decimal form, separated by a period (dot) from other bytes in the address

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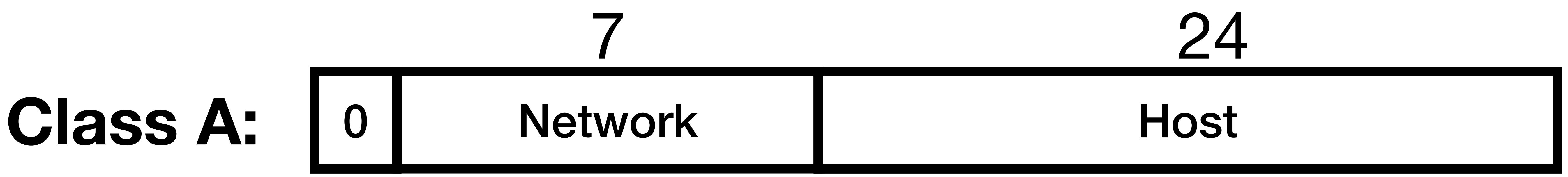
↓

193 . 32 . 216 . 9

How do we partition the 32-bit range to network and hosts?

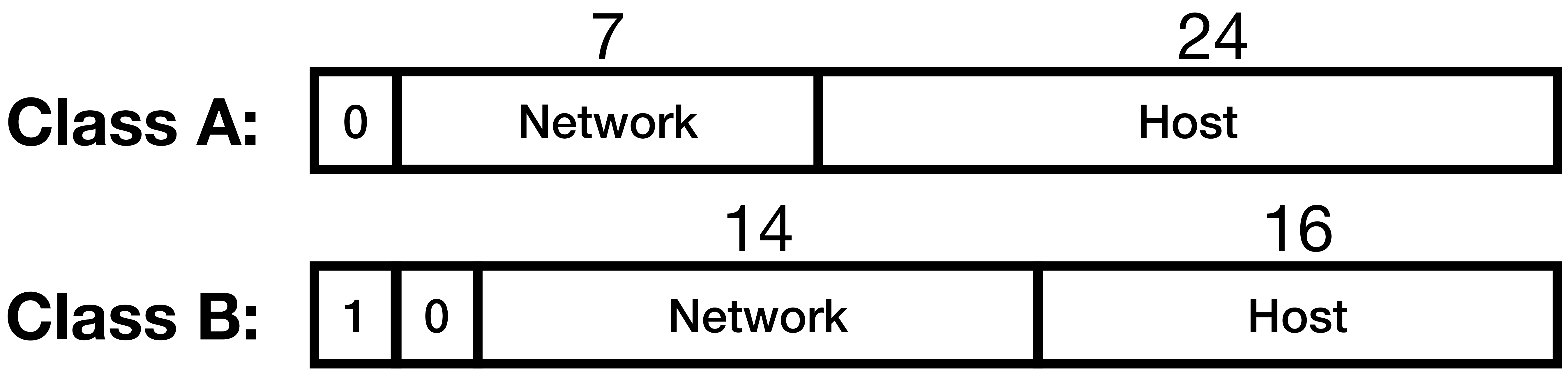
Five IP Classes

- Class A address
  - 1.0.0.0 to 127.0.0.0



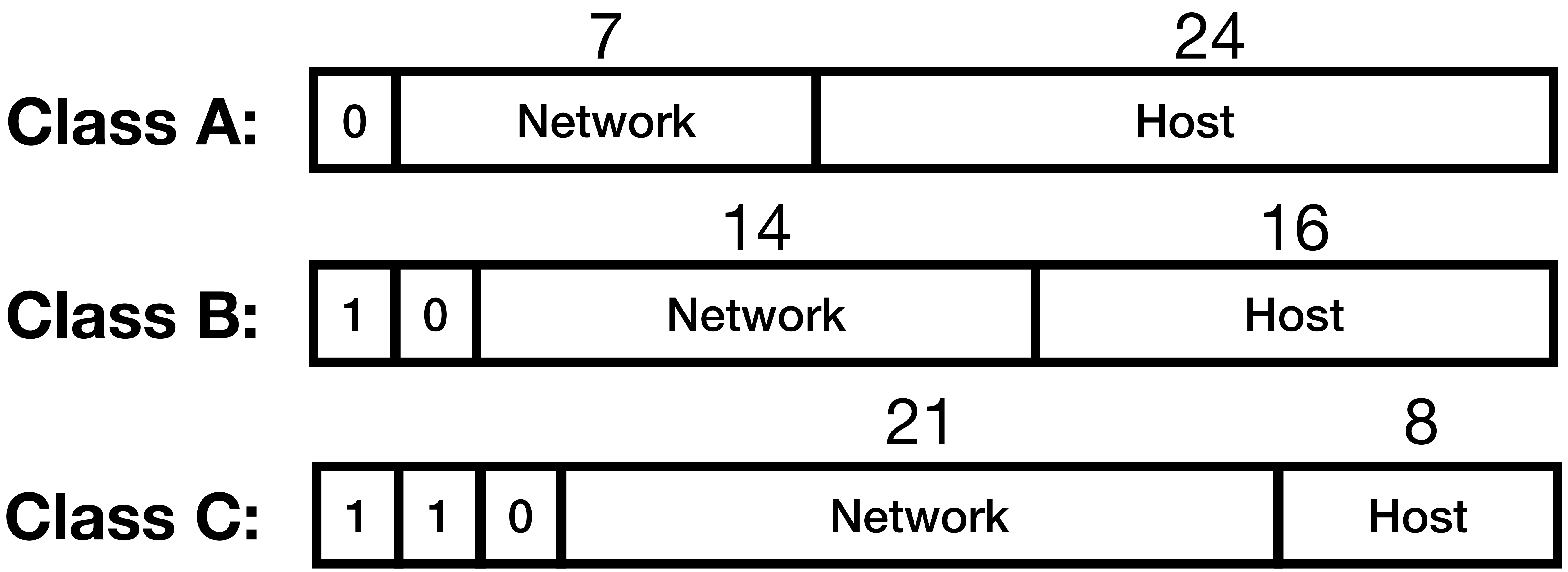
Five IP Classes

- Class B address
  - 128.0.0.0 to 191.255.0.0.0



Five IP Classes

- Class C address
  - 192.0.0.0 to 223.255.255.0



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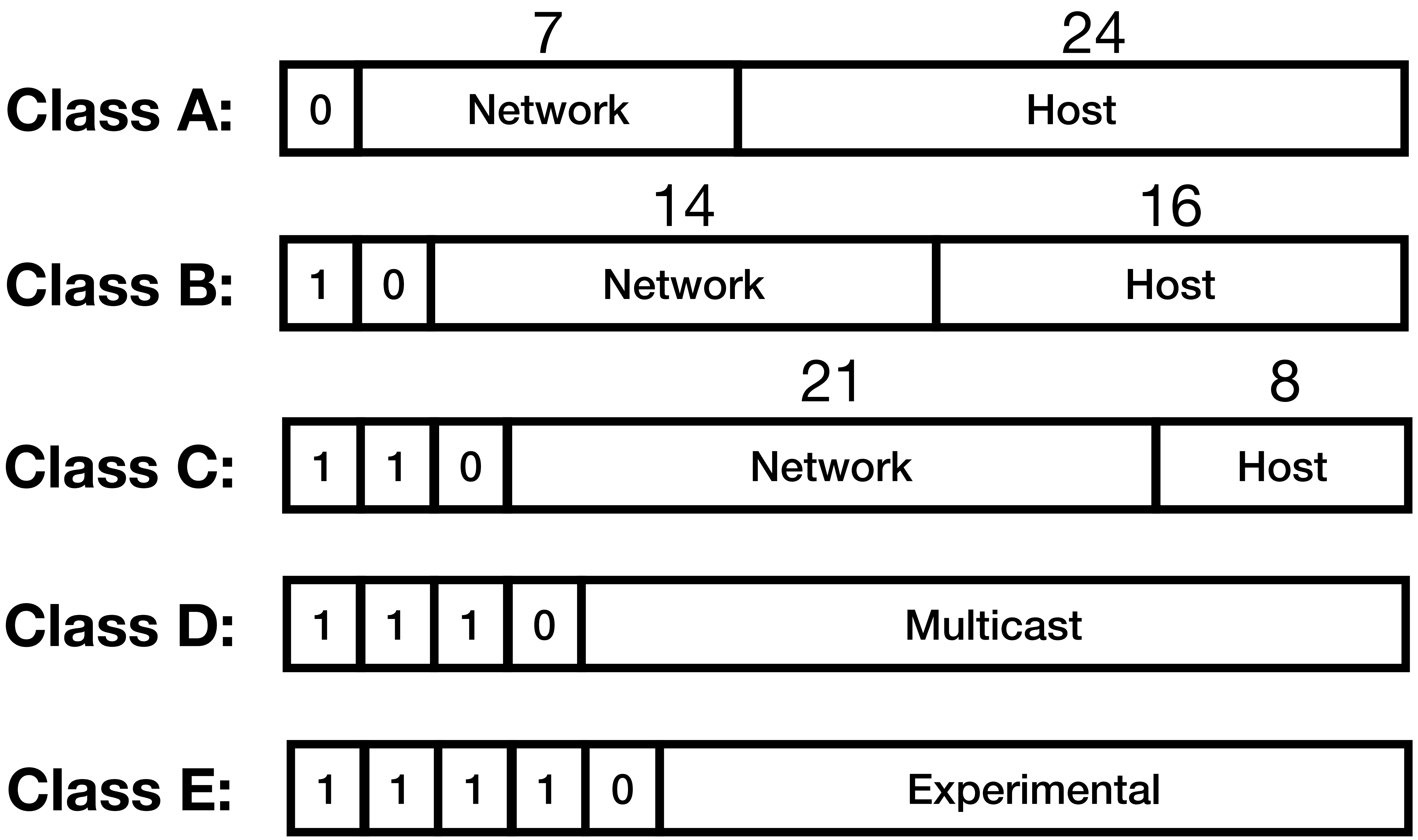
- Class D: reserved for multicasting
- Class E: used for experimental research and development



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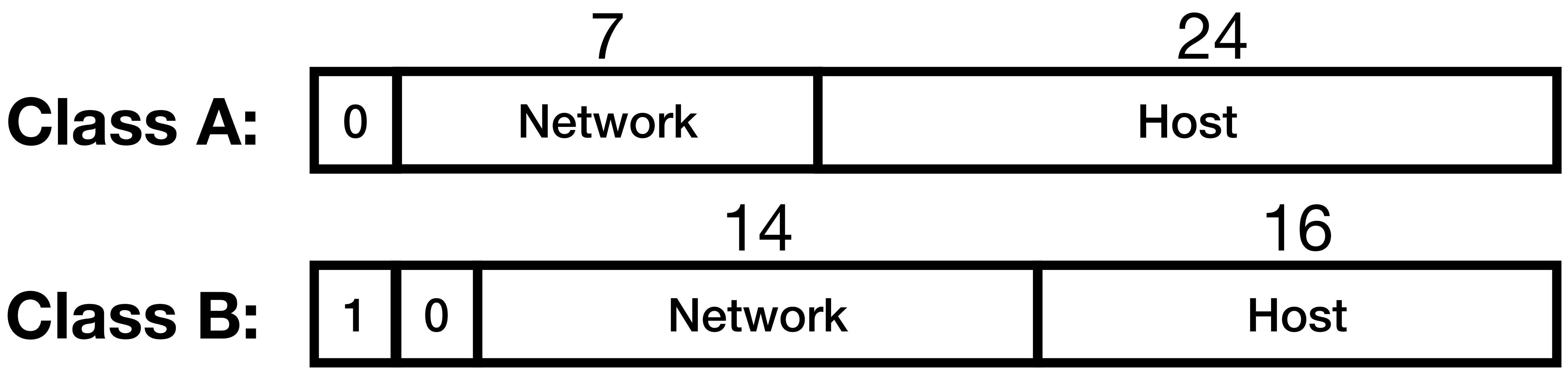

ICANN assigns the network number (or IP address range) for an organization, but not for individual hosts!

As an IT operator, which IP classes should I apply for?

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- The problem becomes increasingly challenging when you consider upgrading

Classful Addressing is Inefficient

- Issue #1: address waste
  - Class C with 2 hosts (2/255 = 0.78% efficiency)
  - Class B with 256 hosts (256/65535 = 0.39% efficiency)

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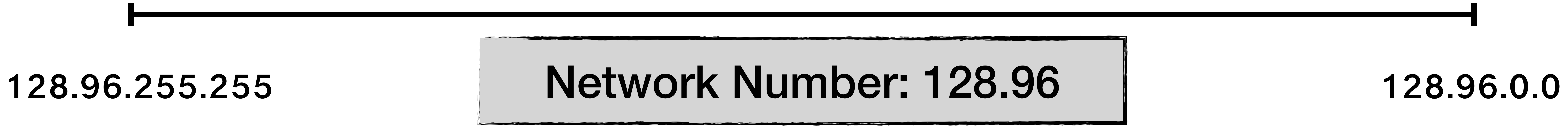
- Issue #2: still too many networks (discussed later)
  - Routing tables become expensive and cannot scale
  - Route propagation protocols do not scale

How can we improve the address usage?

Idea: Flexible Address Partitioning

- Class B address: 128.96.X.X



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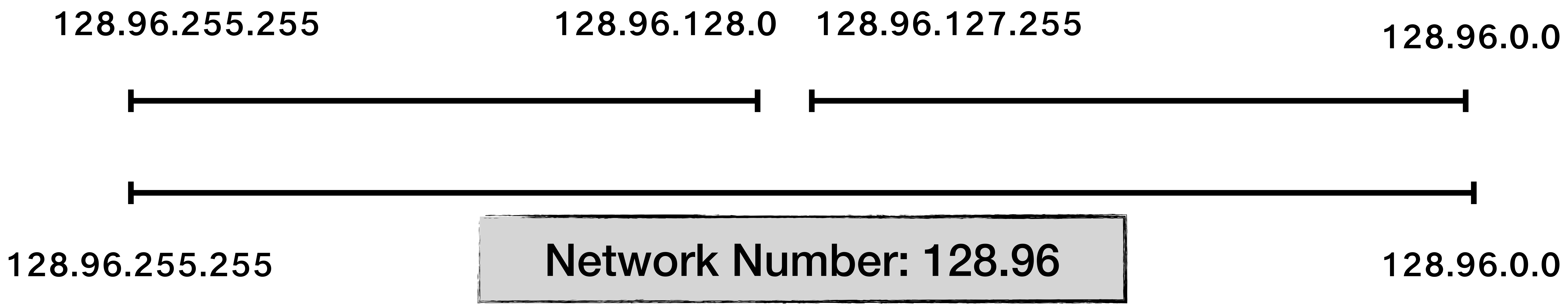

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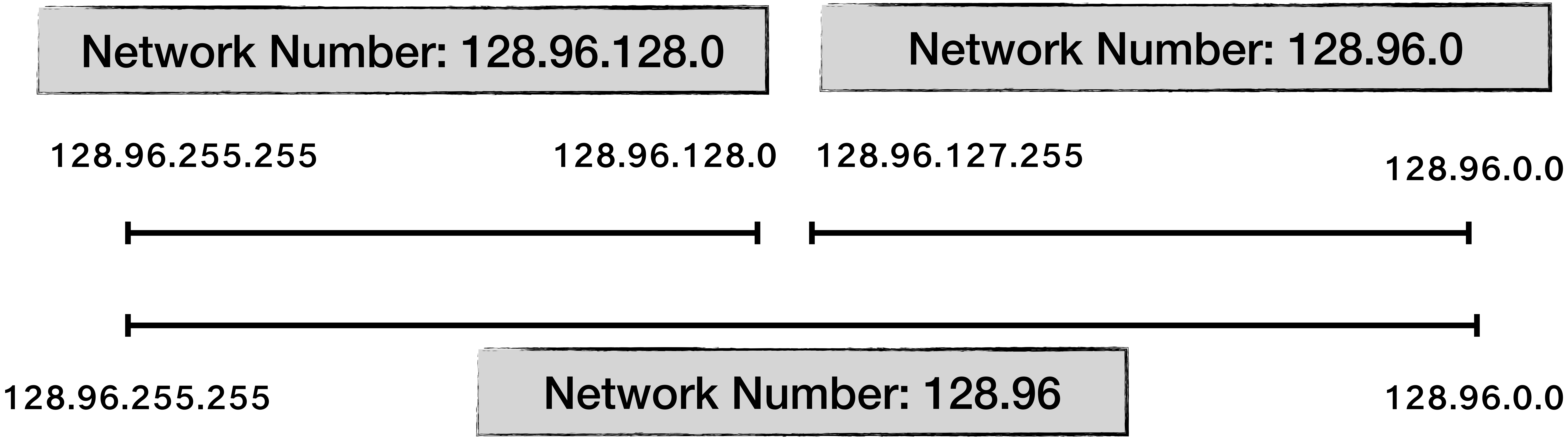

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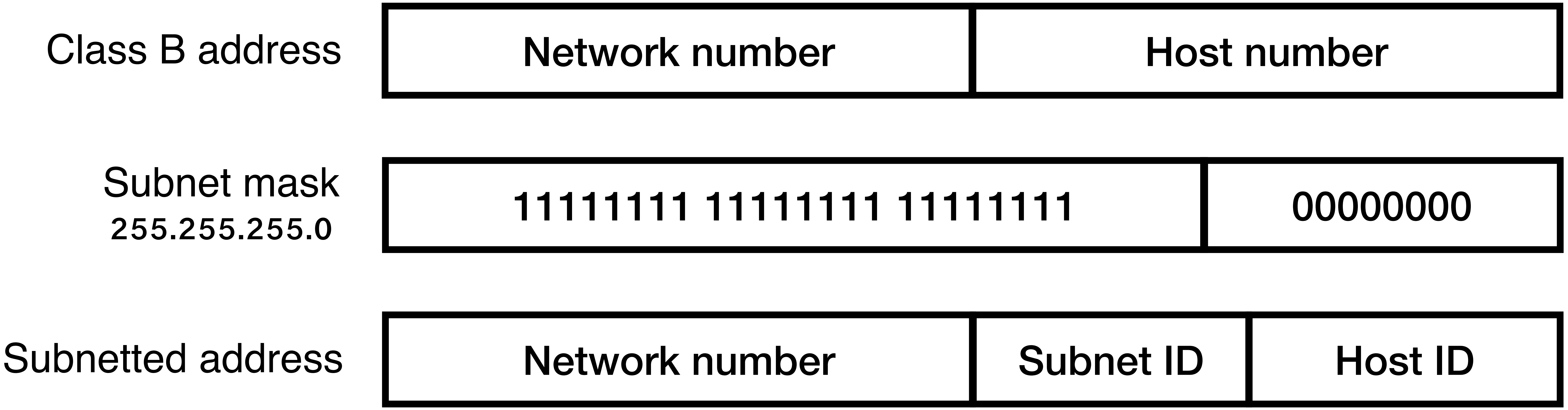

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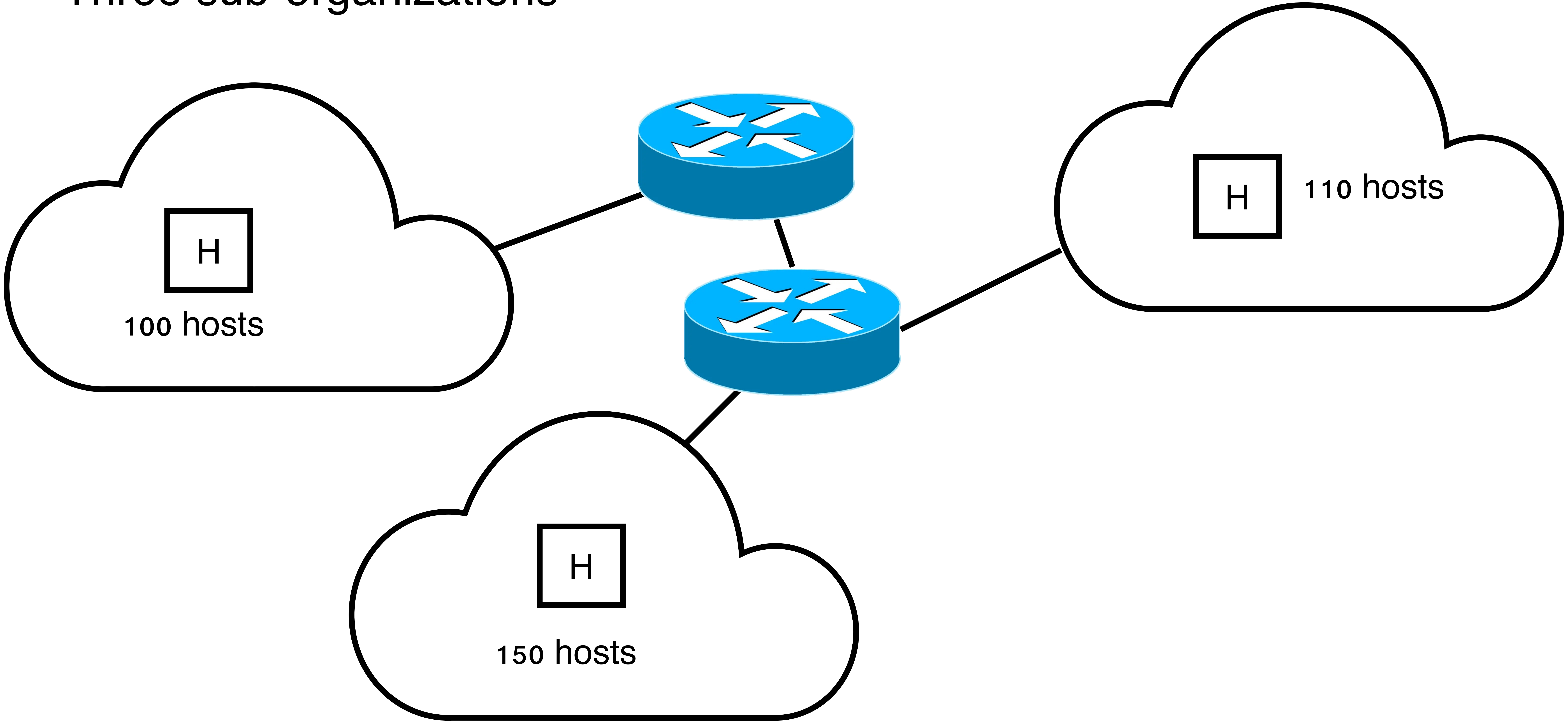
- Suppose the subnet mask is: 255.255.192.0
    - 4 subnets, each holding 2^14 hosts

A Subnet Example

- Get a class B address: 128.96.X.X
  - Three sub-organizations



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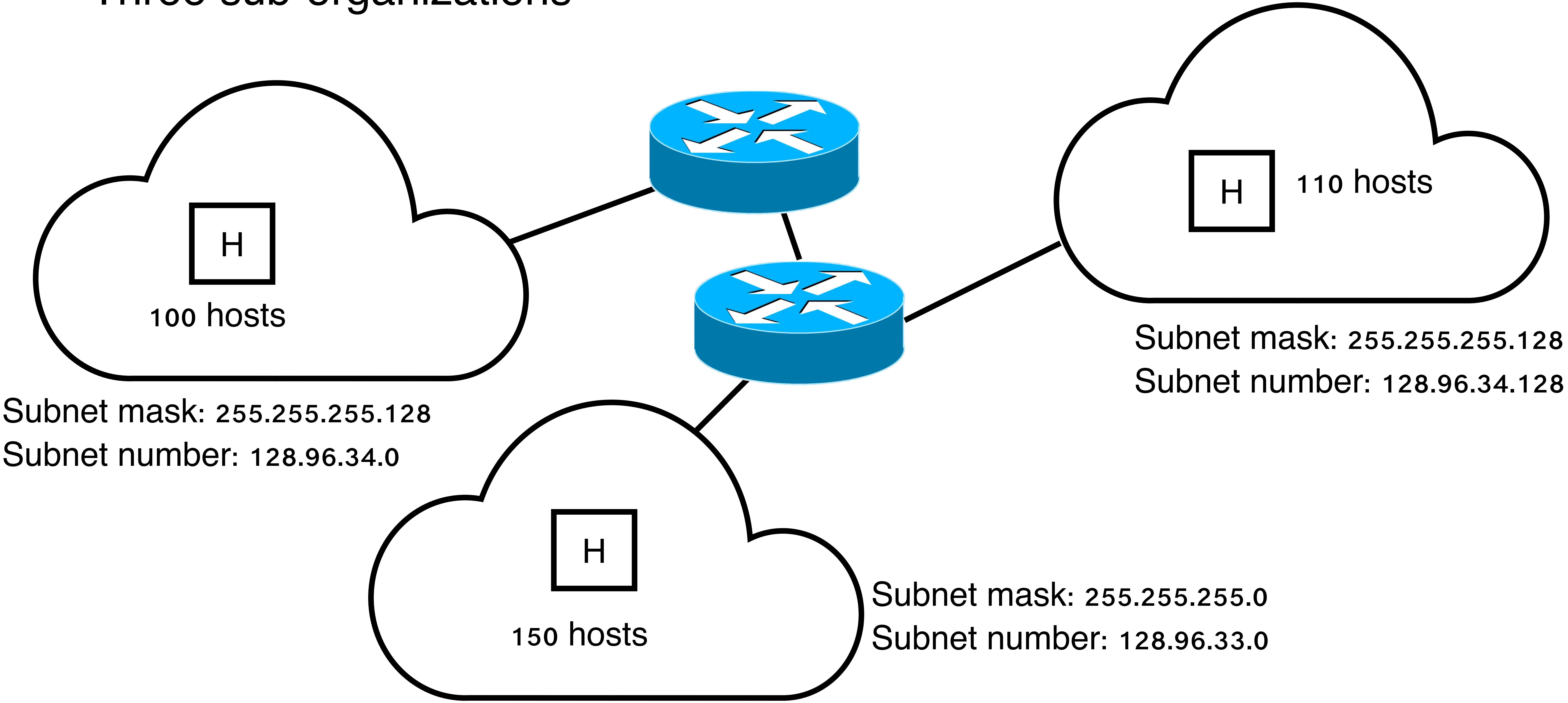

Can We Do Arbitrary Bit Mask Numbers?

- Yes. Chapter 2.2 (RFC 950)
  - It doesn’t care about contiguous bits

```
To support subnets, it is necessary to store one more 32-bit
quantity, called my_ip_mask.  This is a bit-mask with bits set in
the fields corresponding to the IP network number, and additional
bits set corresponding to the subnet number field.

The code then becomes:

   IF bitwise_and(dg.ip_dest, my_ip_mask)
                             = bitwise_and(my_ip_addr, my_ip_mask)
       THEN
           send_dg_locally(dg, dg.ip_dest)
       ELSE
           send_dg_locally(dg,
                  gateway_to(bitwise_and(dg.ip_dest, my_ip_mask)))
```

Can We Do Arbitrary Bit Mask Numbers?

- Yes. Chapter 2.2 (RFC 950)
  - It doesn’t care about contiguous bits

- But not preferred due to computing efficiency
  - AND is more straightforward

- Bit masks: a sequence of N 1 bits followed by a sequence of M 0 bits, where N + M = 32
  - If the subnet number is S (like /24 or slash-24), this means that hosts on the subnet S have IP addresses whose first N bits are 1

Is subnetting enough to solve the address efficiency issue?

Partially Solved, But

- Class B network numbers are highly costly (not everyone needs)
  - Lots of class C addresses are not being used

- The backbone routing tables grow significantly
  - Lots of small networks
  - Route calculation and management require high computing overheads

#2: Supernetting

- Idea: Enable network number to be any length
  - Route aggregation
- Collapse multiple addresses assigned to a single entity
  - Assign a block of continuous network numbers to nearby networks

The CIDR Address Assignement

- CIDR = Classless Interdomain Routing
  - Breaks rigid boundaries between address classes
  - Combine subnetting and supernetting

- An organization can apply class C addresses and merge
  - E.g., 192.4.16.xx to 192.4.31.xx enables a 20-bit network number

CIDR Address

- A CIDR address block: a.b.c.d/x
  - The x most significant bits of an address constitute the network portion
  - Referred to as the prefix
  - 128.211.168.0/21 => 128.211.168.0 — 182.211.175.255

- All possible CIDR masks can be generated
  - /8, /16, /24 refer to traditional class A, B, and C class addresses

- Broadcast address of a CIDR address block
  - All host bits are “1”

An Exercise

A tech startup is assigned the private block 192.168.10.0/24. They need to divide this address space for four distinct departments with different host requirements. Allocate the subnets starting from the largest requirement to the smallest.

- Engineering: 100 hosts
- Marketing: 50 hosts
- Sales: 25 hosts
- Support: 12 hosts

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Solution:

- Engineering (100 hosts): Needs a /25 (128 addresses)
  - Subnet: 192.168.10.0/25
  - Range: .1 to .126 (Broadcast: .127)
- Marketing (50 hosts): Needs a /26 (64 addresses)
  - Subnet: 192.168.10.128/26
  - Range: .129 to .190 (Broadcast: .191)
- Sales (25 hosts): Needs a /27 (32 addresses)
  - Subnet: 192.168.10.192/27
  - Range: .193 to .222 (Broadcast: .223)
- Support (12 hosts): Needs a /28 (16 addresses)
  - Subnet: 192.168.10.224/28
  - Range: .225 to .238 (Broadcast: .239)

How do we assign IP addresses to hosts?

Technique #1: Manual Configure

- Manually choose an IP address based on the network
  - Static allocation
  - `ip a add 192.168.1.100/255.255.255.0 dev eth0`

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- Drawbacks:
  - Lots of work to configure all the hosts in a large network
  - Easy to make mistakes

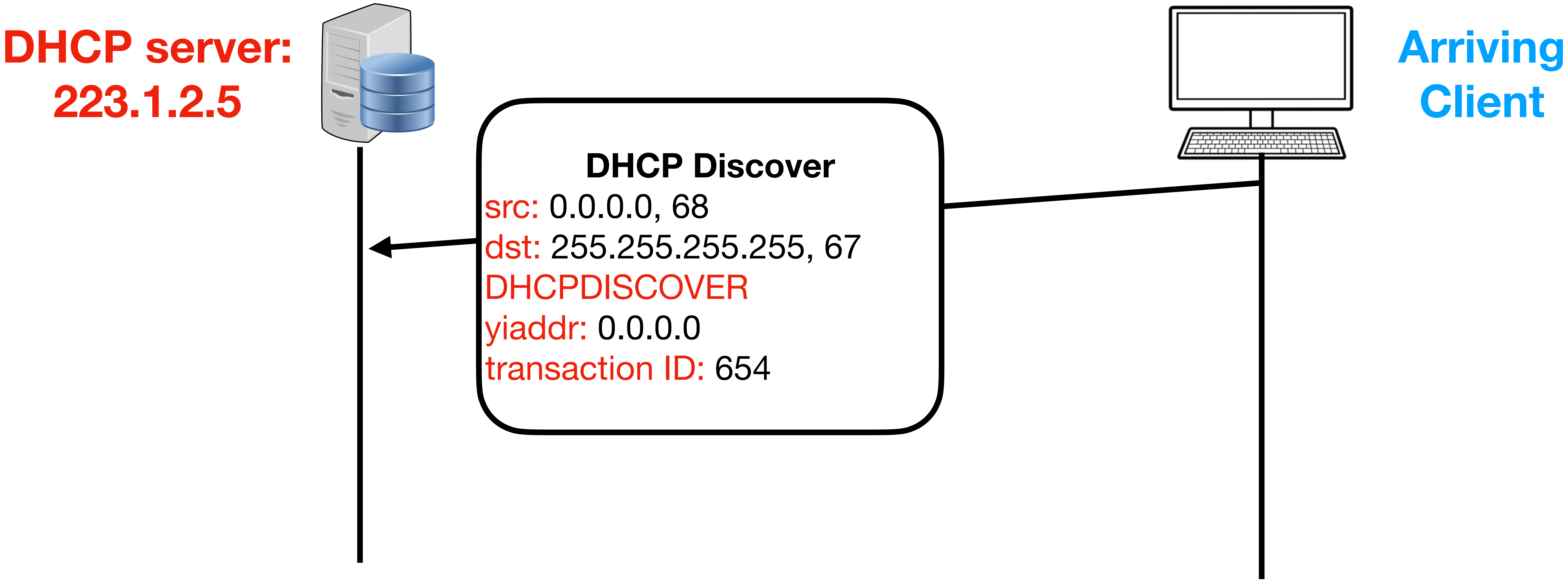
Technique #2: DHCP

- Dynamic Host Configuration Protocol
  - A dedicated service for assigning IP for each administrative domain

- A DHCP server maintains a pool of available addresses
  - Maintain the mapping between hosts and IP addresses
  - Each IP is associated with a lease to ensure flexibility
  - Leases are periodically refreshed

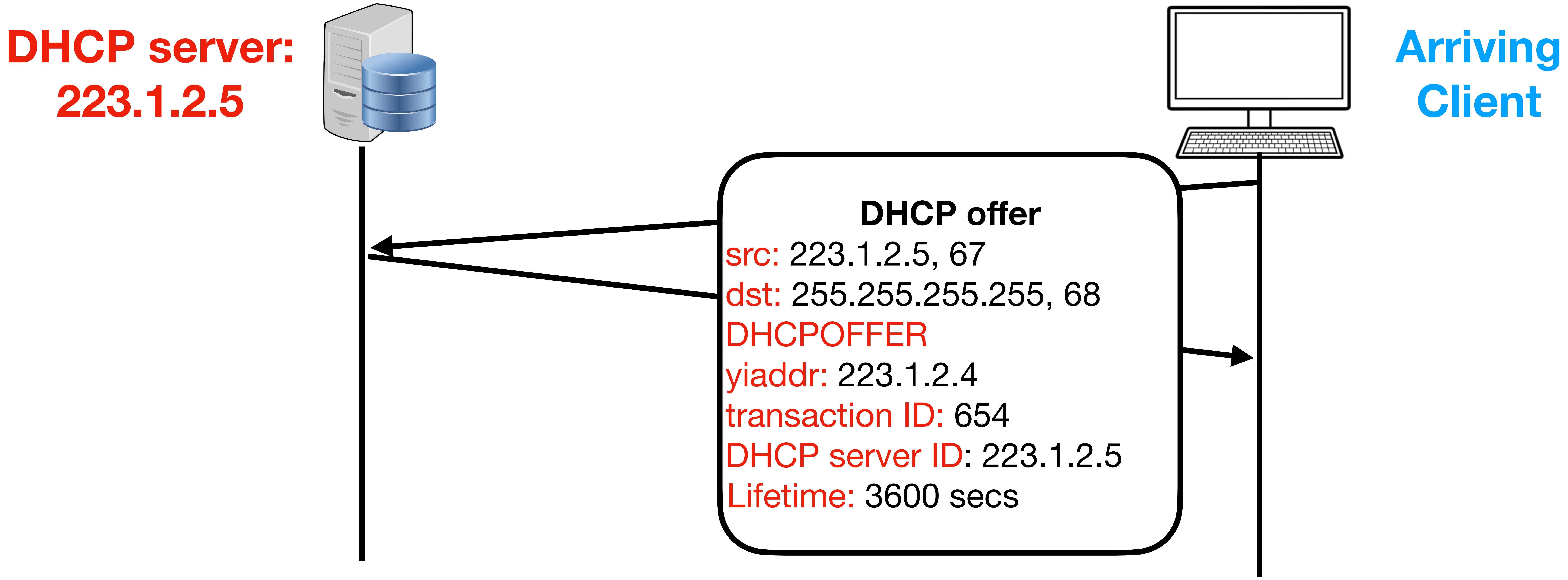
How DHCP Works

- #1: DHCP Discover
  - An arriving client sends a special IP broadcast message to the network



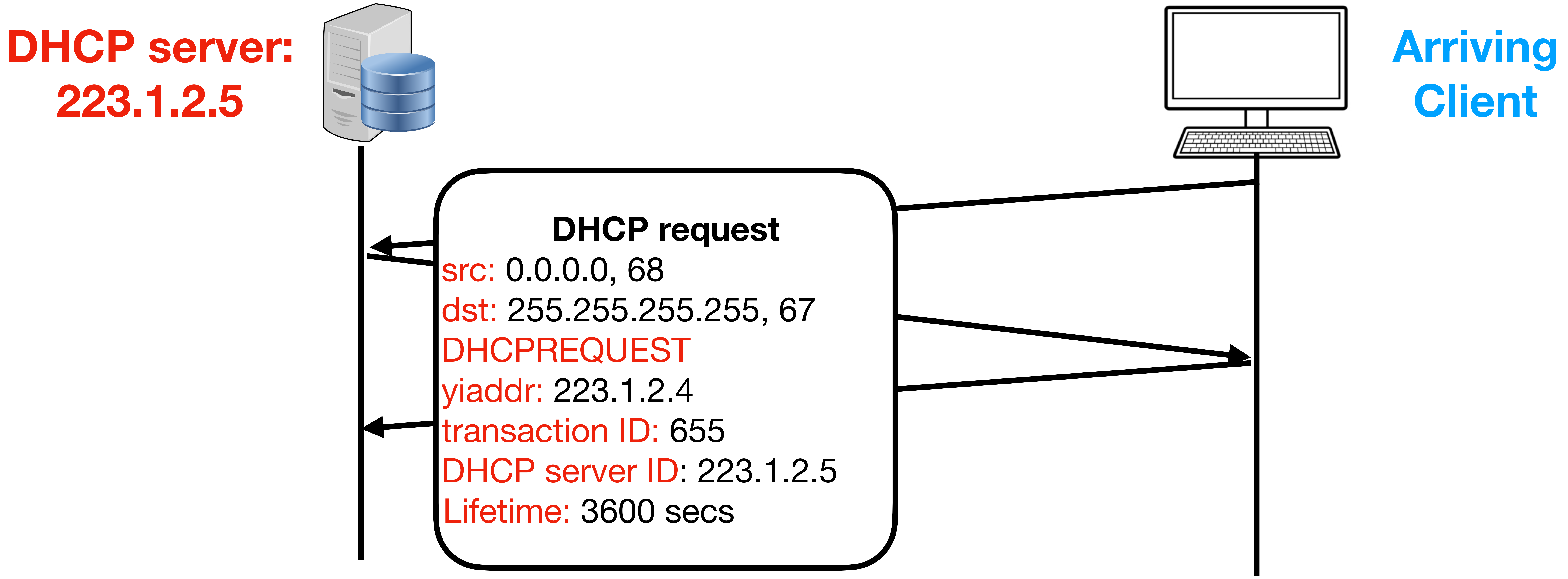
How DHCP Works

- #2: DHCP offer
  - A client can receive multiple offers



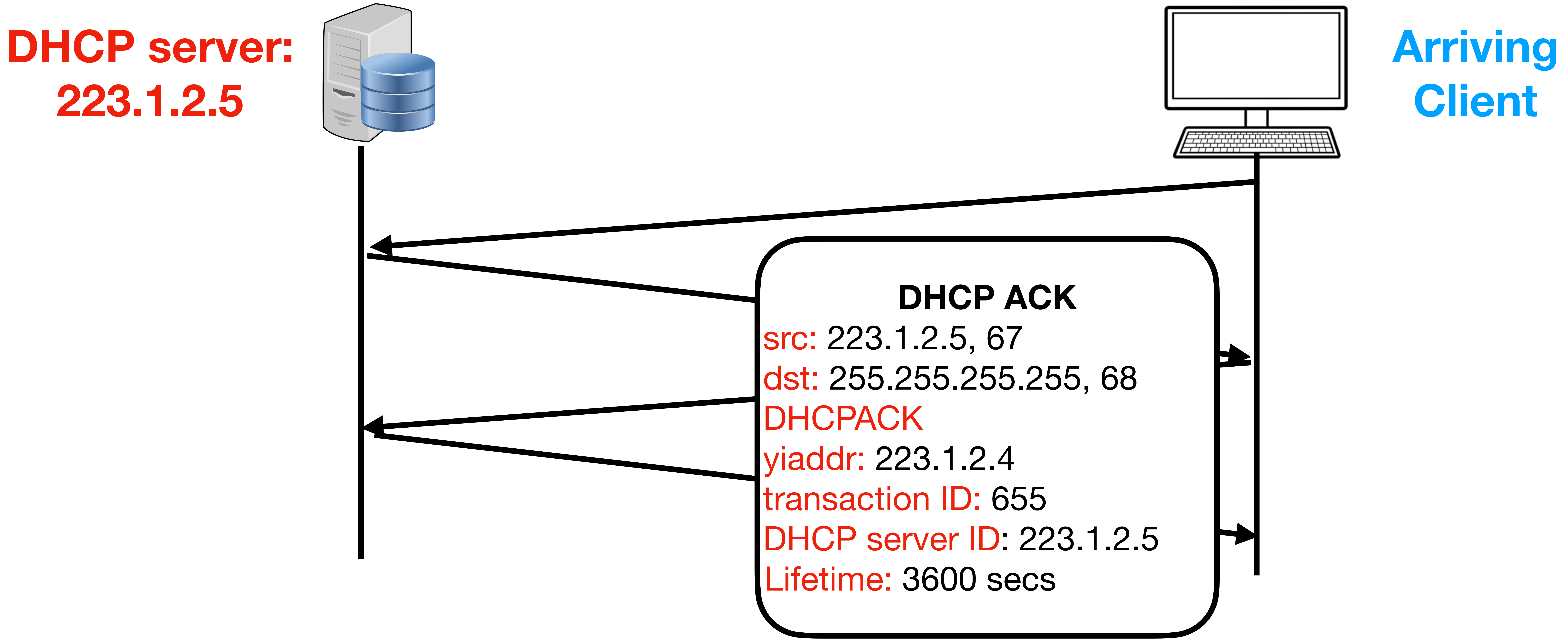
How DHCP Works

- #3: DHCP request
  - The client makes the decision



How DHCP Works

- #4: DHCP ACK
  - The server confirms



Summary

- Today
  - Efficient Addressing

- Next lecture
  - Distance vector routing