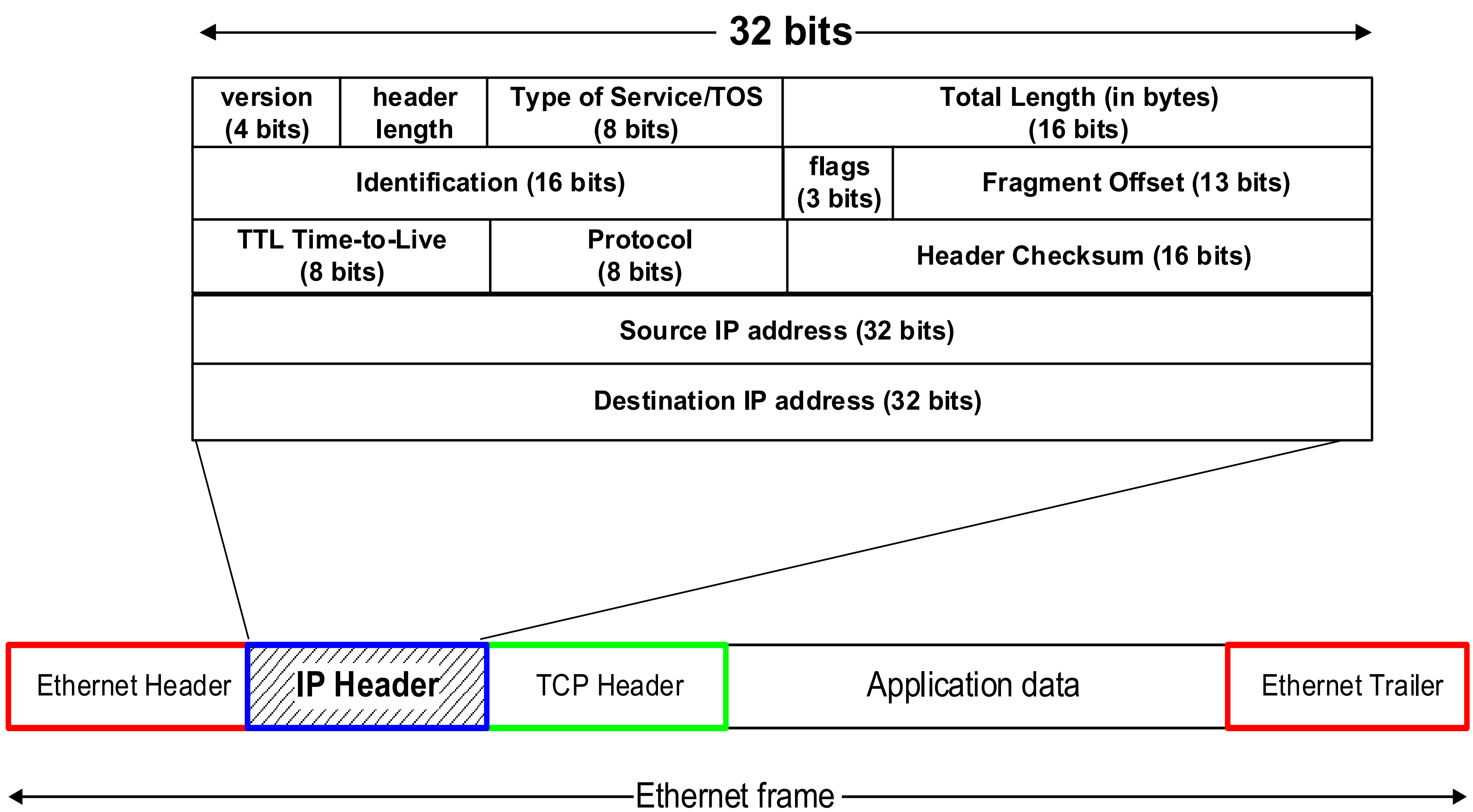
Why IP addresses?

- A MAC address has no structure, so it tells a switch the *identity* (who) of the destination interface but not its *location* (where).
- With just MAC addresses, switches would have to resort to broadcast the first time they encounter a new address.
- Switch forwarding table sizes would be on the order of the total number of MAC addresses.

IP Addresses

- Structure of an IP address
- Subnetting
- CIDR prefixes vs. old classful IP addresses
- IP Version 6 addresses

IP Addresses



What is an IP Address?

- An IP address is a unique global address for a network interface
- Exceptions:
  - Dynamically assigned IP addresses (→ DHCP, Lab 7)
  - IP addresses in private networks (→ NAT, Lab 7)

- An IP address:

  - is a **32 bit long** identifier

  - encodes a network number (**network prefix**) and a **host number**

Network prefix and host number

- The network prefix identifies a network and the host number identifies a specific host (actually, interface on the network).

network prefix	host number

- **How do we know how long the network prefix is?**
  - **Before 1993:** The network prefix is implicitly defined (see **class-based addressing**)

  or

  - **After 1993:** The network prefix is indicated by a **netmask.**

Dotted Decimal Notation

- IP addresses are written in a so-called ***dotted decimal* notation**
- Each byte is identified by a decimal number in the range [0..255]:

- **Example:**

10000000	10001111	10001001	10010000
1st Byte	2nd Byte	3rd Byte	4th Byte
= 128	**= 143**	**= 137**	**= 144**

128.143.137.144

Example

- **Example**: ellington.cs.virginia.edu

128.143	**137.144**

- Network address is: **128.143.0.0** **(or 128.143)**
- Host number is: **137.144**
- Netmask is: **255.255.0.0** (or **ffff0000)**

- Prefix or CIDR notation: **128.143.137.144/16**
  - » Network prefix is 16 bits long

Special IP Addresses

- **Reserved or (by convention) special addresses:**

  Loopback interfaces
    - all addresses 127.0.0.1-127.255.255.255 are reserved for loopback interfaces
    - Most systems use 127.0.0.1 as loopback address
    - loopback interface is associated with name “localhost”

  IP address of a network
    - Host number is set to all zeros, e.g., 128.143.**0.0**

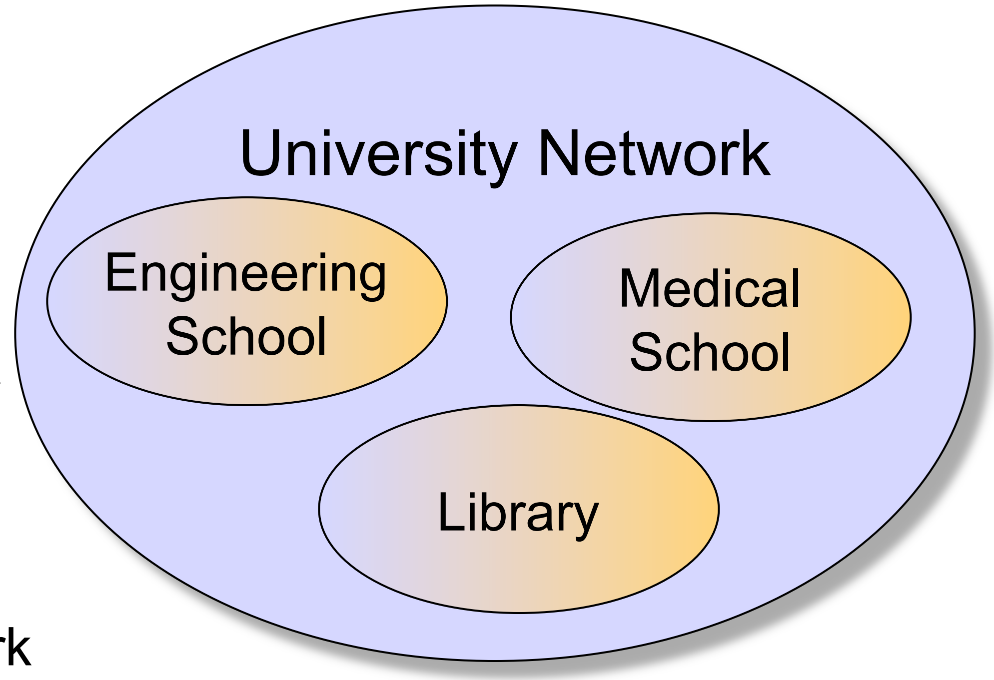
  Broadcast address
    - Host number is all ones, e.g., 128.143.**255.255**
    - Broadcast goes to all hosts on the network
    - Often ignored due to security concerns
- **Test / Experimental addresses**
  Certain address ranges are reserved for “experimental use”. Packets should get dropped if they contain this destination address (see RFC 1918):

10.0.0.0	-	10.255.255.255
172.16.0.0	-	172.31.255.255
192.168.0.0	-	192.168.255.255

- **Convention (but not a reserved address)**
  Default gateway has host number set to ‘1’, e.g., e.g., 192.0.1.**1**

Subnetting

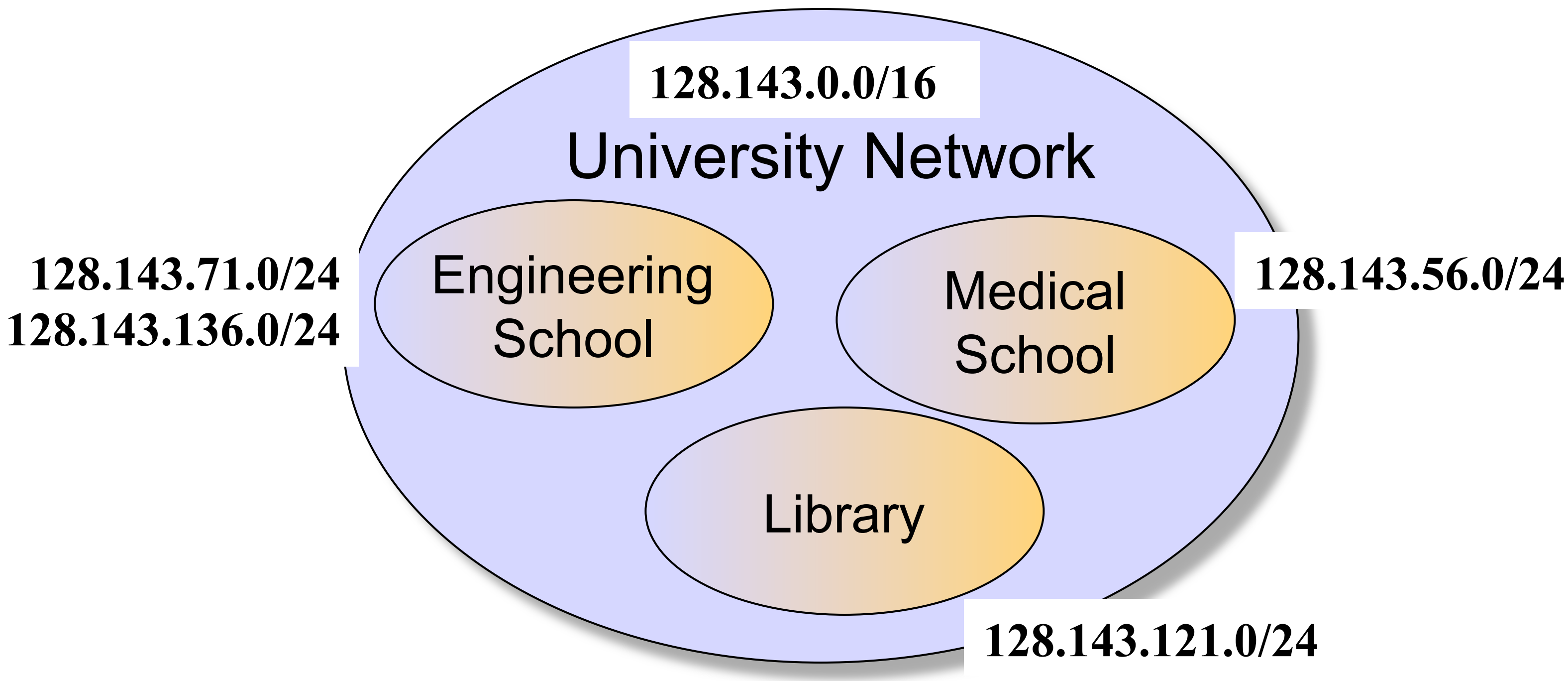
- **Problem**: Organizations have multiple networks which are independently managed
  - **Solution 1:** Allocate a separate network address for each network
    - Difficult to manage
    - From the outside of the organization, each network must be addressable.
  - **Solution 2:** Add another level of hierarchy to the IP addressing structure



Subnetting

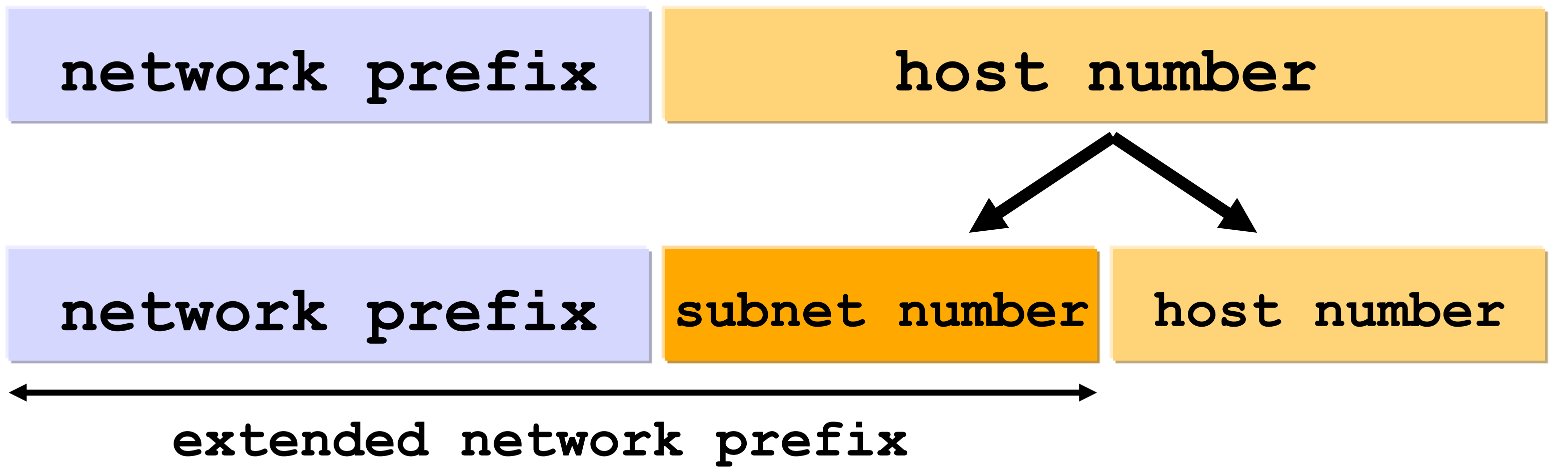
Address assignment with subnetting

- Each part of the organization is allocated a range of IP addresses (subnets or subnetworks)
- Addresses in each subnet can be administered locally



Basic Idea of Subnetting

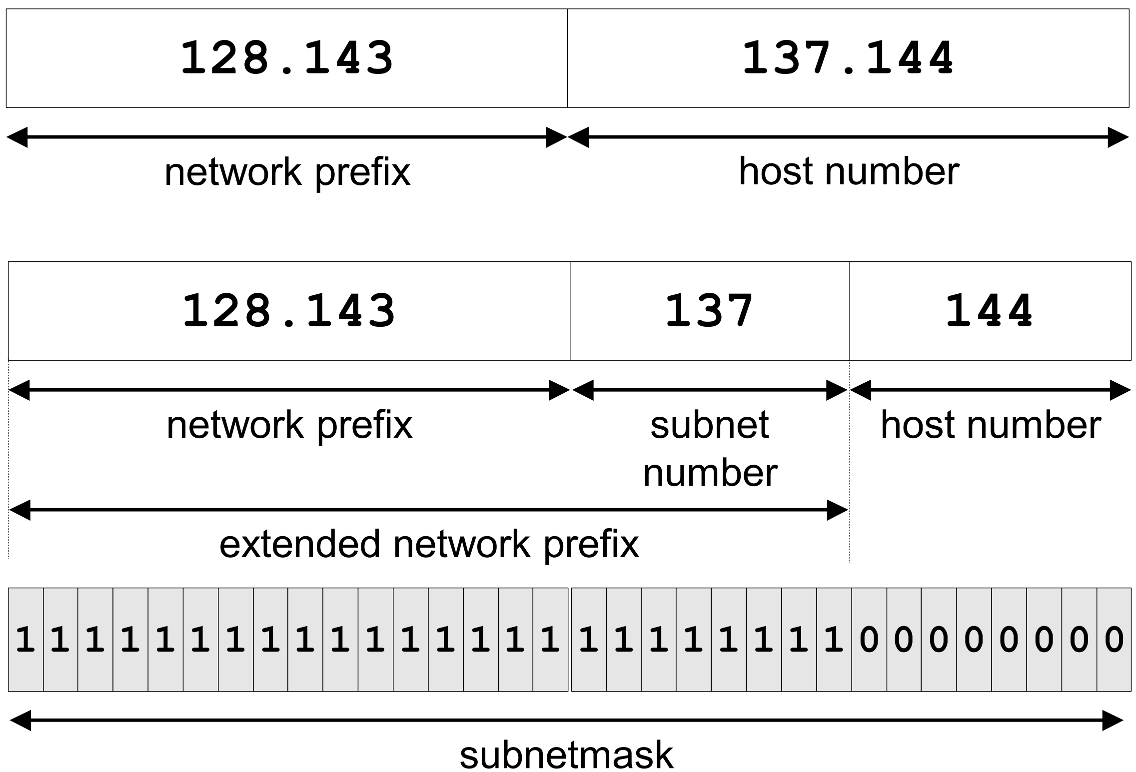
- Split the host number portion of an IP address into a `subnet number` and a (smaller) `host number`.
- Result is a 3-layer hierarchy



- Then:
  - Subnets can be freely assigned within the organization
  - Internally, subnets are treated as separate networks
  - Subnet structure is not visible outside the organization

Subnetmask

- Routers and hosts use an **extended network prefix** (**subnetmask)** to identify the start of the host numbers



Advantages of Subnetting

- With subnetting, IP addresses use a 3-layer hierarchy:
  - » Network
  - » Subnet
  - » Host

- Reduces router complexity. Since external routers do not know about subnetting, the complexity of routing tables at external routers is reduced.

- Note: Length of the subnet mask need not be identical at all subnetworks.

Example: Subnetmask

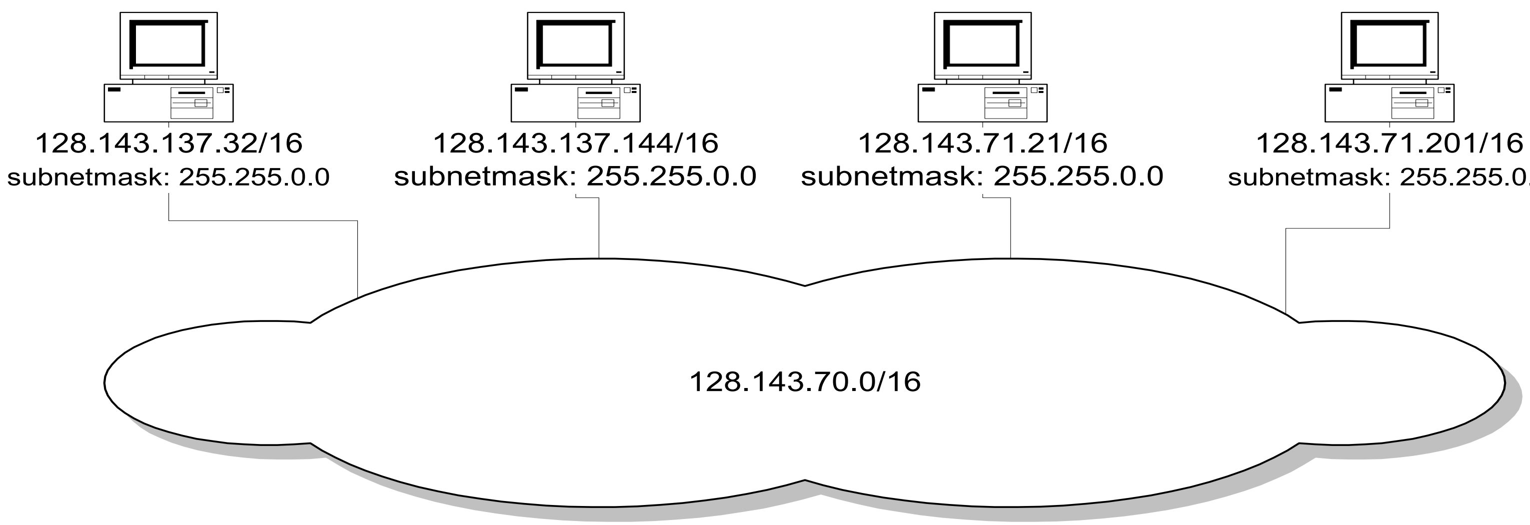
- 128.143.0.0/16 is the IP address of the network
- 128.143.137.0/24 is the IP address of the subnet

- 128.143.137.144 is the IP address of the host
- 255.255.255.0 (or ffffff00) is the subnetmask of the host

- When subnetting is used, one generally speaks of a “subnetmask” (instead of a netmask) and a “subnet” (instead of a network)
- Use of subnetting or length of the subnetmask if decided by the network administrator
- Consistency of subnetmasks is responsibility of administrator

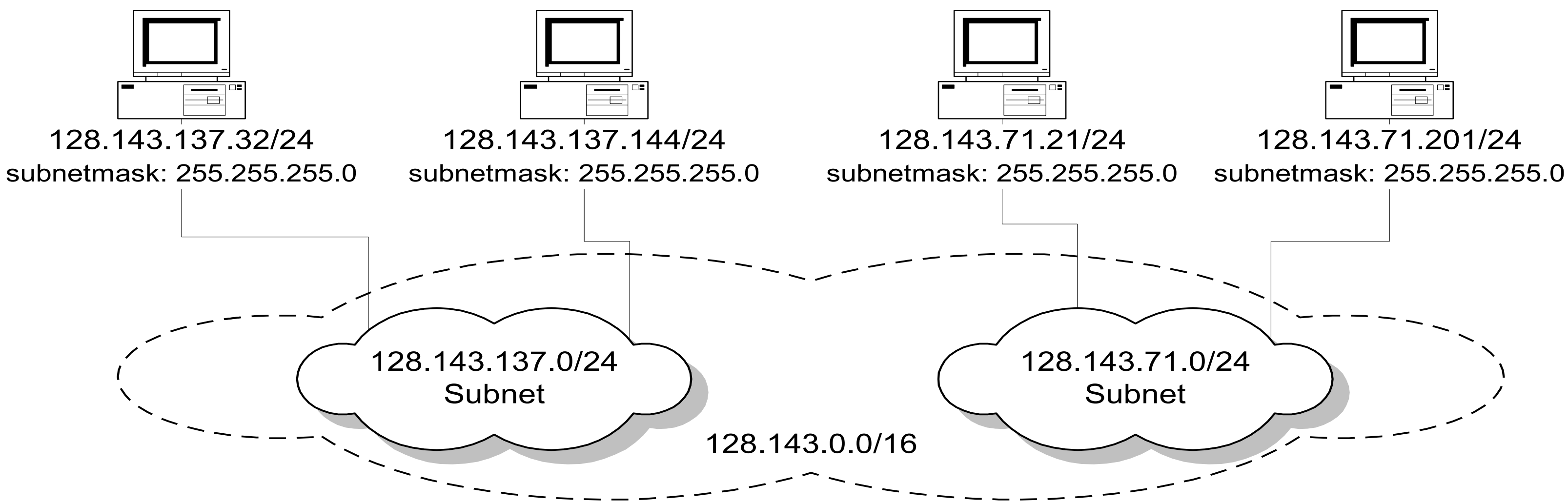
No Subnetting

- All hosts think that the other hosts are on the same network



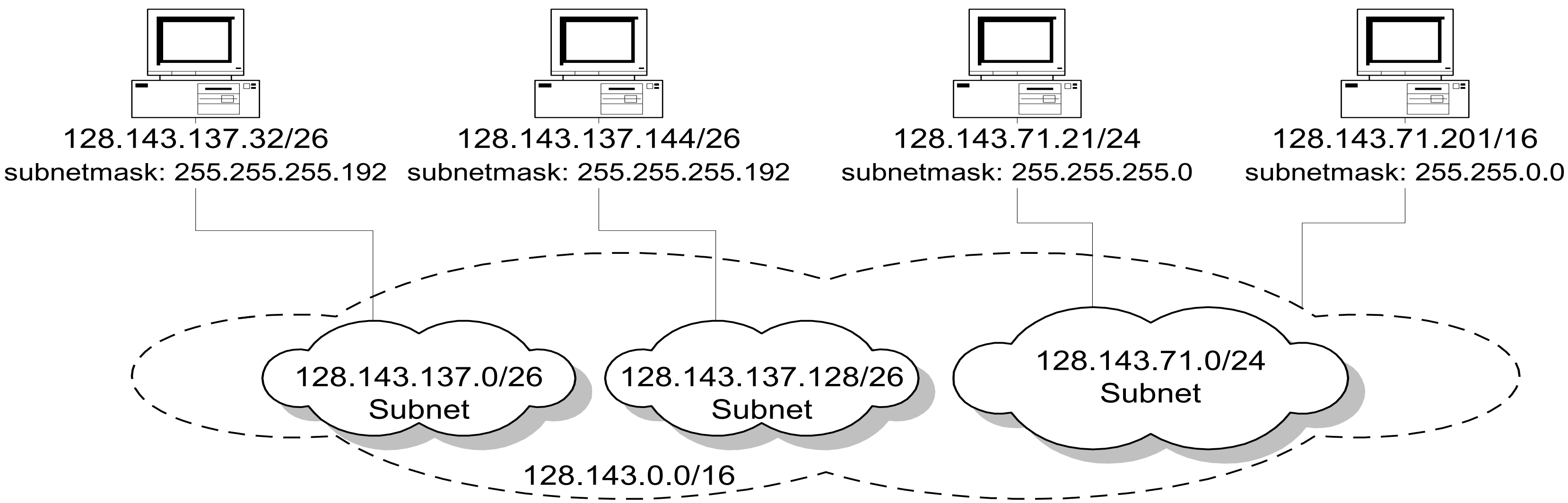
With Subnetting

- Hosts with same extended network prefix belong to the same network



With Subnetting

- Different subnetmasks lead to different views of the size of the scope of the network

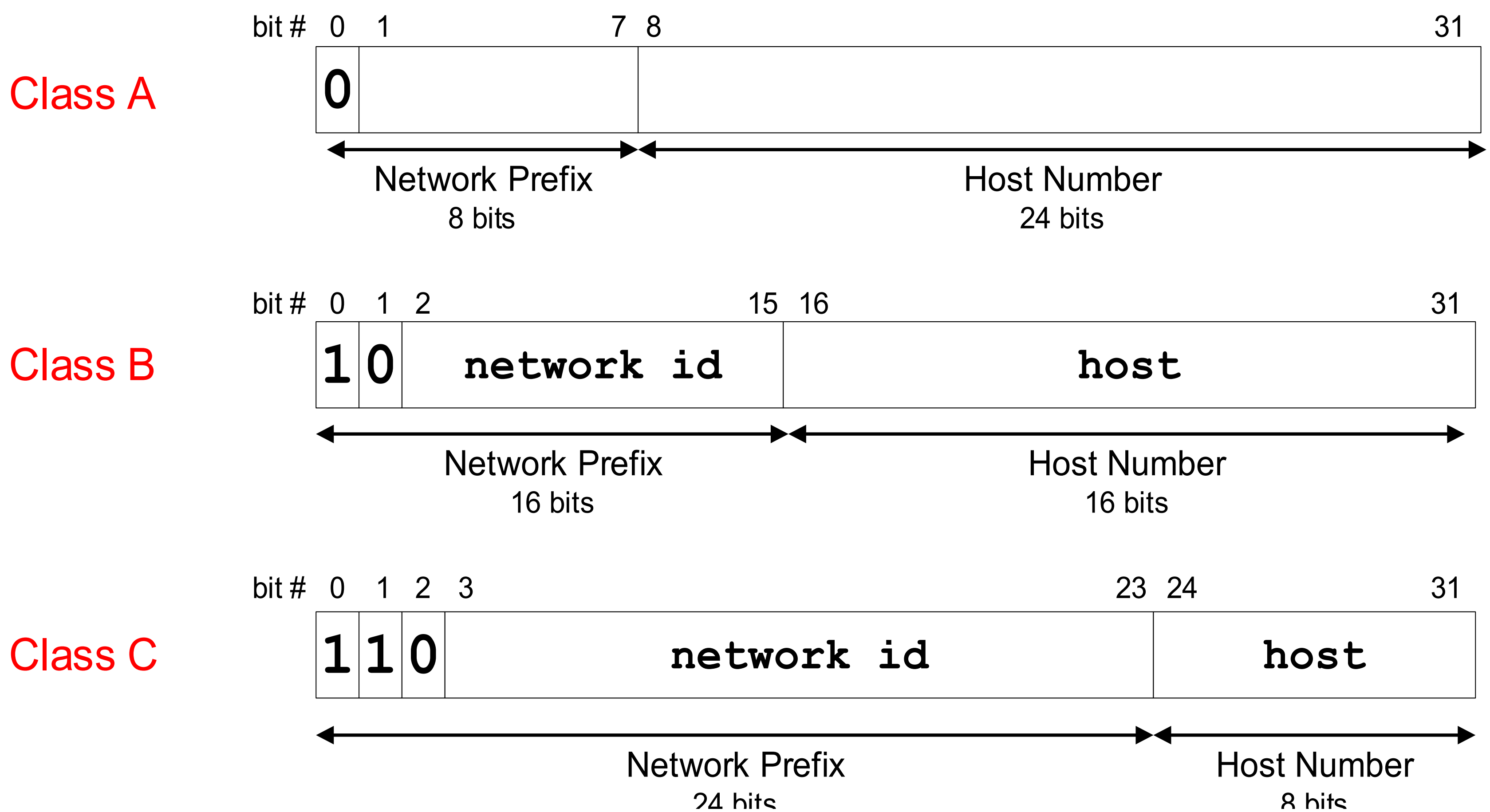


Classful IP Adresses (Until 1993)

- When Internet addresses were standardized (early 1980s), the Internet address space was divided up into classes:
  - **Class A:** Network prefix is 8 bits long
  - **Class B:** Network prefix is 16 bits long
  - **Class C:** Network prefix is 24 bits long

- Each IP address contained a key which identifies the class:
  - **Class A:** IP address starts with "0"
  - **Class B:** IP address starts with "10"
  - **Class C:** IP address starts with "110"

The old way: Internet Address Classes



The old way: Internet Address Classes

Class D

bit #	0	1	2	3	4 ... 31
	1	1	1	0	`multicast group id`

Class E

bit #	0	1	2	3	4	5 ... 31
	1	1	1	1	0	`(reserved for future use)`

- We will learn about multicast addresses later in this course.

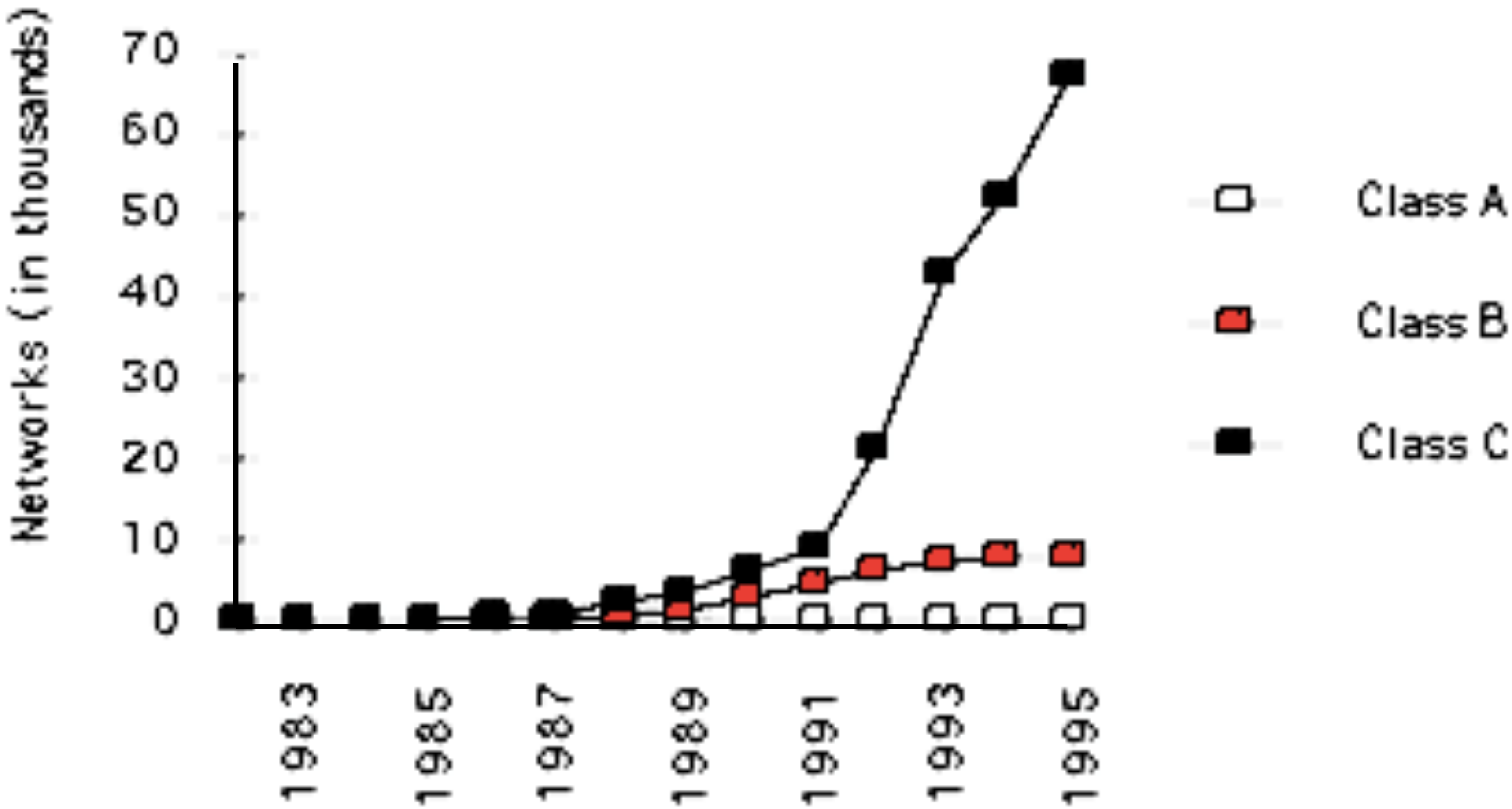
Problems with Classful IP Addresses

- By the early 1990s, the original classful address scheme had a number of problems
  - **Flat address space.** Routing tables on the backbone Internet need to have an entry for each network address. When Class C networks were widely used, this created a problem. By the 1993, the size of the routing tables started to outgrow the capacity of routers.

Other problems:

  - **Too few network addresses for large networks**
    - Class A and Class B addresses were gone
  - **Limited flexibility for network addresses:**
    - Class A and B addresses are overkill (>64,000 addresses)
    - Class C address is insufficient (requires 40 Class C addresses)

Allocation of Classful Addresses



CIDR - Classless Interdomain Routing

- IP backbone routers have one routing table entry for each network address:
  - With subnetting, a backbone router only needs to know one entry for each Class A, B, or C networks
  - This might have been acceptable for Class A and Class B networks
    - 2^7 = 128 Class A networks
    - 2^{14} = 16,384 Class B networks
  - But this was not acceptable for Class C networks
    - 2^{21} = 2,097,152 Class C networks
- In 1993, the size of the routing tables started to outgrow the capacity of routers
- Consequence: The Class-based assignment of IP addresses had to be abandoned

CIDR - Classless Interdomain Routing

- **Goals:**
  - New interpretation of the IP address space
  - Restructure IP address assignments to increase efficiency
  - Permits route aggregation to minimize route table entries

- CIDR (Classless Interdomain routing)
  - abandons the notion of classes
  - **Key Concept:** The length of the network prefix in the IP addresses is kept arbitrary
  - Consequence: Size of the network prefix must be provided with an IP address

CIDR Notation

- CIDR notation of an IP address:

  192.0.2.0/18

  - "18" is the prefix length. It states that the first 18 bits are the network prefix of the address (and 14 bits are available for specific host addresses)

- CIDR notation can replace the use of subnetmasks (but is more general)
  - IP address 128.143.137.144 and subnetmask 255.255.255.0 becomes 128.143.137.144/24

- CIDR notation allows to drop traling zeros of network addresses:

  192.0.2.0/18 can be written as **192.0.2/18**

CIDR address blocks

- CIDR notation can nicely express blocks of addresses
- Blocks are used when allocating IP addresses for a company and for routing tables (route aggregation)

CIDR Block Prefix	# of Host Addresses
/27	32
/26	64
/25	128
/24	256
/23	512
/22	1,024
/21	2,048
/20	4,096
/19	8,192
/18	16,384
/17	32,768
/16	65,536
/15	131,072
/14	262,144
/13	524,288

CIDR and Address assignments

- Backbone ISPs obtain large block of IP addresses space and then reallocate portions of their address blocks to their customers.

Example:

- Assume that an ISP owns the address block 206.0.64.0/18, which represents 16,384 (2^{14}) IP addresses
- Suppose a client requires 800 host addresses
- With classful addresses: need to assign a class B address (and waste ~64,700 addresses) or four individual Class Cs (and introducing 4 new routes into the global Internet routing tables)
- With CIDR: Assign a /22 block, e.g., 206.0.68.0/22, and allocated a block of 1,024 (2^{10}) IP addresses.

CIDR and Routing

- **Aggregation** of routing table entries:
  - 128.143.0.0/16 and 128.144.0.0/16 are represented as 128.142.0.0/15
- **Longest prefix match**: Routing table lookup finds the routing entry that matches the longest prefix

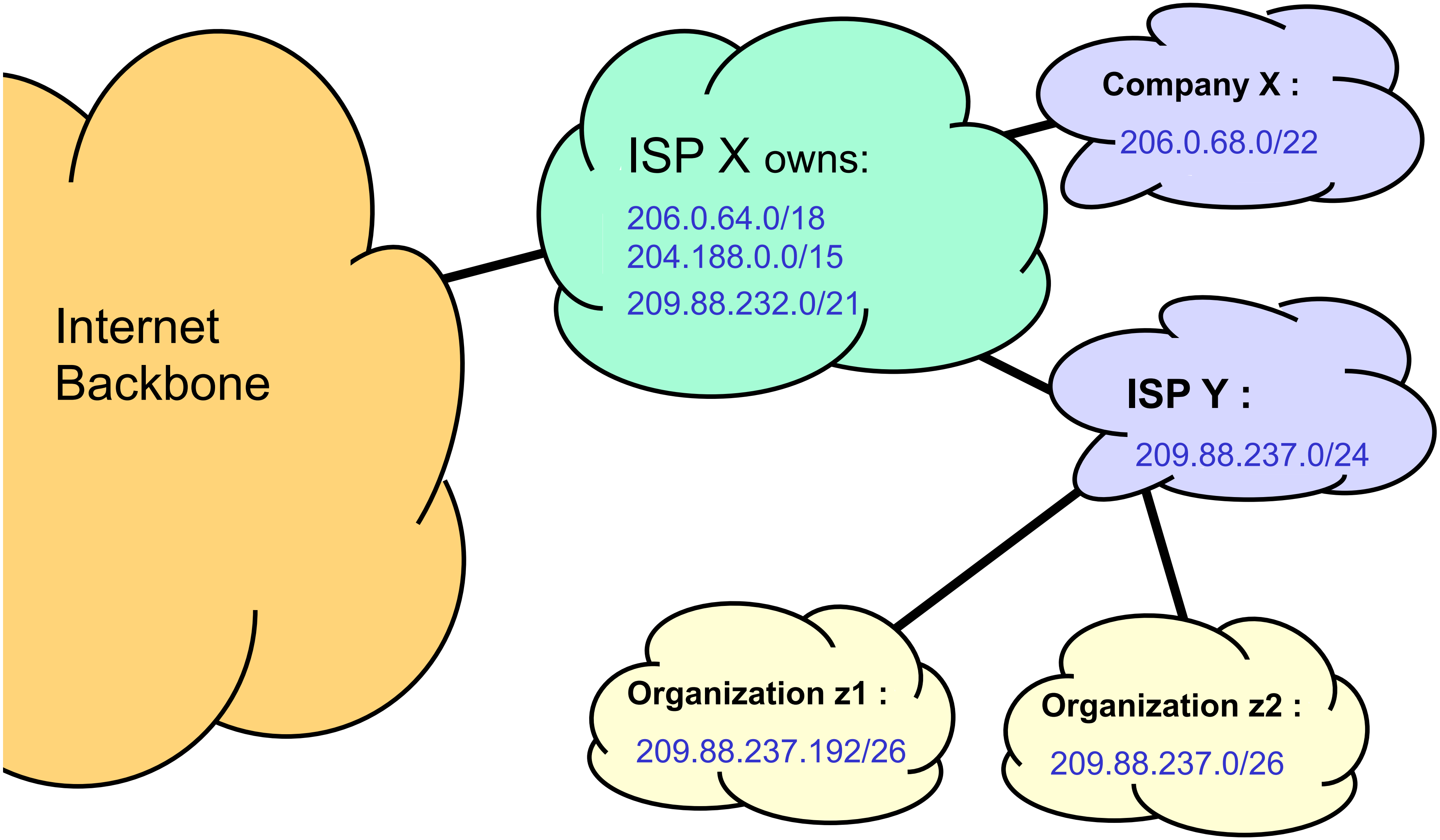
What is the outgoing interface for 128.143.137.0/24 ?

Prefix	Interface
128.0.0.0/4	interface #5
128.128.0.0/9	interface #2
128.143.128.0/17	interface #1

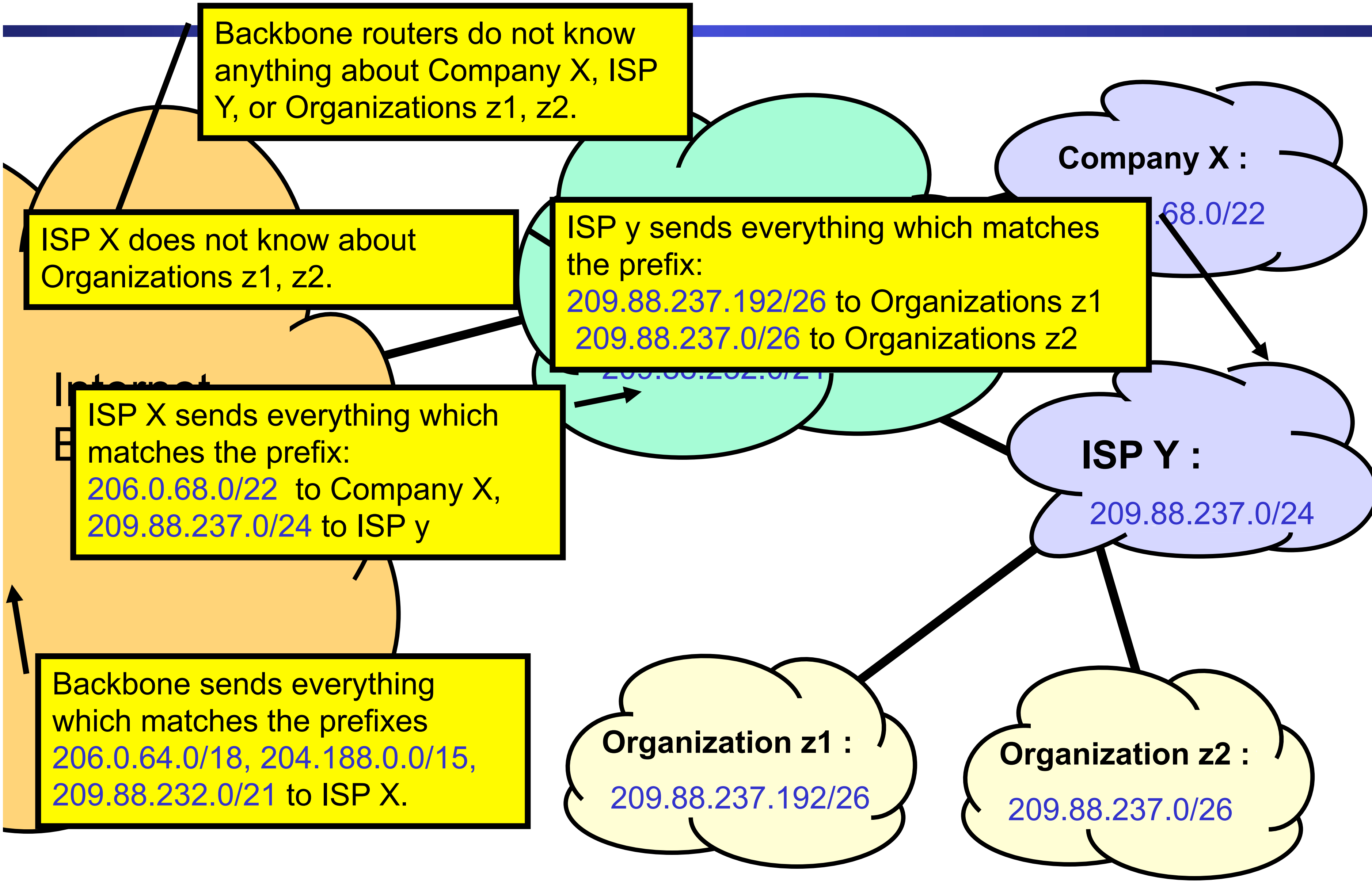
Routing table

Route aggregation can be exploited when IP address blocks are assigned in an hierarchical fashion

CIDR and Routing Information



CIDR and Routing Information



What if organization changes ISPs?

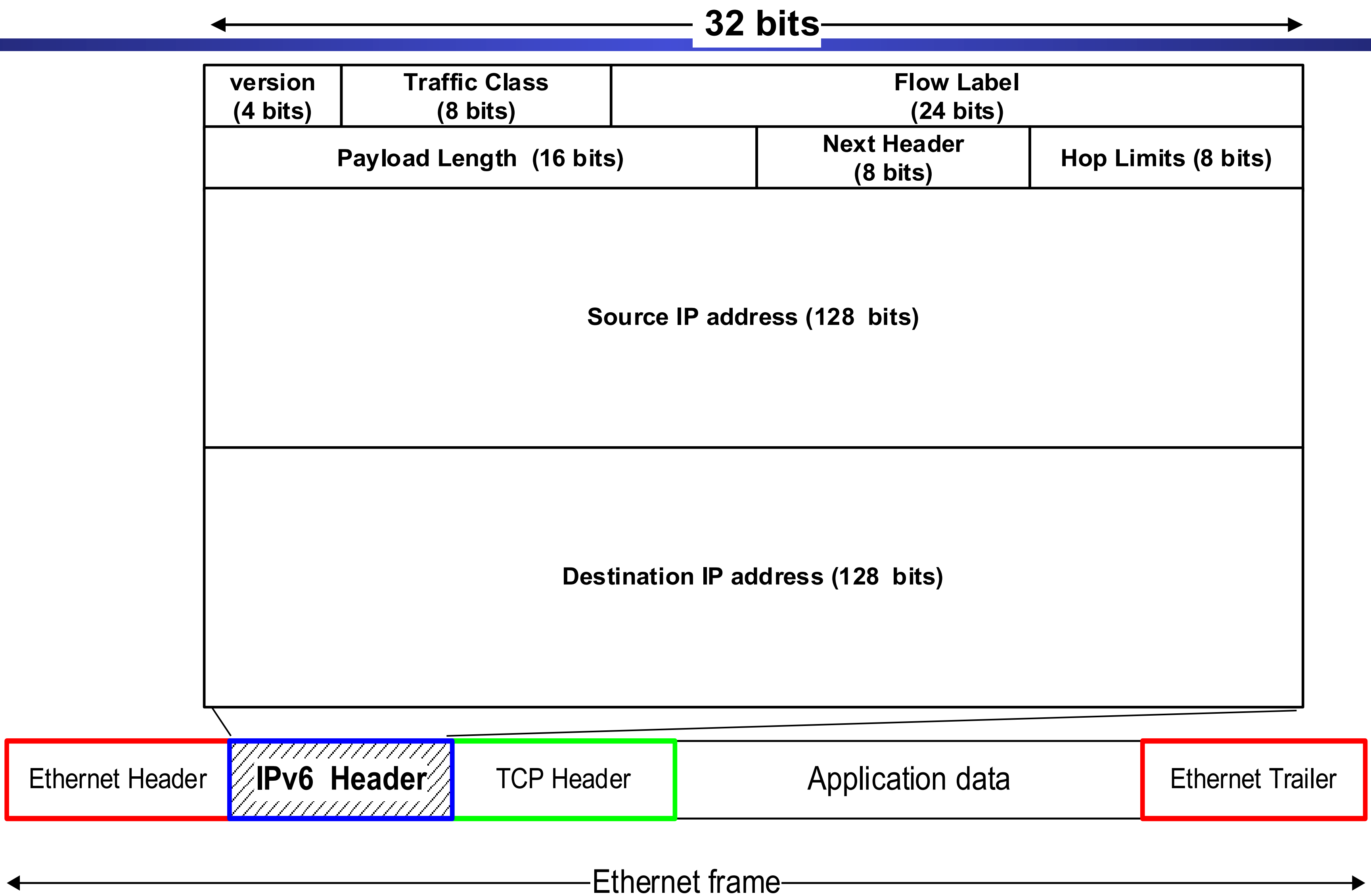
- For example, organization z2 moves from Y to X?

IPv6 - IP Version 6

- **IP Version 6**
  - Is the successor to the currently used IPv4
  - Specification completed in 1994
  - Makes improvements to IPv4 (no revolutionary changes)

- One (not the only !) feature of IPv6 is a significant increase in of the IP address to **128 bits (16 bytes)**
  - IPv6 will solve – for the foreseeable future – the problems with IP addressing
  - 10^{24} addresses per square inch on the surface of the Earth.

IPv6 Header


32 bits
version
(4 bits)
Traffic Class
(8 bits)
Flow Label
(24 bits)
Payload Length (16 bits)
Next Header
(8 bits)
Hop Limits (8 bits)
Source IP address (128 bits)
Destination IP address (128 bits)
Ethernet Header
IPv6 Header
TCP Header
Application data
Ethernet Trailer
Ethernet frame

IPv6 vs. IPv4: Address Comparison

- **IPv4** has a maximum of

  $2^{32} \approx 4$ billion addresses

- **IPv6** has a maximum of

  $\mathbf{2^{128} = (2^{32})^4 \approx 4}$ **billion x 4 billion x 4 billion x 4 billion addresses**

Notation of IPv6 addresses

- **Convention**: The 128-bit IPv6 address is written as **eight 16-bit integers** (using hexadecimal digits for each integer)

CEDF:BP76:3245:4464:FACE:2E50:3025:DF12

- **Short notation:**
- Abbreviations of leading zeroes:

CEDF:BP76:0000:0000:009E:0000:3025:DF12

→ **CEDF:BP76:0:0:9E :0:3025:DF12**

- ":0000:0000:" can be written as "::"

CEDF:BP76:0:0:FACE:0:3025:DF12 → **CEDF:BP76::FACE:0:3025:DF12**

- IPv6 addresses derived from IPv4 addresses have 96 leading zero bits. Convention allows to use IPv4 notation for the last 32 bits.

::80:8F:89:90 → **::128.143.137.144**

IPv6 Provider-Based Addresses

- The first IPv6 addresses will be allocated to a provider-based plan

010	Registry ID	Provider ID	Subscriber ID	Subnetwork ID	Interface ID

- Type: Set to “010” for provider-based addresses
- Registry: identifies the agency that registered the address

The following fields have a variable length (recommeded length in “()”)

- Provider: Id of Internet access provider *(16 bits)*
- Subscriber: Id of the organization at provider *(24 bits)*
- Subnetwork: Id of subnet within organization *(32 bits)*
- Interface: identifies an interface at a node *(48 bits)*