IP Addressing

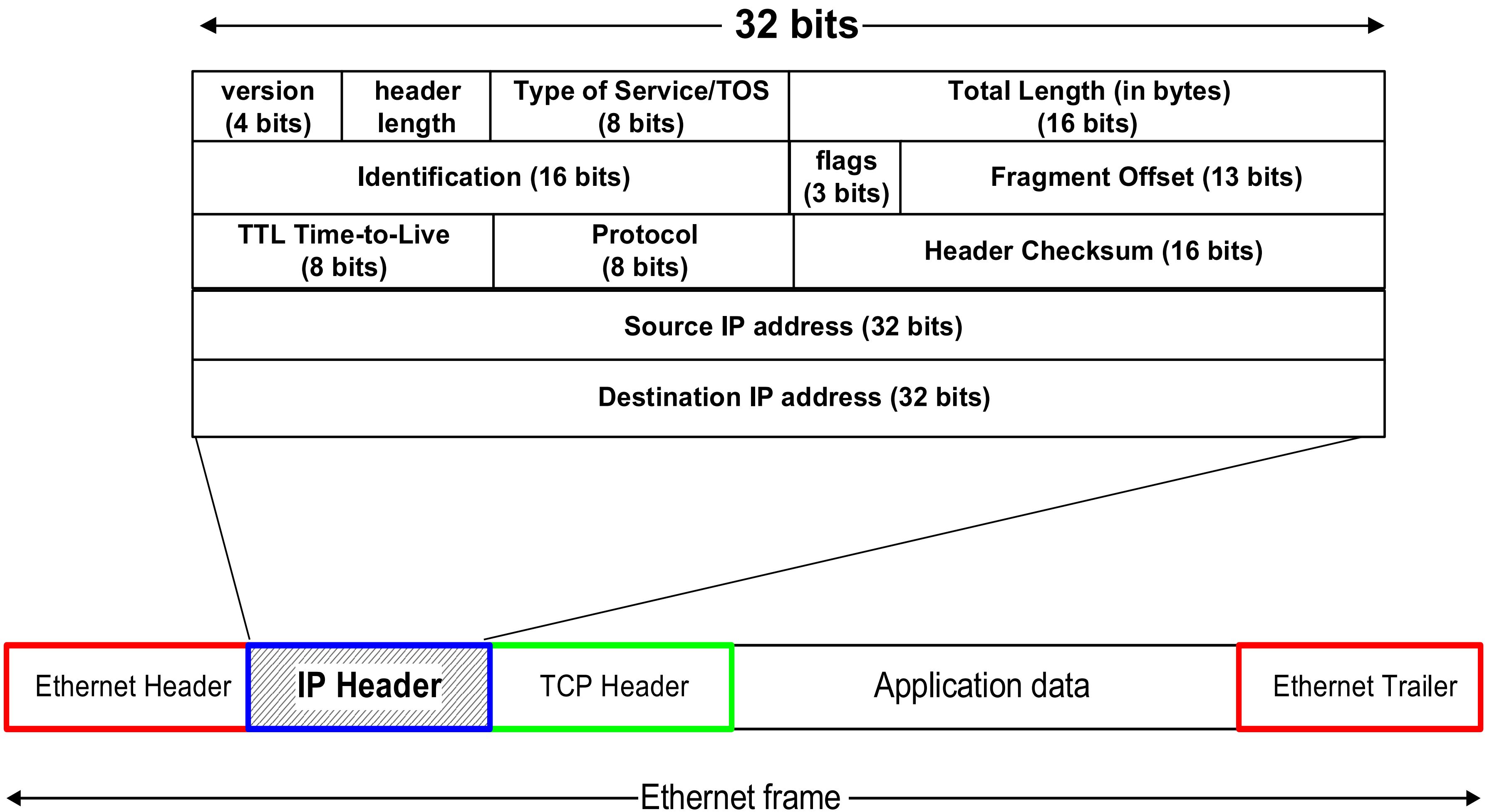
Introductory material.

An entire module devoted to IP addresses.

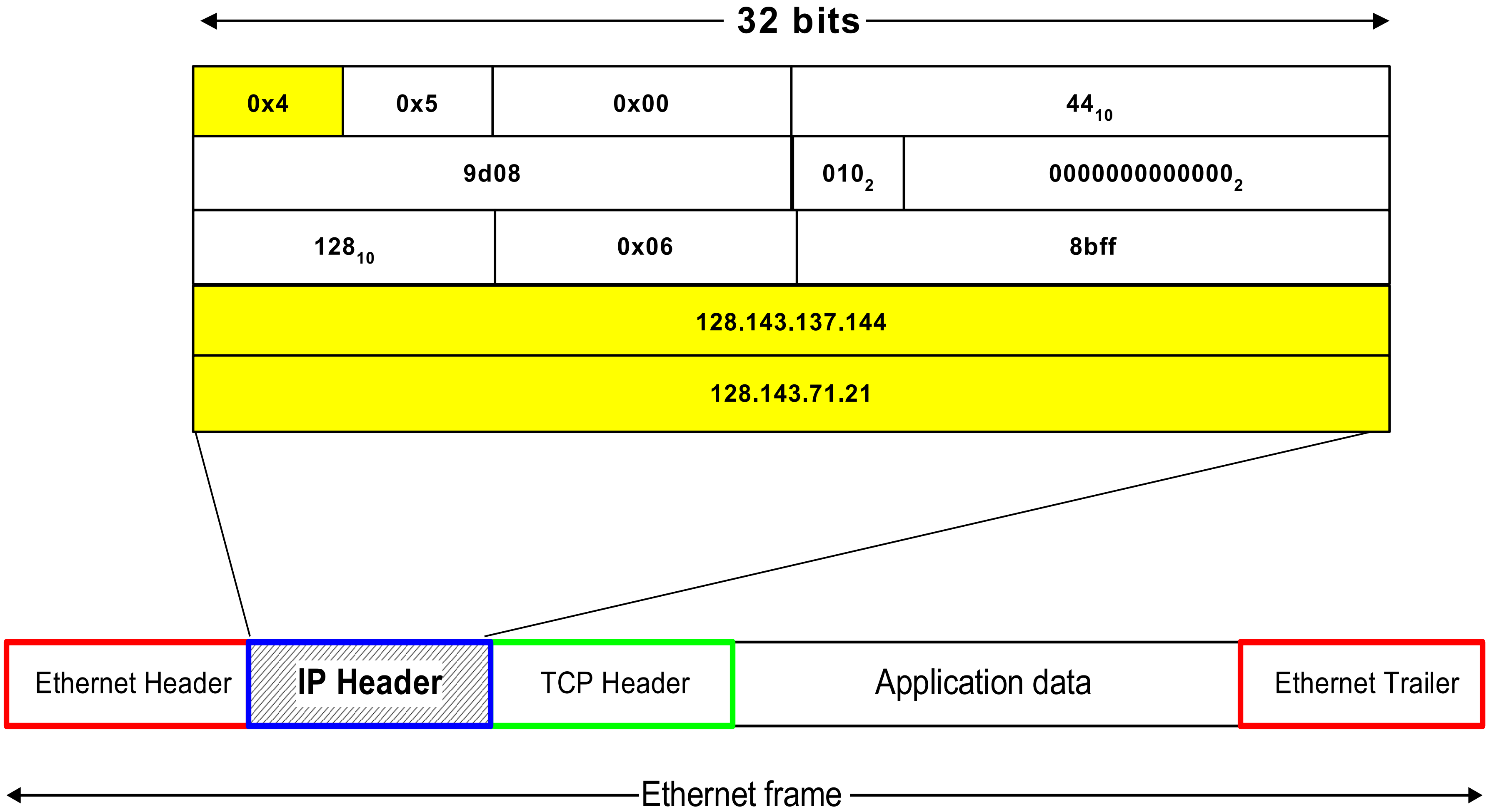
IP Addresses

- Structure of an IP address
- Classful IP addresses
- Limitations and problems with classful IP addresses
- Subnetting
- CIDR
- IP Version 6 addresses

IP Addresses



IP Addresses



What is an IP Address?

- An IP address is a unique global address for a network interface

- An IP address:

  - is a **32 bit long** identifier

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

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]:

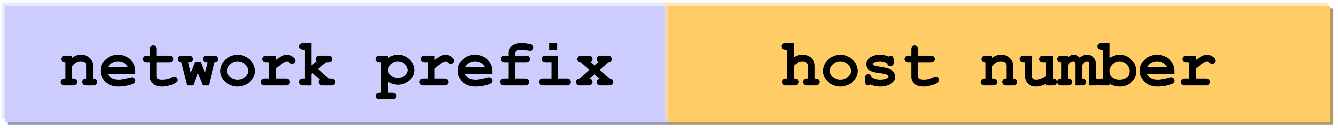
- **Example:**

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

128.143.137.144

Network prefix and Host number

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



- **How do we know how long the network prefix is?**
  - The network prefix is implicitly defined (see **class-based addressing**)
  - The network prefix is indicated by a **netmask.**

Example

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

`128.143`	`137.144`

- Network id is: `128.143.0.0`
- Host number is: `137.144`
- Network mask is: `255.255.0.0` or `ffff0000`

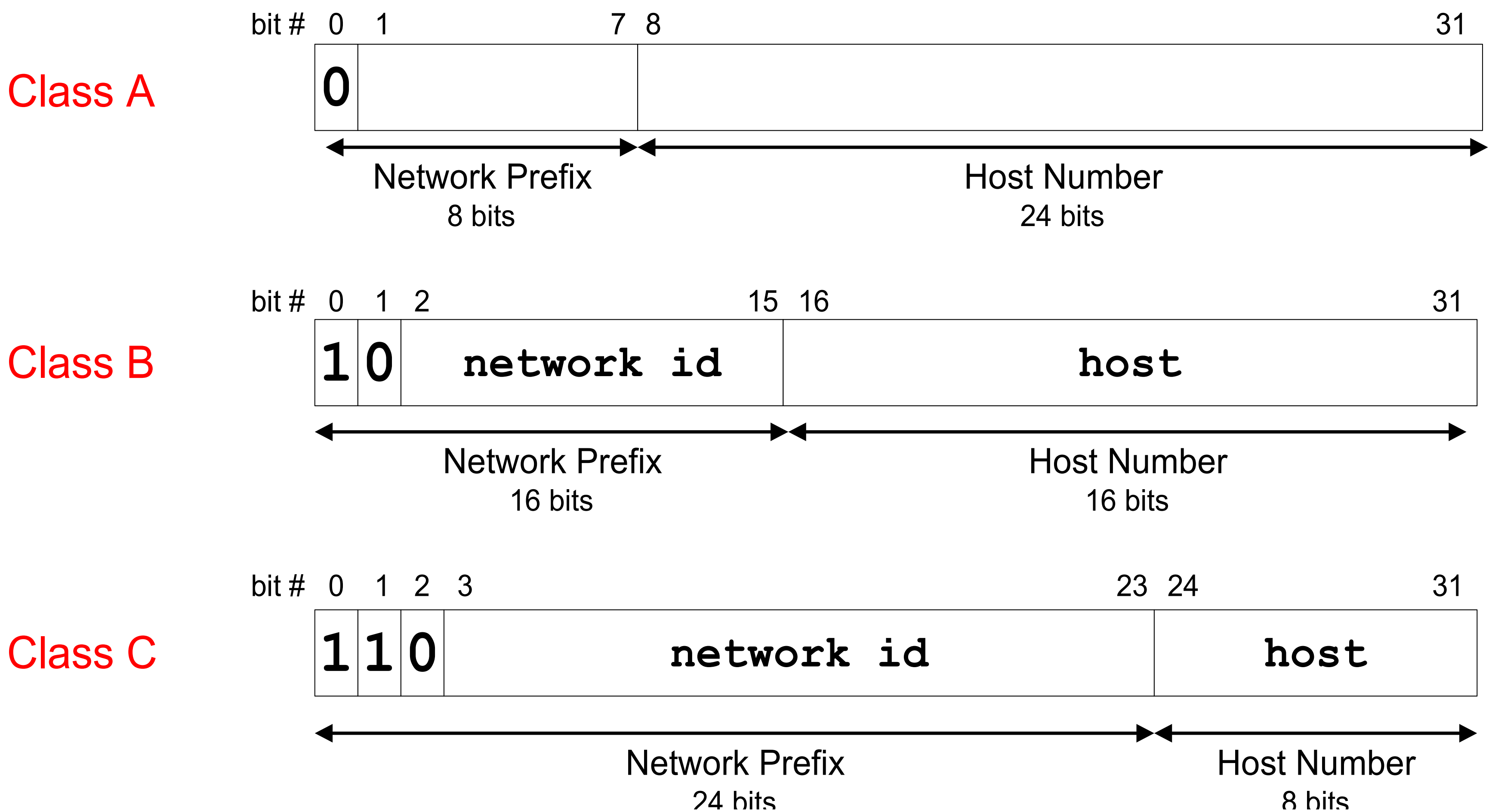
- Prefix notation: `128.143.137.144/16`
  - » Network prefix is 16 bits long

The old way: Classful IP Adresses

- 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

- The original classful address scheme had a number of problems

Problem 1. Too few network addresses for large networks

- Class A and Class B addresses are gone

Problem 2. Two-layer hierarchy is not appropriate for large networks with Class A and Class B addresses.

- **Fix #1: Subnetting**

Problems with Classful IP Addresses

Problem 3. Inflexible. Assume a company requires 2,000 addresses

- Class A and B addresses are overkill
- Class C address is insufficient (requires 8 Class C addresses)

- **Fix #2: Classless Interdomain Routing (CIDR)**

Problems with Classful IP Addresses

Problem 4: Exploding Routing Tables: Routing on the backbone Internet needs to have an entry for each network address. In 1993, the size of the routing tables started to outgrow the capacity of routers.

- **Fix #2: Classless Interdomain Routing (CIDR)**

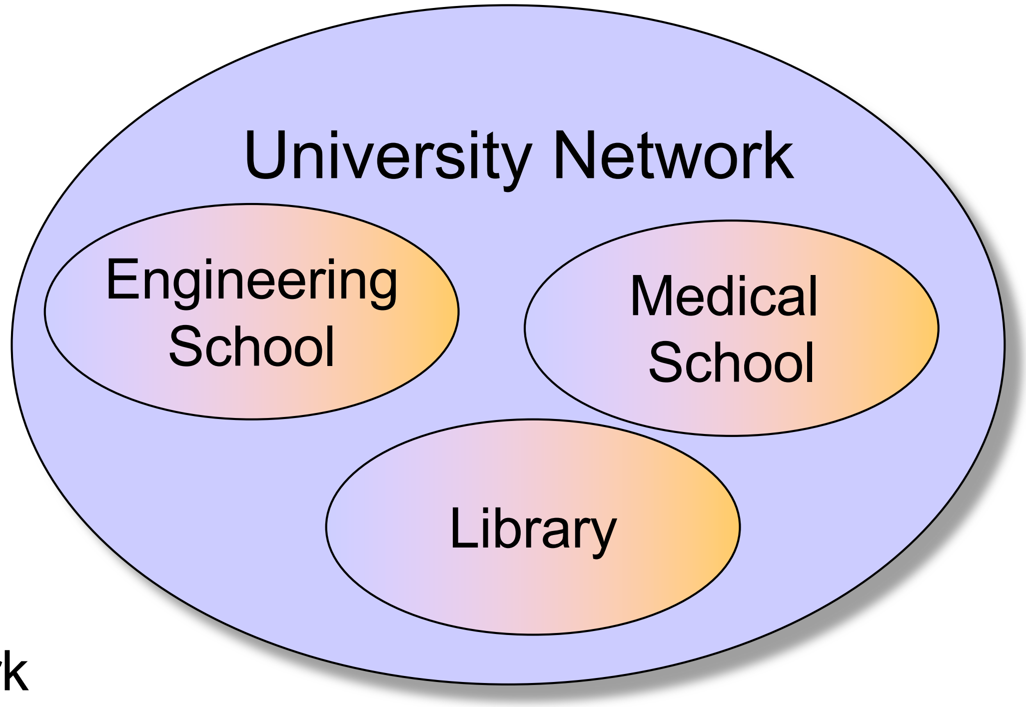
Problems with Classful IP Addresses

Problem 5. The Internet is going to outgrow the 32-bit addresses

- **Fix #3: IP Version 6**

Subnetting

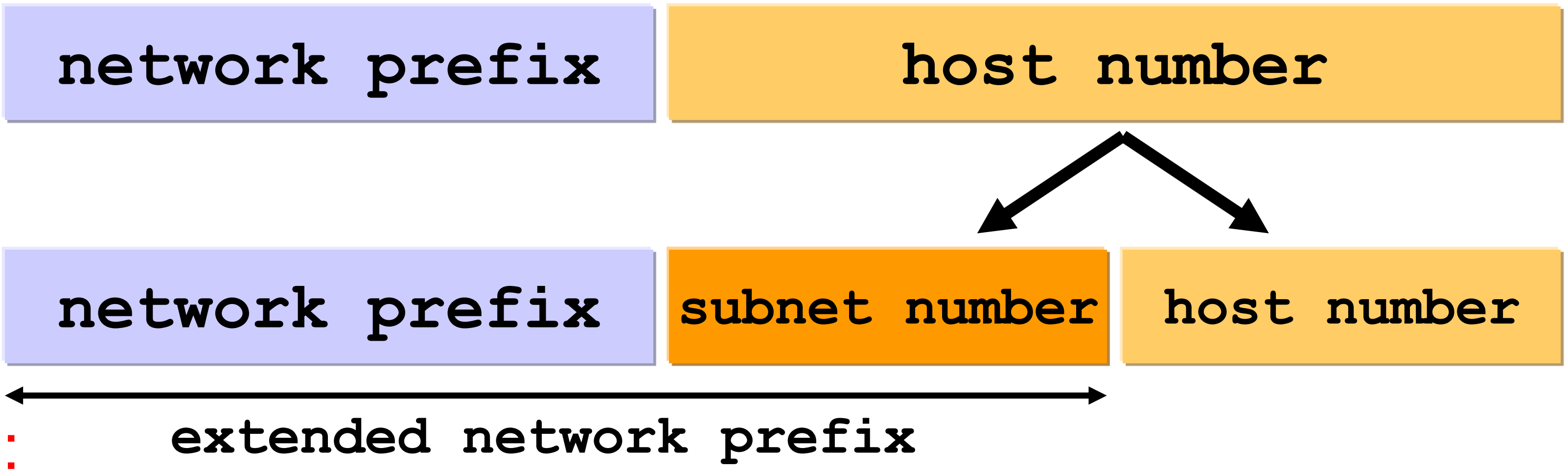
- **Problem**: Organizations have multiple networks which are independently managed
  - **Solution 1:** Allocate one or more Class C address for each network
    - Difficult to manage
    - From the outside of the organization, each network must be addressable.
  - **Solution 2:** Add another level of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



→ **Subnetting**

Basic Idea of Subnetting

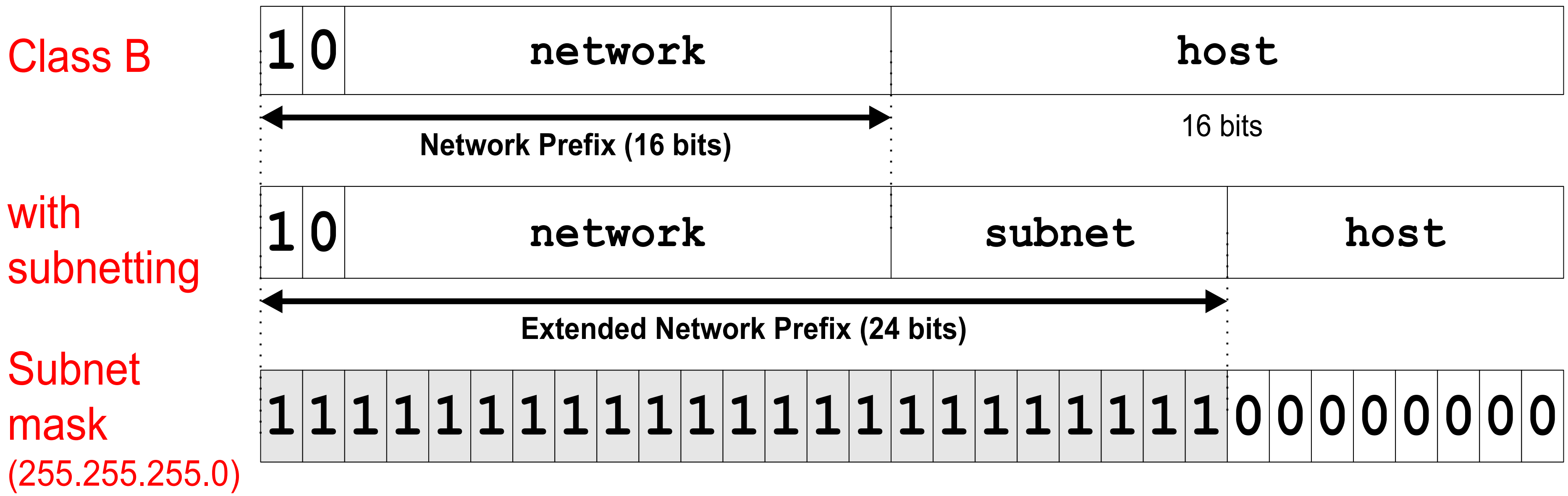
- Split the host number portion of an IP address into a **subnet number** and a (smaller) **host number**.
- Result is a 3-layer hierarchy



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

Subnet Masks

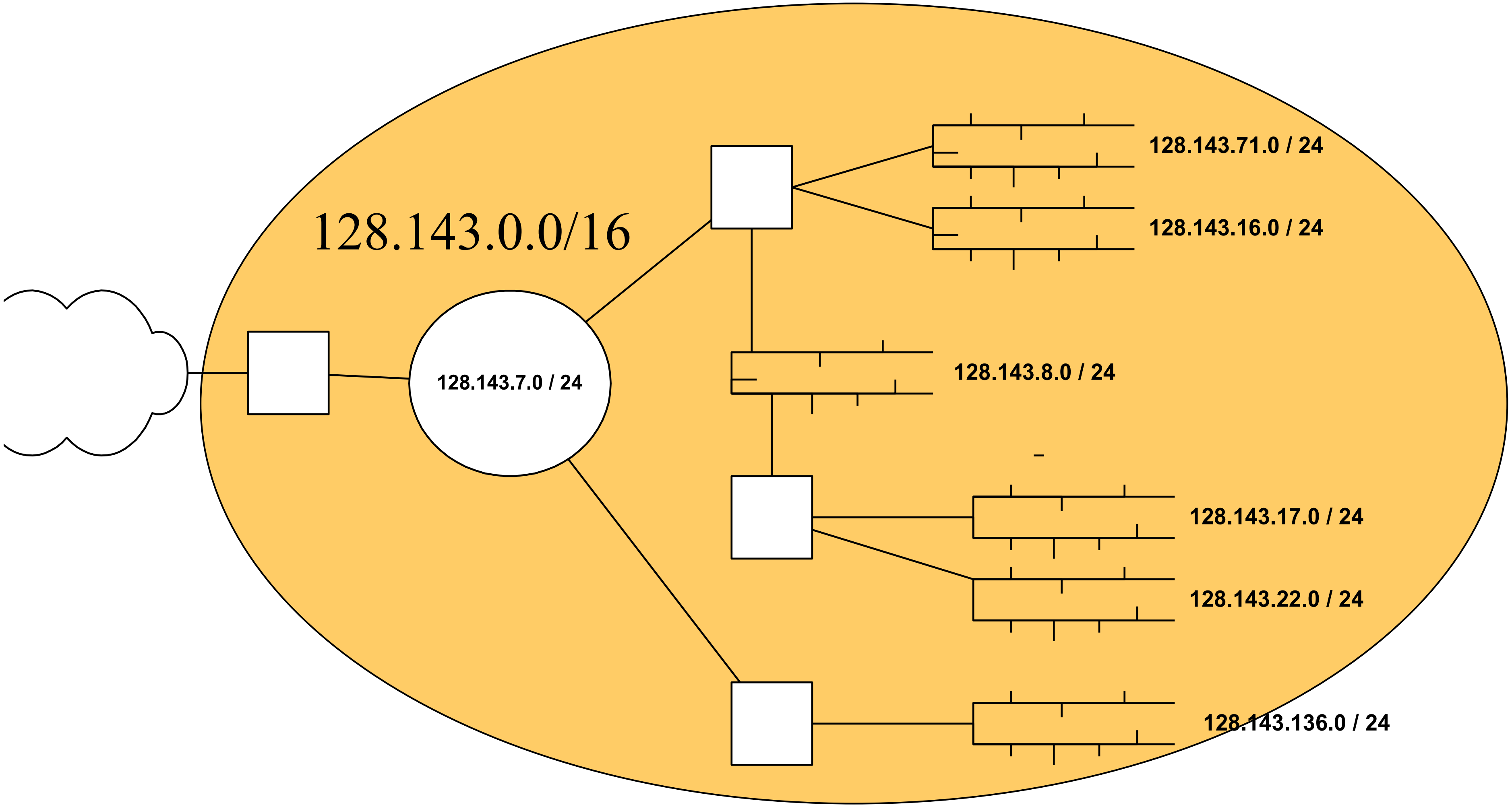
- Routers and hosts use an **extended network prefix** (**subnet mask)** to identify the start of the host numbers



* There are different ways of subnetting. Commonly used netmasks for university networks with /16 prefix (Class B) are 255.255.255.0 and 255.255.0.0

Typical Addressing Plan for an Organization that uses subnetting

- Each layer-2 network (Ethernet segment, FDDI segment) is allocated a subnet address.



Advantages of Subnetting

- With subnetting, IP addresses use a 3-layer hierarchy:
  - » Network
  - » Subnet
  - » Host
- Improves efficiency of IP addresses by not consuming an entire Class B or Class C address for each physical network/
- 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.

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 is acceptable for Class A and Class B networks
    - 2^7 = 128 Class A networks
    - 2^{14} = 16,384 Class B networks
  - But this is 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:**
  - Restructure IP address assignments to increase efficiency
  - Hierarchical routing aggregation to minimize route table entries

- CIDR (Classless Interdomain routing) abandons the notion of classes:

  Key Concept: The length of the network id (prefix) in the IP addresses is kept arbitrary

- Consequence: Routers advertise the IP address and the length of the prefix

CIDR Example

- CIDR notation of a network address:

  192.0.2.0/18

  - "18" says that the first 18 bits are the network part of the address (and 14 bits are available for specific host addresses)
- The network part is called the prefix

- Assume that a site requires a network address with 1000 addresses
- With CIDR, the network is assigned a continuous block of 1024 addresses with a 22-bit long prefix

CIDR: Prefix Size vs. Network Size

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

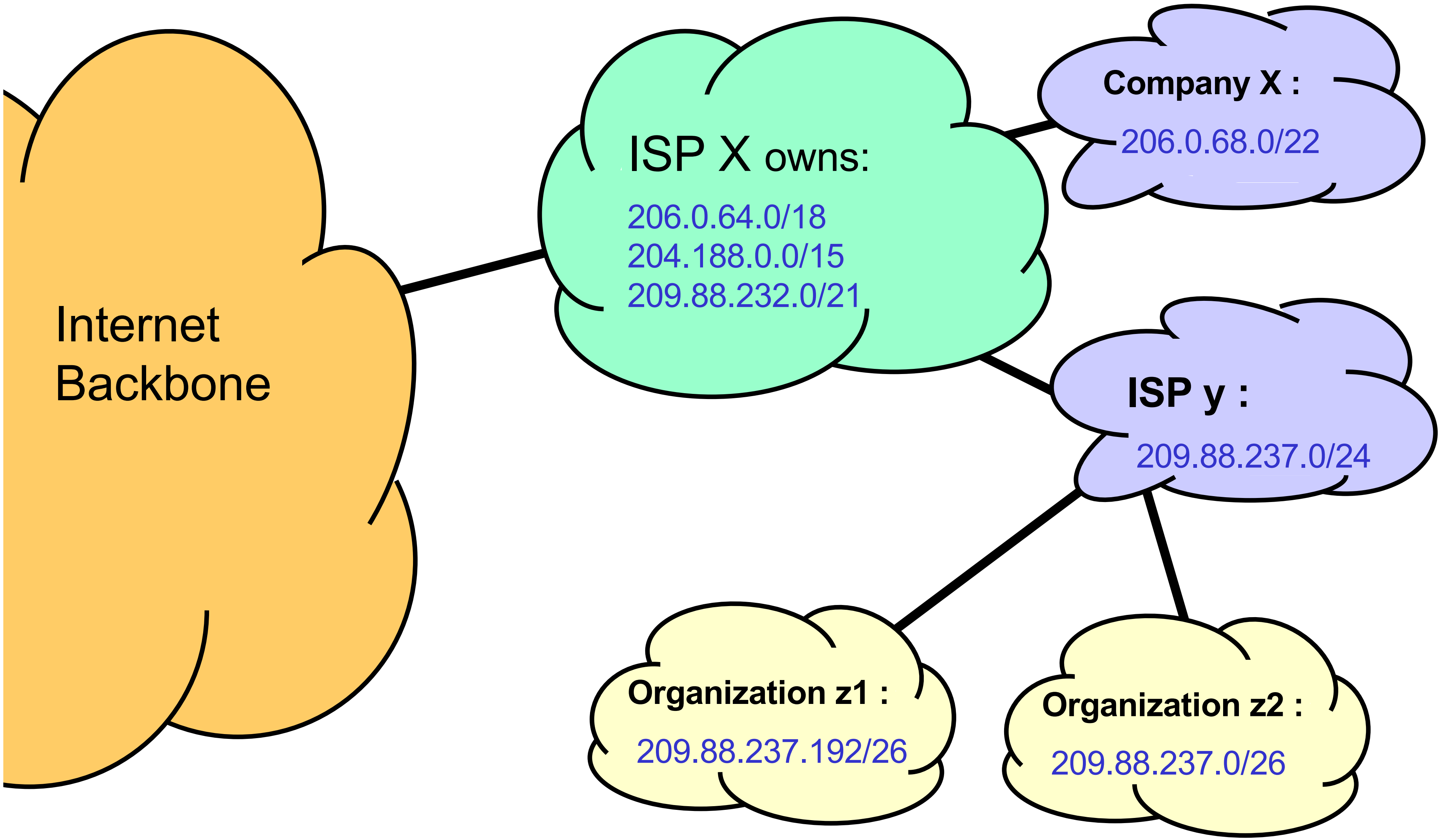
CIDR and Address assignments

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

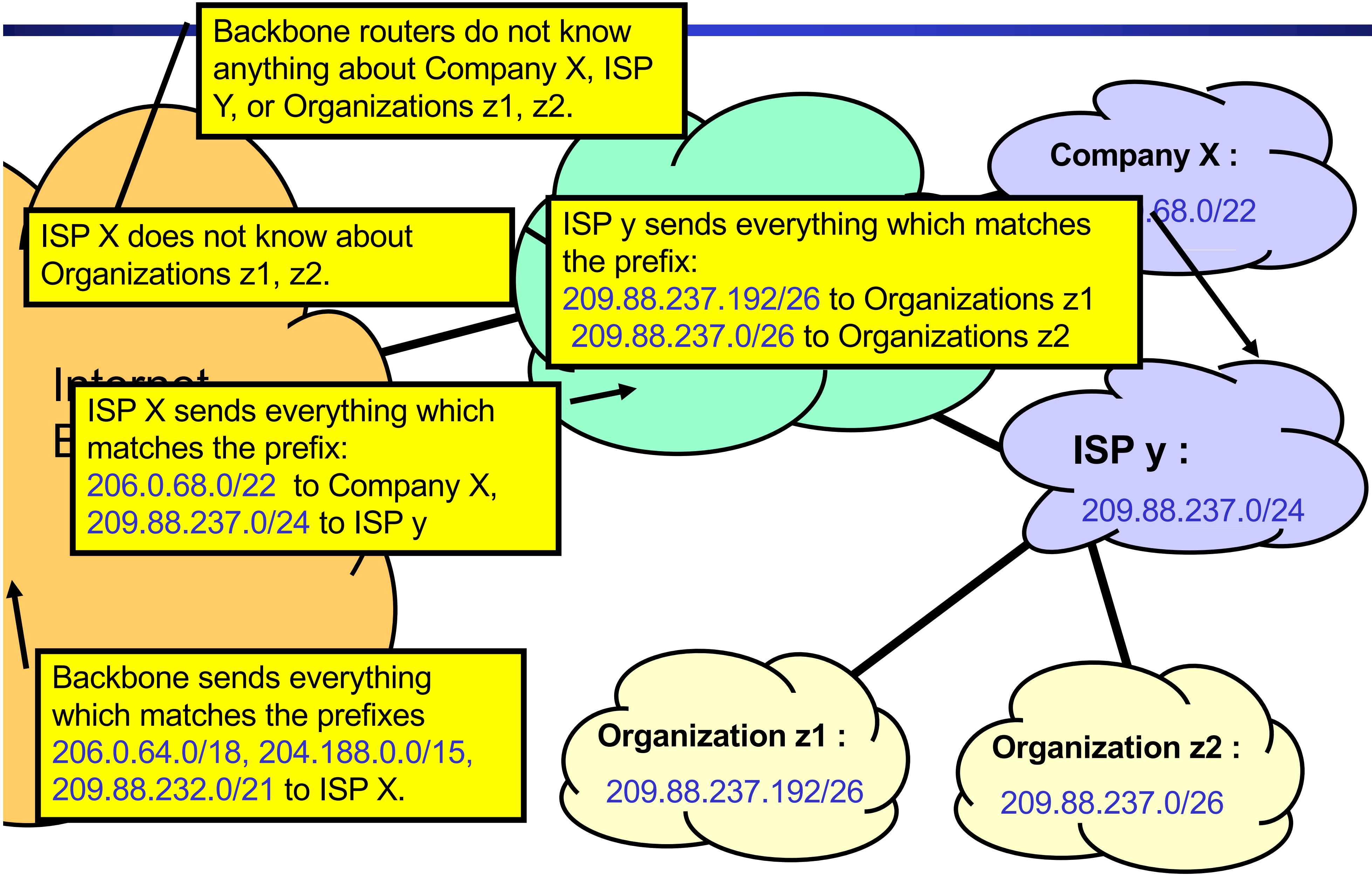
Example:

- 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 Information



CIDR and Routing Information



Example

You can find about ownership of IP addresses in North America via http://www.arin.net/whois/

- The IP Address: 207.2.88.170

207	2	88	170
11001111	00000010	01011000	10101010

Belongs to:
City of Charlottesville, VA: 207.2.88.0 - 207.2.92.255

11001111	00000010	01011000	00000000

Belongs to:
Cable & Wireless USA 207.0.0.0 - 207.3.255.255

11001111	00000000	00000000	00000000

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 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

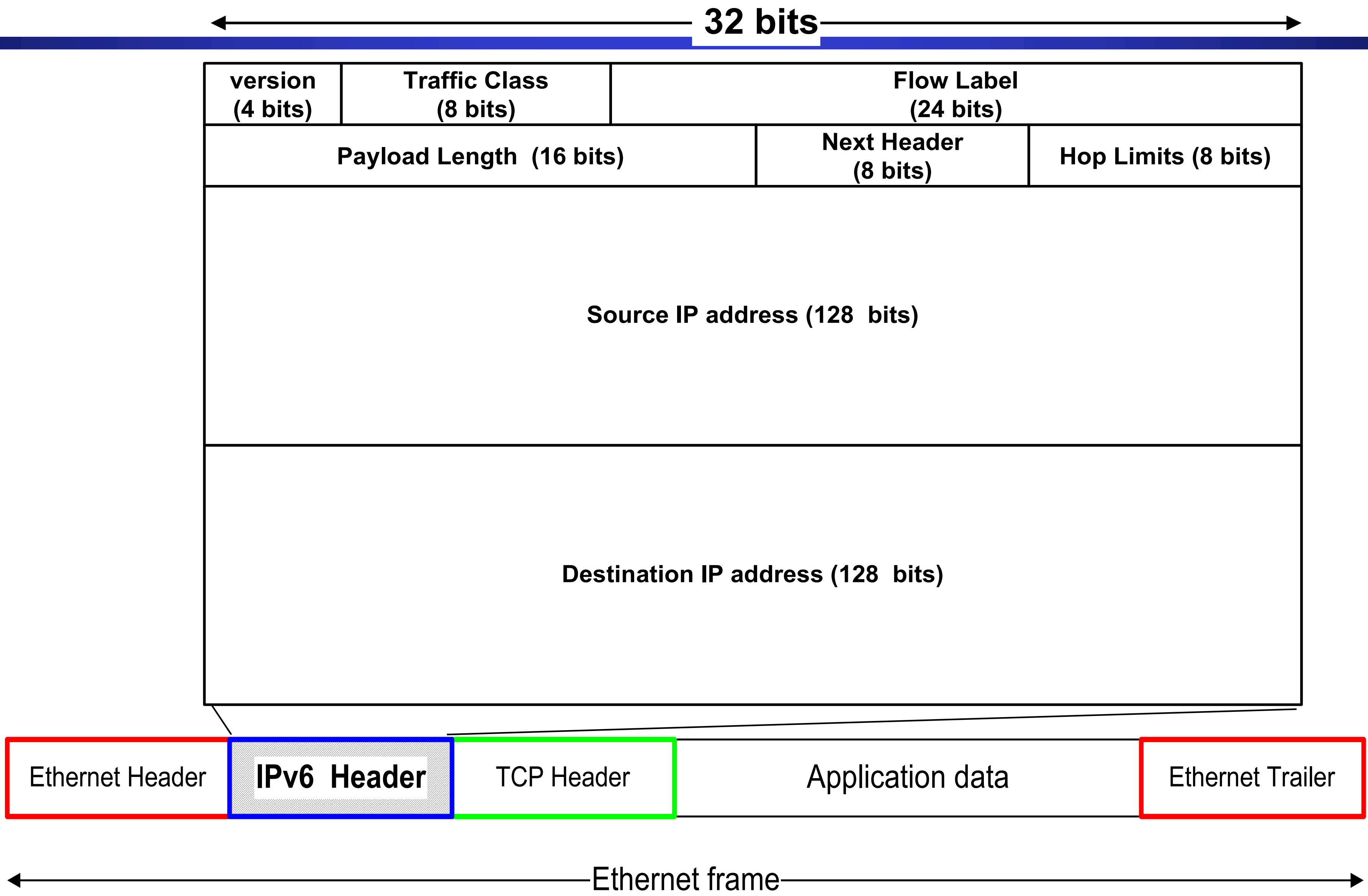
Routing table

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

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

  $2^{128} = (2^{32})^4 \approx$ 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
- ":0000:0000:0000" 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)*

More on IPv6 Addresses

- The provider-based addresses have a similar flavor as CIDR addresses
- IPv6 provides address formats for:
  - Unicast – identifies a single interface
  - Multicast – identifies a group. Datagrams sent to a multicast address are sent to all members of the group
  - Anycast – identifies a group. Datagrams sent to an anycast address are sent to one of the members in the group.