IP Addressing

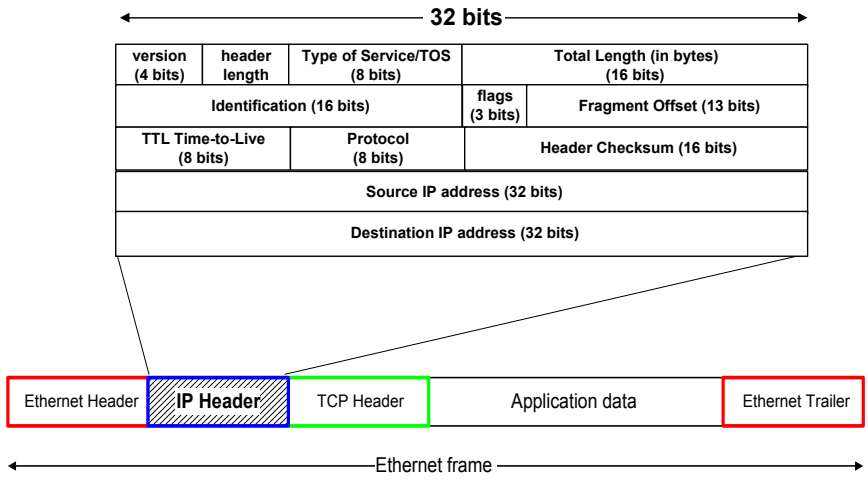
Introductory material.

An entire module devoted to IP addresses.

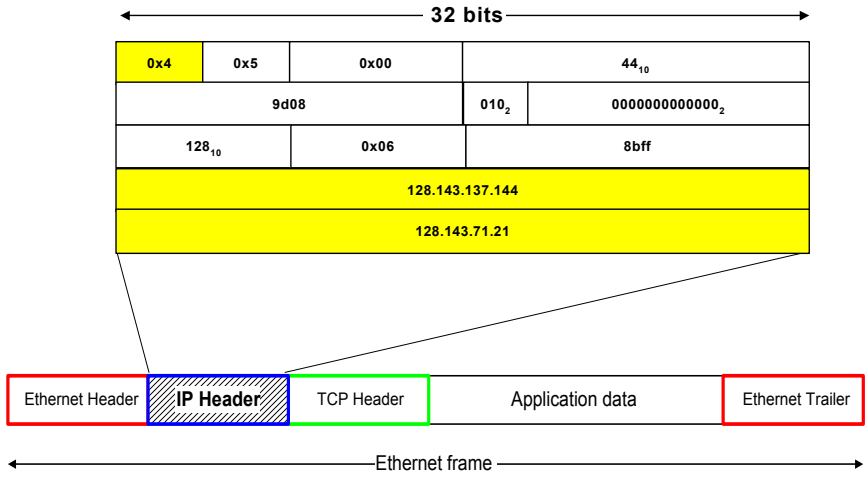
IP Addresses

- 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
- 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).

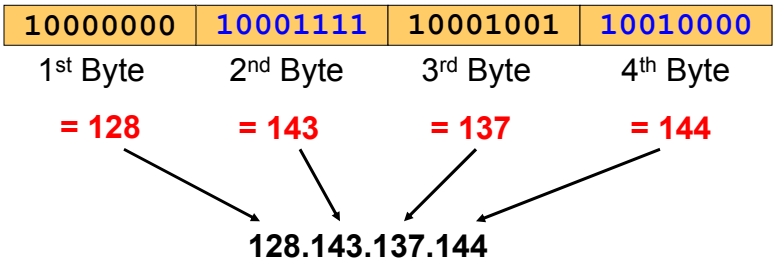
- **How do we know how long the network prefix is?**
  - **Before 1993:** The network prefix is implicitly defined (see **class-based addressing**)

  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:**



Example

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

- 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 127.0.0.1-127.0.0.255 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

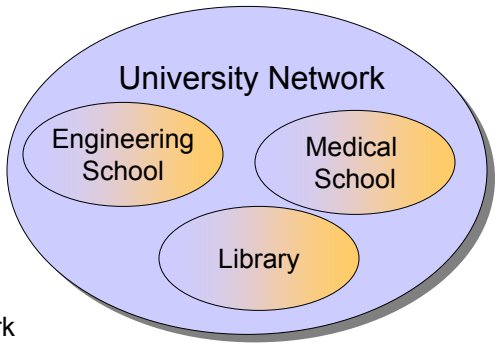
- **Test / Experimental addresses**
  Certain address ranges are reserved for "experimental use". Packets should get dropped if they contain this destination address (see RFC 1918):

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

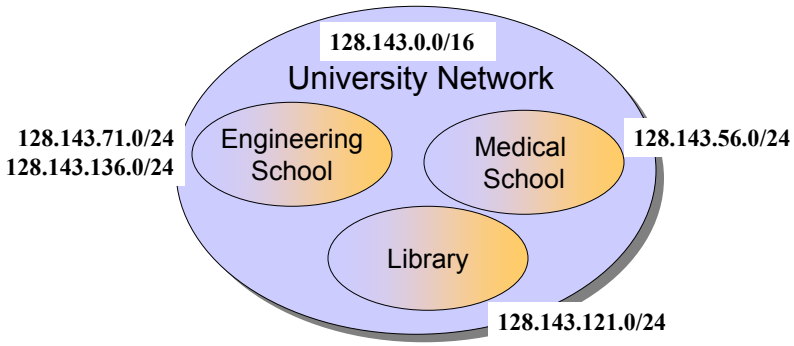
- **Problem**: Organizations have multiple networks which are independently managed
  - **Solution 1:** Allocate a separate network address for each network
    - Difficult to manage
    - From the outside of the organization, each network must be addressable.
  - **Solution 2:** Add another level of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



→ **Subnetting**

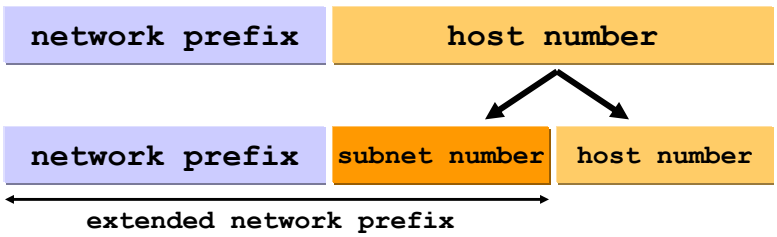
Address assignment with subnetting

- 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

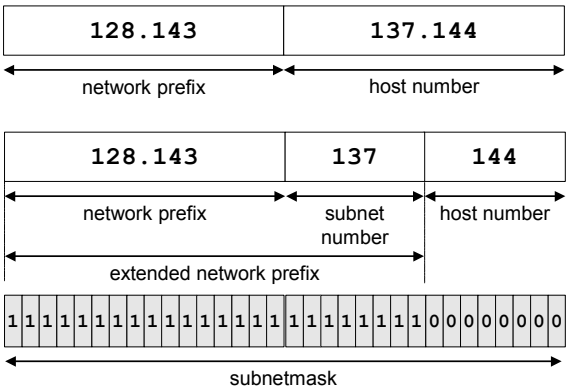
- Split the host number portion of an IP address into a **subnet number** and a (smaller) **host number**.
- Result is a 3-layer hierarchy



- 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

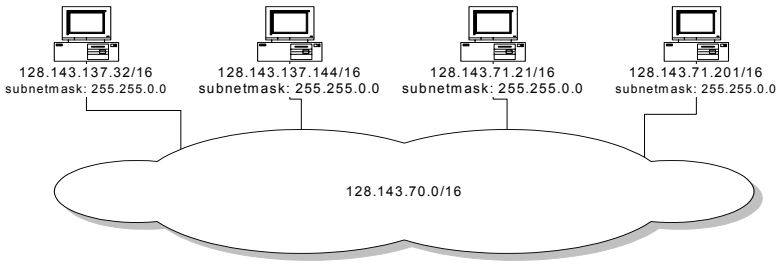
- 128.143.0.0/16 is the IP address of the network
- 128.143.137.0/24 is the IP address of the subnet

- 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

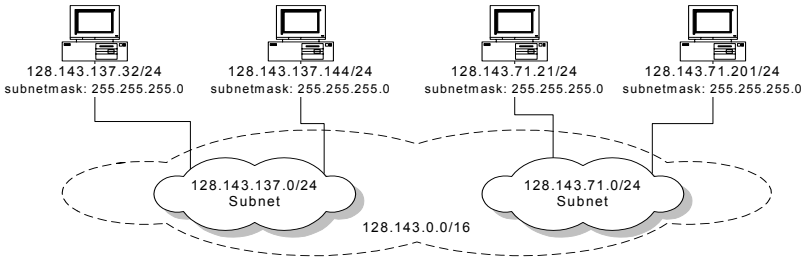
No Subnetting

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



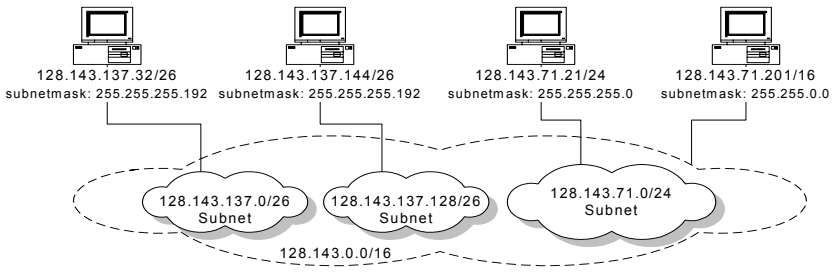
With Subnetting

- 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

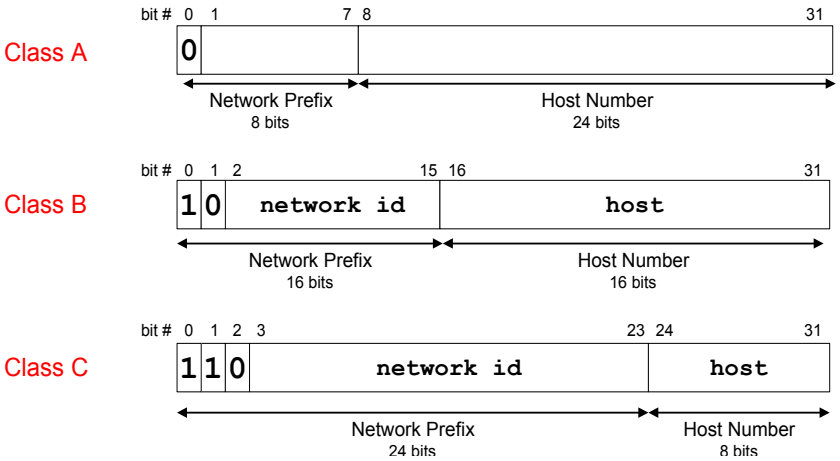


Classful IP Adresses (Until 1993)

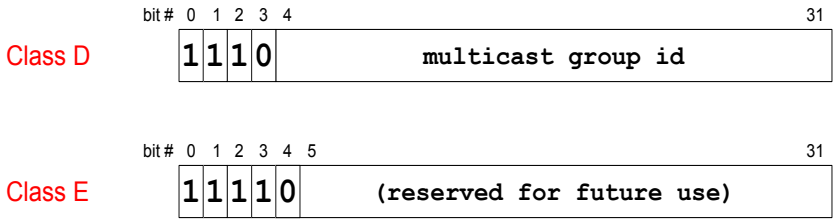
- When Internet addresses were standardized (early 1980s), the Internet address space was divided up into classes:
  - **Class A:** Network prefix is 8 bits long
  - **Class B:** Network prefix is 16 bits long
  - **Class C:** Network prefix is 24 bits long

- 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



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

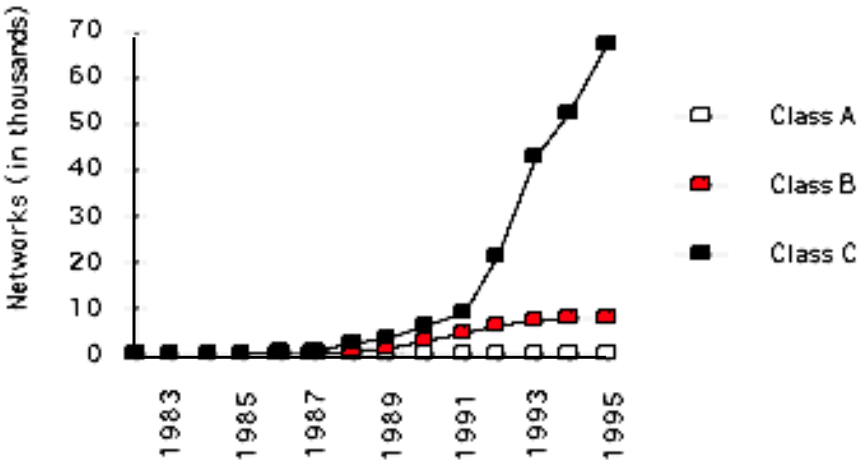
Problems with Classful IP Addresses

- 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 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:**
  - 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**

Why do people still talk about

- CIDR eliminates the concept of class A, B, and C networks and replaces it with a network prefix
- Existing classful network addresses are converted to CIDR addresses:
  128.143.0.0 → 128.143.0.0/16
- The change has not affected many (previously existing) enterprise networks
  - Many network administrators (especially on university campuses) have not noticed the change (and still talk about

(Note: CIDR was introduced with the role-out of BGPv4 as interdomain routing protocol.)

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

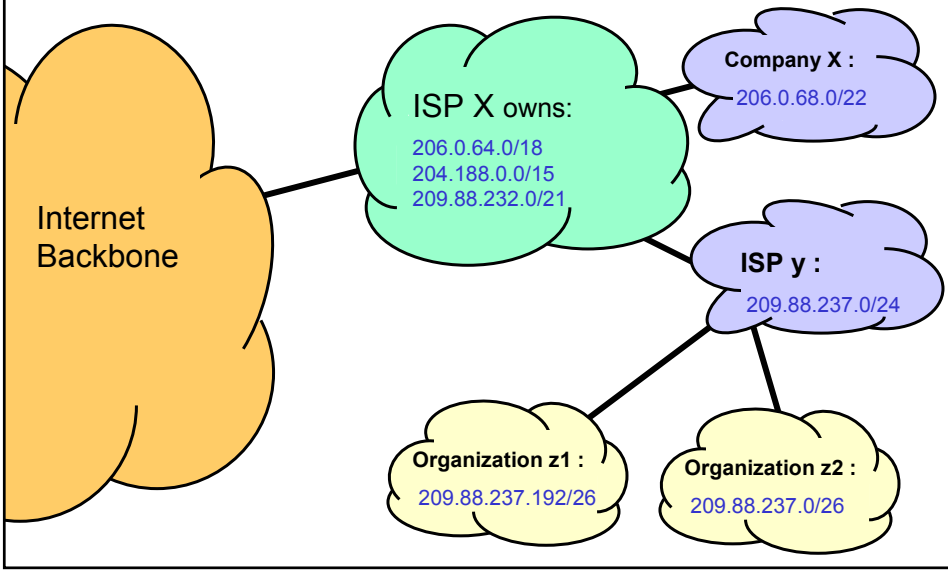
What is the outgoing interface for 128.143.137.0/24 ?

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

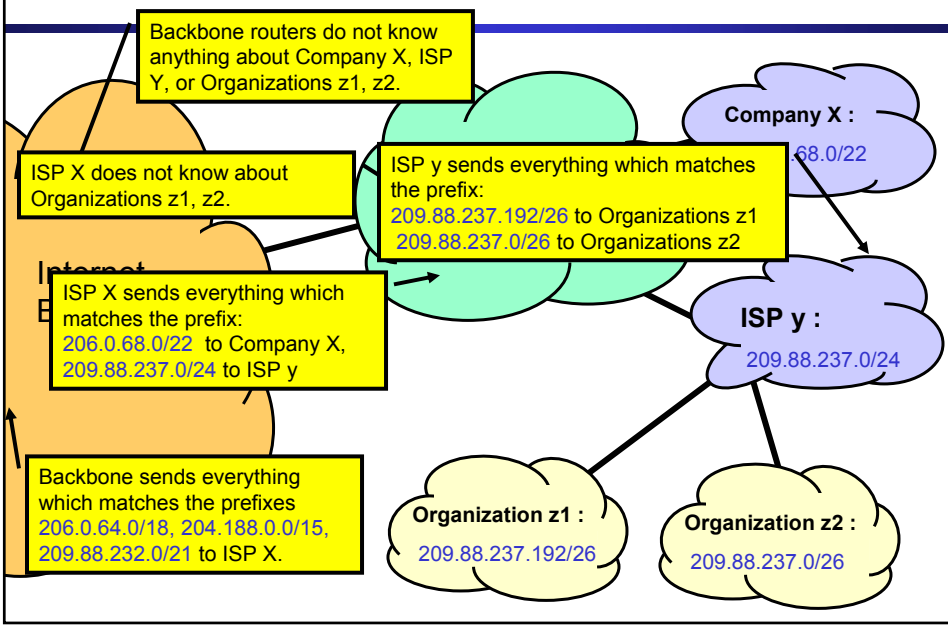
Routing table

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

CIDR and Routing Information



CIDR and Routing Information

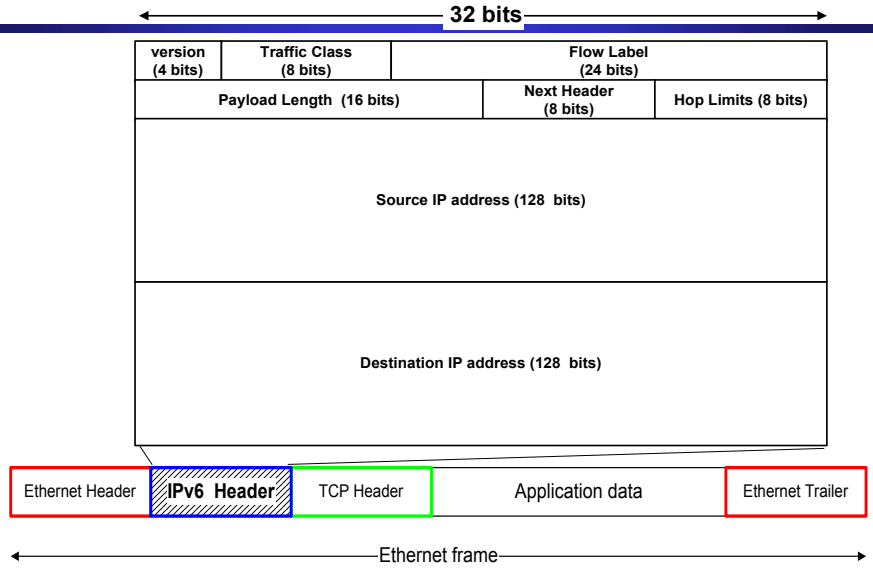


IPv6 - IP Version 6

- **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



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

- 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)*