

IP Addressing

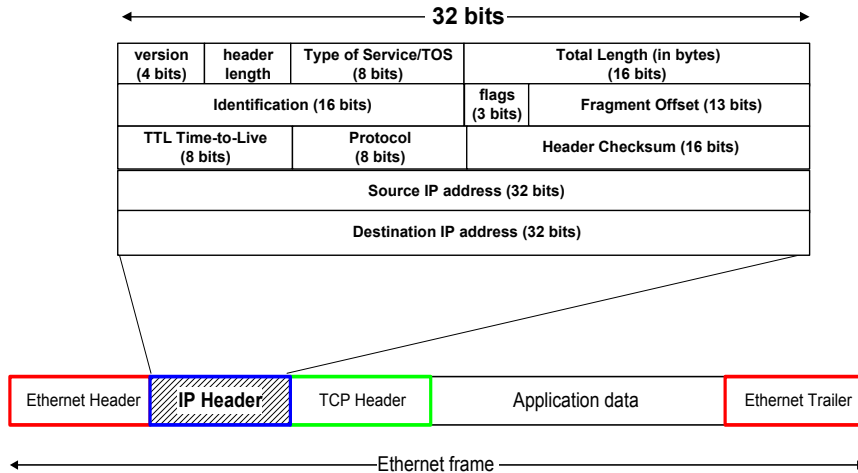
Introductory material.

An entire module devoted to IP addresses.

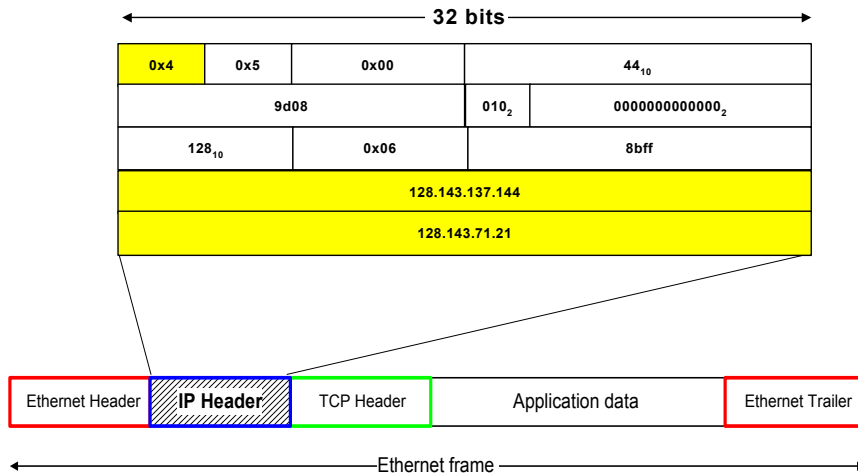
IP Addresses

- 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).

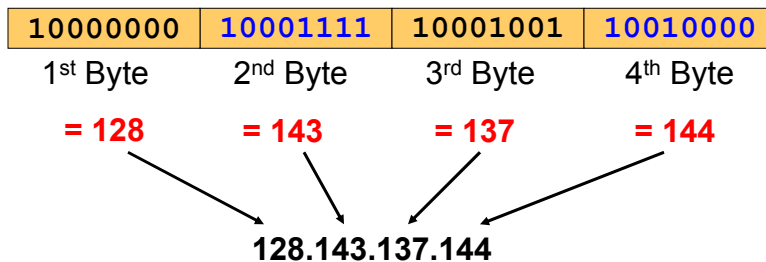
network prefix	host number
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- **How do we know how long the network prefix is?**
 - **Before 1993:** The network prefix is implicitly defined (see **class-based addressing**)
 - or
 - **After 1993:** The network prefix is indicated by a **netmask**.

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

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 127.0.0.1-127.0.0.255 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)**

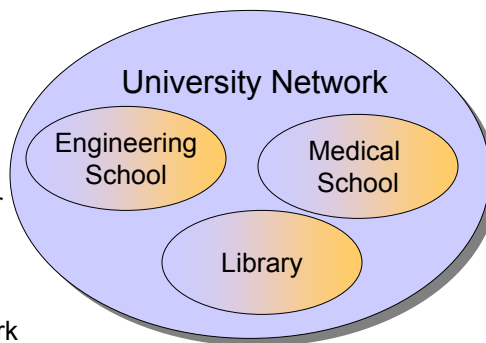
Default gateway has host number set to '1', e.g., e.g., 192.0.1.1

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.

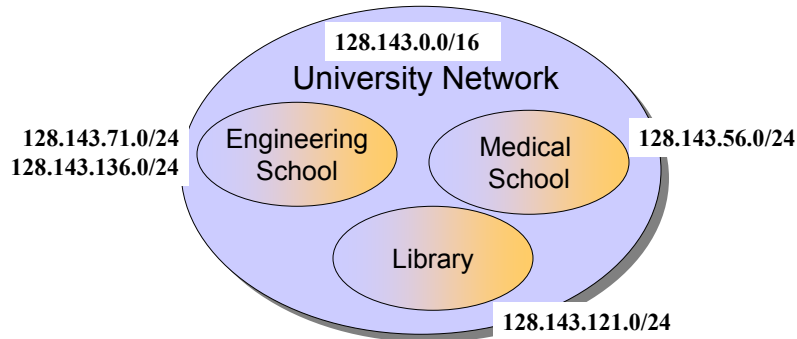
- **Solution 2:** Add another level of hierarchy to the IP addressing structure



→ **Subnetting**

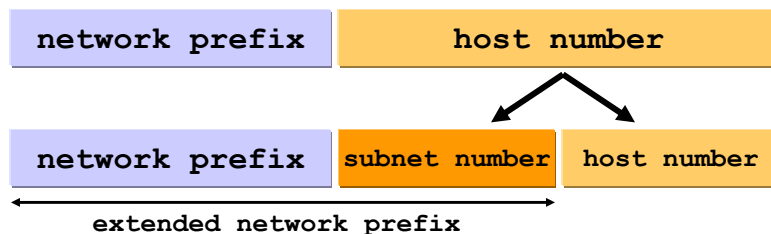
Address assignment with subnetting

- 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

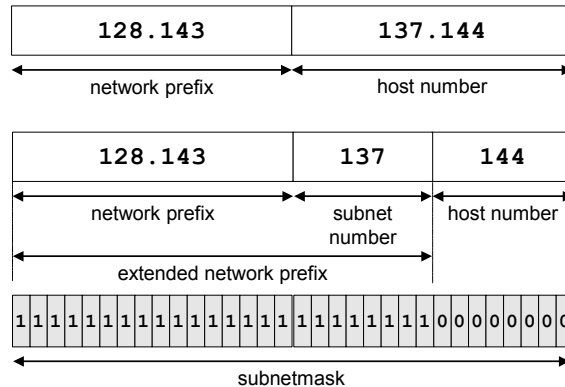
- Split the host number portion of an IP address into a **subnet number** and a (smaller) **host number**.
- Result is a 3-layer hierarchy



- **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

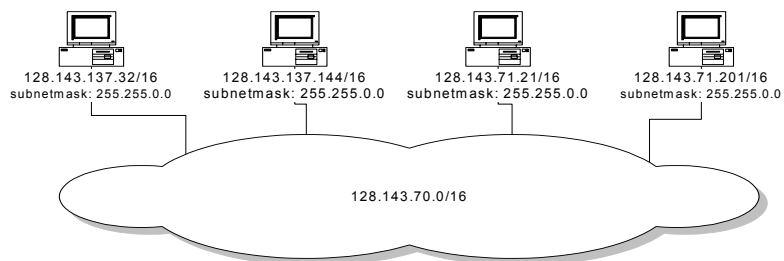
- With subnetting, IP addresses use a 3-layer hierarchy:
 - » Network
 - » Subnet
 - » Host
- Reduces router complexity. Since external routers do not know about subnetting, the complexity of routing tables at external routers is reduced.
- Note: Length of the subnet mask need not be identical at all 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 fffffff0) 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 is decided by the network administrator
- Consistency of subnetmasks is responsibility of administrator

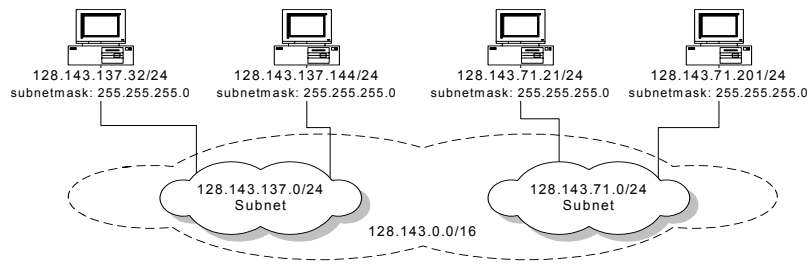
No Subnetting

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



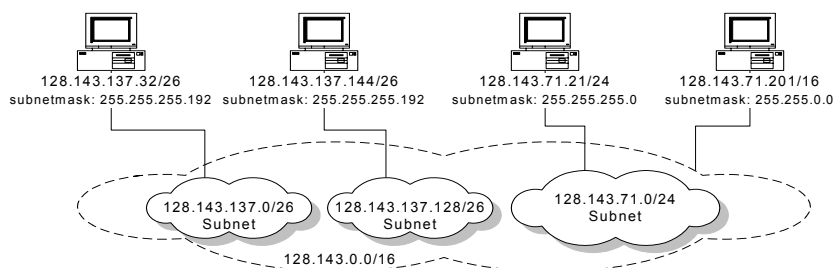
With Subnetting

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



With Subnetting

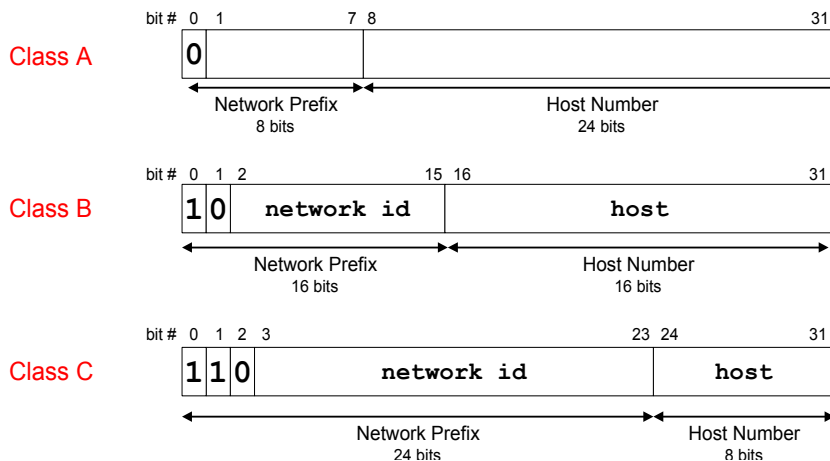
- Different subnetmasks lead to different views of the size of the network



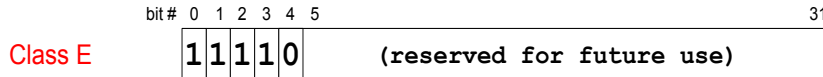
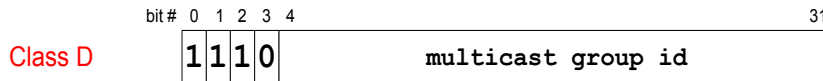
Classful IP Adresses (Until 1993)

- 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.

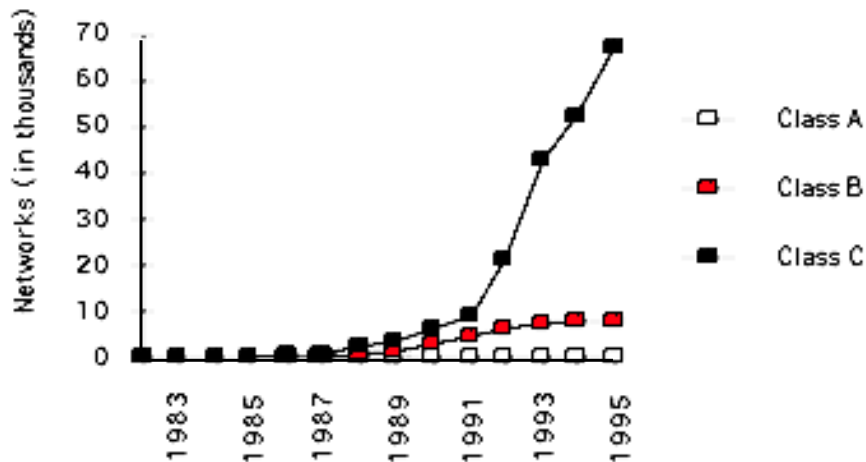
Problems with Classful IP Addresses

- 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 trailing 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

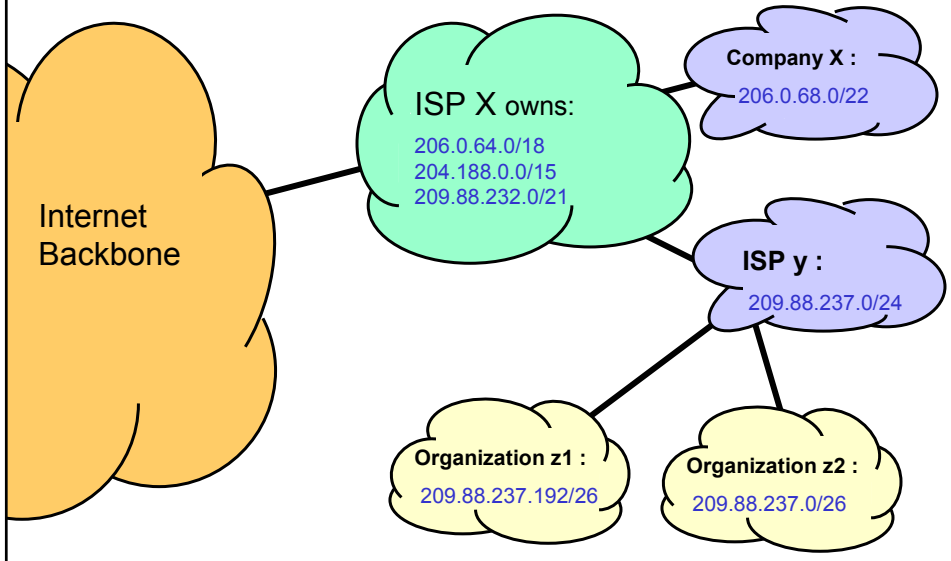
What is the outgoing interface for 128.143.137.0/24 ?

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

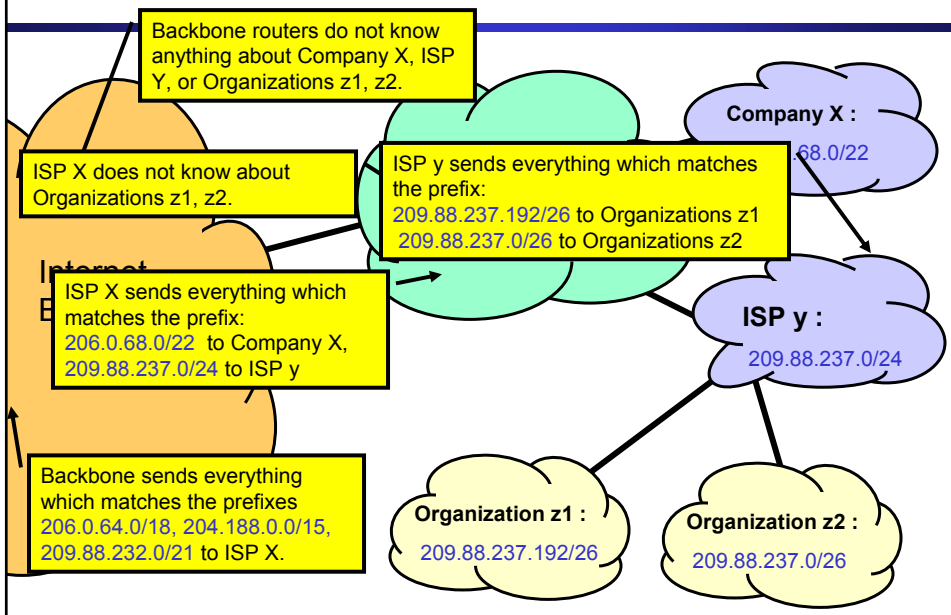
Route aggregation can be exploited when IP address blocks are assigned in an hierarchical fashion

Routing table

CIDR and Routing Information



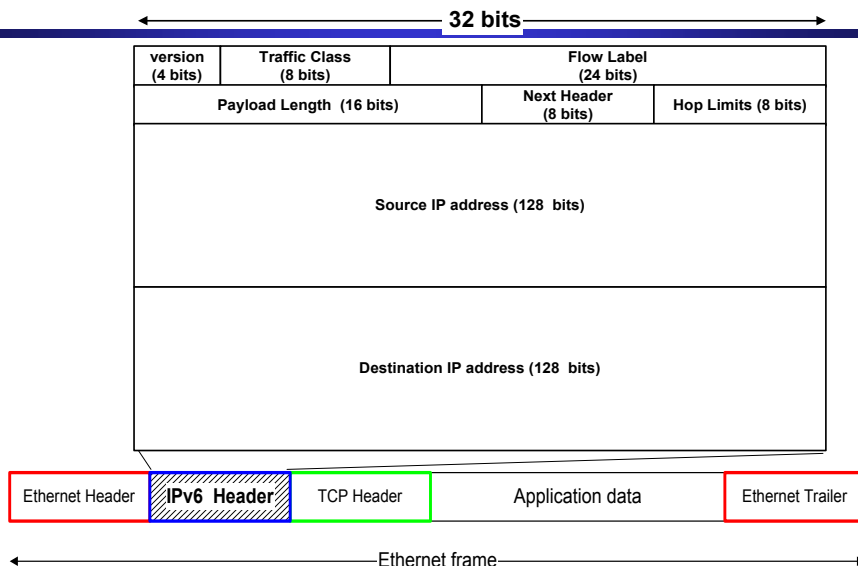
CIDR and Routing Information



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
 $2^{32} \approx 4 \text{ billion addresses}$
- **IPv6** has a maximum of
 $2^{128} = (2^{32})^4 \approx 4 \text{ billion} \times 4 \text{ billion} \times 4 \text{ billion} \times 4 \text{ billion}$
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
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- Type:** Set to “010” for provider-based addresses
- Registry:** identifies the agency that registered the address

The following fields have a variable length (recommended 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)