Chapter 7
Introduction to IPV6

- ***Outline:***

  7.1 IPv6- Advantages
  7.2 Packet formats
  7.3 Extension headers
  7.4 Transition from IPv4 to IPv6: Dual stack, Tunneling, Header Translation
  7.5 Multicasting

Why IPv6

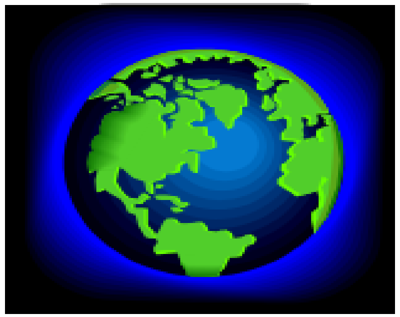
- Internet has **grown exponentially** and the address space allowed by IPv4 is saturating. New devices like **phones, TV** need IP address.
- IPv4 on its own does not provide **any security feature**. Data has to be **encrypted with some other security application** before being sent on the Internet.
- **Data prioritization in** IPv4 is **not up to date**. Though IPv4 has a few bits reserved for Type of Service or Quality of Service, but they do not provide much functionality.
- IPv4 enabled clients can be configured manually or they need some address configuration mechanism. **It does not have a mechanism to configure a device to have globally unique IP address.**

Limitation of IPv4

- **Address Space**
- **Various unnecessary header fields**
- **Variable header fields**
- **Fragmentation in Router**
- **Addressing Model**
- **NAT**
- **Broadcast Versus Multicast**
- **Quality of Service**

IPv6 Address

- **IPv4: 32 bits**
  - 4,200,000,000 possible addressable nodes
- **IPv6: 128 bits or 16 bytes**
  - ***FFEA:085B:1F1F:0000:0000:0000:00A9:1234***
  - 3.4 * 10^{38} possible addressable nodes
  - 340,282,366,920,938,463,374,607,432,768,211,456
  - 5 * 10^{28} addresses per person



World's population is approximately 6.5 billion

$$\frac{2^{128}}{6.5 \text{ Billion}}$$ = 52 Trillion Trillion IPv6 addresses per person

IPv6: Address Abbreviation

- **Abbreviation Rules**
  1. **Drop leading zeros**
     - Example: 1000:2345:3423:**0012**:4332:**0008**:FED2:**0AFC**
     - *Dropping leading zeros*:1000:2345:3423:**12**:4332:**8**:FED2:**AFC**
  2. **A group of 4 zeros cab be replaced with a single zero**
     - Example: 1000:2345:3423:**0000:0000:0008**:FED2:**0AFC**

       1000:2345:3423**:0:0:8:**FED2:**AFC**
  3. **Contiguous groups of zeros can be replaced with a double colon, but that can only be done once in an address**
     - Example 1: 1000:2345:3423:**0000:0000**:0008:FED2:0AFC

       1000:2345:3423**::**8:FED2:AFC
     - Example 2: 1000:2345:3423:**0000:0000:0000**:FED2:0AFC

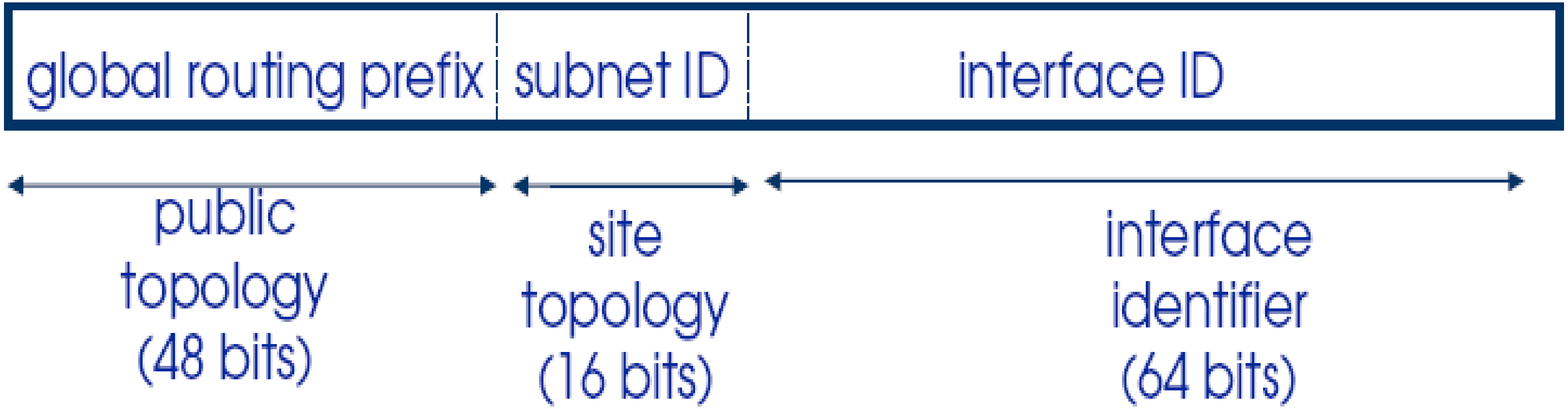
       1000:2345:3423**::**FED2:AFC

IPv6 Address Type

- **Unicast:** Address is for a single interface.
- **Multicast**
  - One-to-many
  - Enables more efficient use of the network.
  - Uses a larger address range.
- **Anycast**
  - In this addressing mode, **multiple interfaces** (hosts) are assigned **same Anycast IP address.**
  - When a host **wishes to communicate** with a host equipped **with an Anycast IP** address, it **sends a Unicast message**.
  - With the help of complex routing mechanism, that Unicast message is **delivered to the host closest to the Sender in terms of Routing cost.**

IPv6 Address Type

- **Global Unicast Address**
  - Global Unicast addresses in IPv6 are **globally identifiable and uniquely addressable.**
  - Used for talking out to **the public internet.**
  - The range of ***2001::/16*** is assigned to the global register.

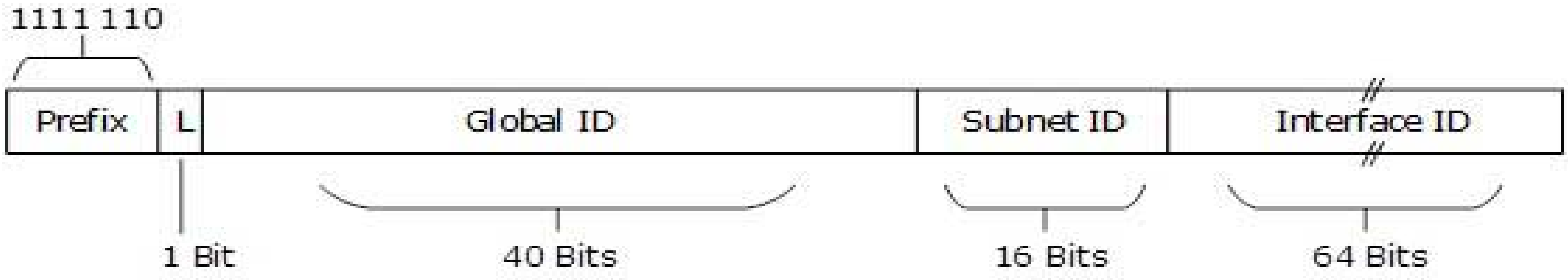


IPv6 Address Type

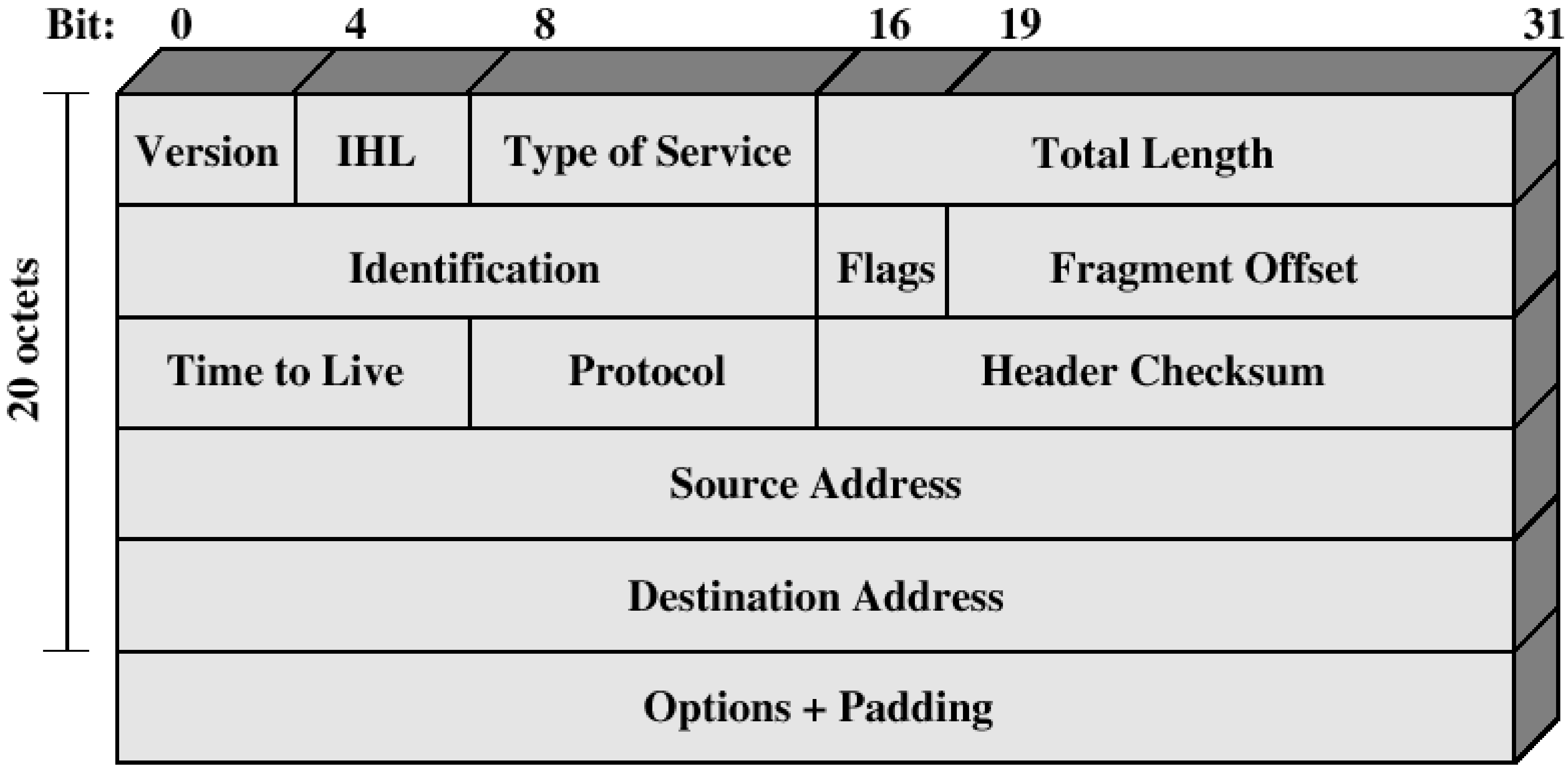
- **Link-Local Address**
  - Unicast address for the **local network link only**.
  - **Automatically generated** for each IPv6 network interface.
  - The first 16 bits of link-local address is always set to 1111 1110 1000 0000 (FE80). The next 48-bits are set to 0. And last 64 bits are Interface ID(Host Bits). **Predefined prefix of FE80::/64.**
  - These **addresses are not routable**, so a Router **never forwards** these addresses **outside the link**.
- **Every computer will have a link-local IPv6 address.**
- **Every computer will have a multiple IPv6 addresses.**
- **The default gateway is the link-local IPv6 address of the gateway router.**

IPv6 Address Type

- **Unique-Local Address (Site Local)**
  - This type of IPv6 address is **globally unique**, but it should be **used in local communication.**
  - **Equivalent to IPv4's private address**, these are **not routable** on the internet.
  - The second half of this address contain **Interface ID** and the first half is divided among **Prefix, Local Bit, Global ID and Subnet ID**.
  - Prefix is always set to 1111 110. L bit, is set to 1 if the address is locally assigned. So far, the meaning of L bit to 0 is not defined.



IPv4 Header


Bit: 0 4 8 16 19 31
20 octets
Version
IHL
Type of Service
Total Length
Identification
Flags
Fragment Offset
Time to Live
Protocol
Header Checksum
Source Address
Destination Address
Options + Padding

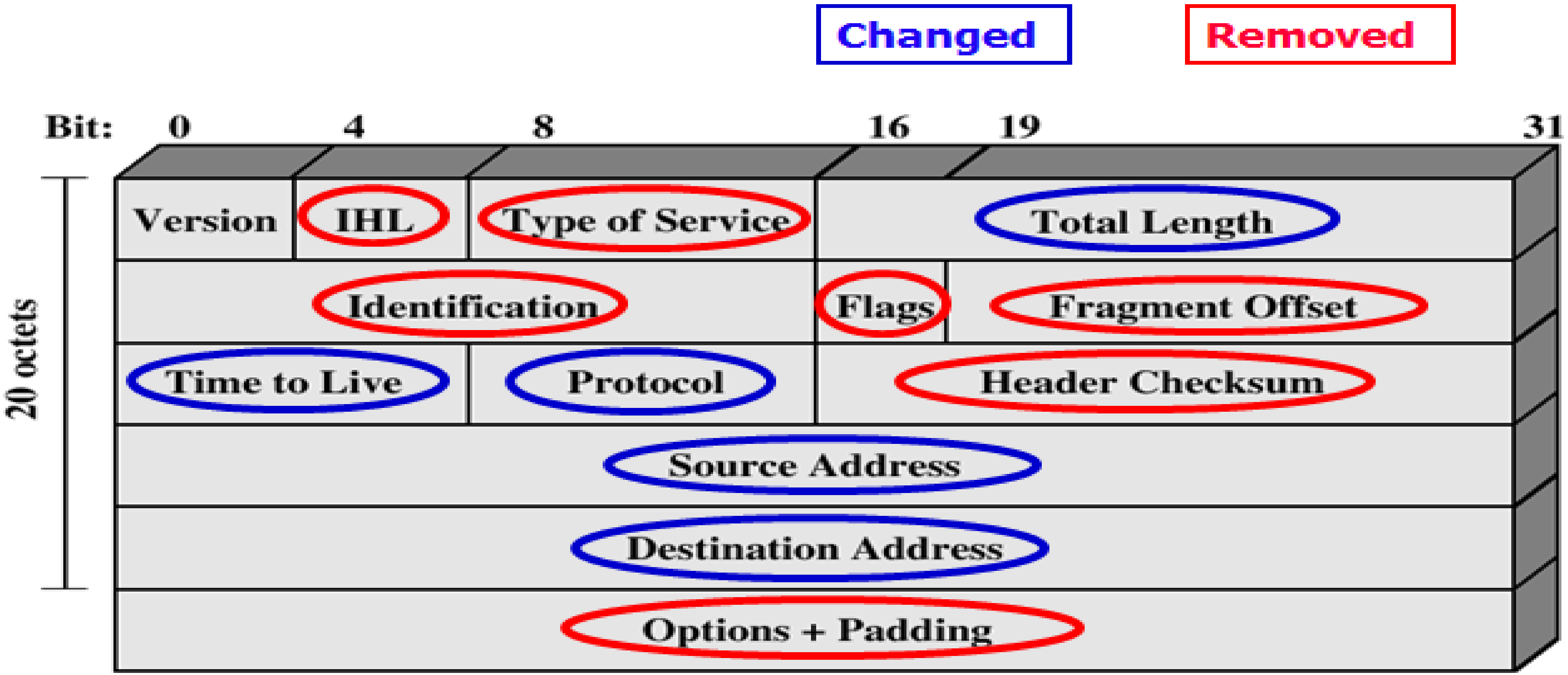
IPv4 Header

- **Version:** Indicates the version of IP currently used.
- **IP Header Length (IHL):** Indicates the datagram header length in 32-bit words.
- **Type-of-Service:** The Type of service field provided 3 bits to signal priority and 3 bits to signal whether a host cared more about delay, throughput, or reliability. The bottom 2 bits are used to carry explicit congestion notification information, such as whether the packet has experienced congestion;
- **Total Length**: Specifies the length, in bytes, of the entire IP packet. The maximum length is 65,535 bytes.
- **Identification:** Contains an integer that identifies the current datagram. All the fragments of a packet contain the same *Identification* value.
- **Time-to-Live:** Maintains a counter that gradually decrements down to zero, at which point the datagram is discarded. This keeps packets from looping endlessly.

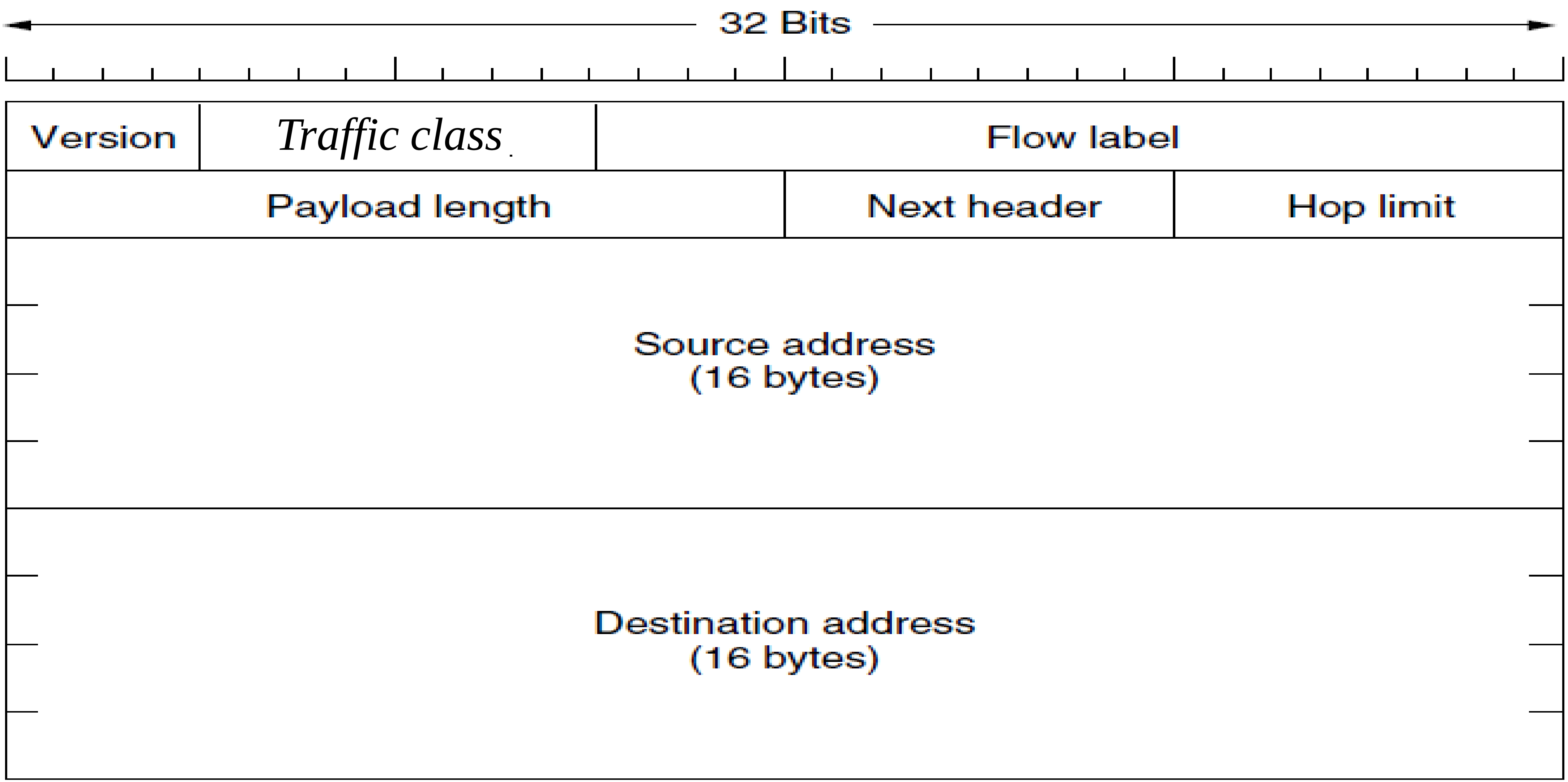
IPv4 Header

- **Flags:** The two low-order (least-significant) bits control fragmentation. The low-order bit specifies whether the packet can be fragmented. The middle bit specifies whether the packet is the last fragment in a series of fragmented packets. The third or high-order bit is not used.
- **Fragment Offset:** Indicates the position of the fragment's data relative to the beginning of the data in the original datagram.
- **Protocol:** Indicates which upper-layer protocol receives incoming packets after IP processing is complete.
- **Header Checksum:** Helps ensure IP header integrity. the *Header checksum* is assumed to be zero upon arrival. Such a checksum is useful for detecting errors while the packet travels through the network
- **Options:** Allows IP to support various options, such as security.

Header from IPv4 to IPV6



IPv6 Header Format



IPv6 Header Format

- **Version (4 bits)**
  - Identifies the version of IP protocol. **The *Version* field is always 6 for IPv6.**
- **Traffic Class (8 bits)**
  - These 8 bits are **divided into two parts**. The most significant **6 bits** are used for **Type of Service** to let the Router Known what services should be provided to this packet.
  - The least significant **2 bits** are used for Explicit Congestion Notification (**ECN**).
- **Flow Label (20 bits)**
  - This label is used **to maintain the sequential flow** of the packets belonging to a communication.
  - The source labels the sequence to help the router **identify that a particular packet belongs** to a specific flow of information.
  - This field helps **avoid re-ordering of data packets**. It is designed for streaming / real-time media.

IPv6 Header Format

- **Payload Length (16 bits)**
  - This field is used **to tell the routers** how much **information a particular** packet contains in its payload.
  - Payload is composed of **Extension Headers and Upper Layer data**.
  - With 16 bits, up to **65535 bytes** can be indicated; but if the Extension Headers contain **Hop-by-Hop Extension Header**, then the payload may exceed 65535 bytes and this field **is set to 0**.
- **Next Header (8 bits)**
  - This field is **used to indicate** either the type of **Extension Header**, or if the **Extension Header is not present** then it indicates the **Upper Layer PDU**.
  - The values for the type of Upper Layer PDU **are same as IPv4's**.

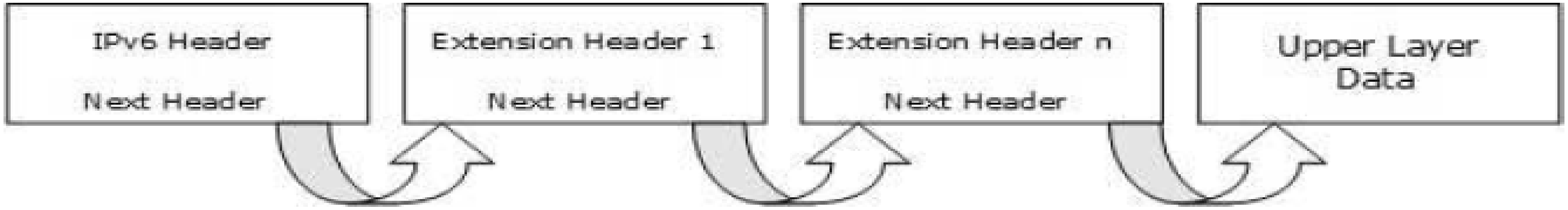
IPv6 Header Format

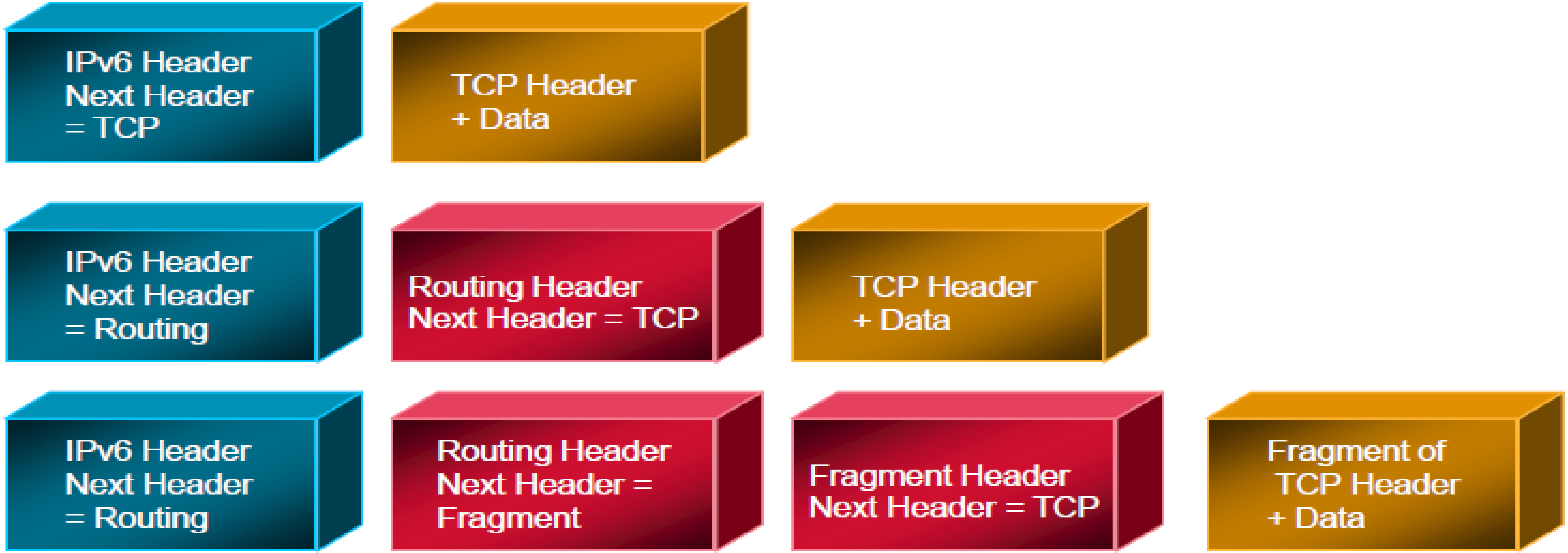
- **Hop Limit (8 bits)**
  - Replaces the **time to live field of IPv4**.
  - This value **is decremented** by one at **each intermediate node visited** by the packet. When the **counter reaches 0** the packet is **discarded.**
- **Source Address (128 bits)**
  - This field indicates the address of originator of the packet.
- **Destination Address (128 bits)**
  - This field provides the address of intended recipient of the packet .

IPv6 Extension Headers

- In IPv6, the **Fixed Header contains only that much information which is necessary**, **avoiding** those information which is **either not required or is rarely used.**
- All such information is **put between the Fixed Header and the Upper layer header** in the form of Extension Headers.
- Each Extension Header is **identified by a distinct value.**
- When Extension Headers are used, IPv6 **Fixed Header's Next Header field points** to the **first Extension Header**.
- If there is one **more Extension Header**, then the first Extension Header's '**Next-Header' field points to the second one, and so on.**
- The last Extension Header's '**Next-Header' field points to the Upper Layer Header.**
- Thus, all the headers **points to the next one in a linked list manner.**

IPv6 Extension Headers





IPv6 Extension Headers

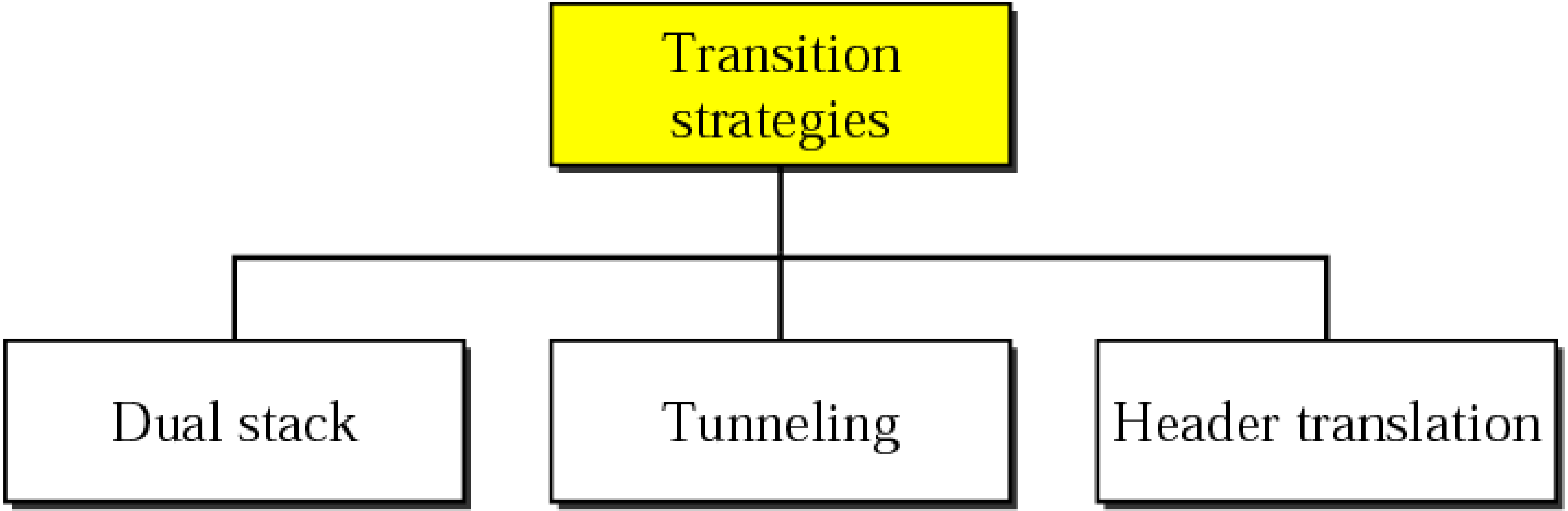
Extension Header Order

Order	Header Type	Next Header Code
1	Basic IPv6 Header	
2	Hop-by-Hop Options	0
4	Routing header	43
5	Fragment header	44
6	Authentication header	51
7	Encapsulation Security Payload header	50
8	Destination Options	60
9	Mobility header	135
	No Next header (Null)	59
	Upper layer: TCP, UDP, ICMP	6, 17, 58

IPv6 Extension Headers

- **Hop-by-Hop Options**
  - Must be first header extension
  - Examined by every node on a delivery path
- **Routing Header**
  - List of one or more intermediate nodes to visit
  - Not looked at by each node on path
- **Fragment Header**
  - IPv6 fragmentation & reassembling is an end-to-end function
  - Only the source node can fragment a packet in IPv6
- **Authentication Header**
  - for authentication/integrity only
- **Encapsulating Security Payload**
  - Provides Encryption security
  - Confidentiality
- **Destination Options**
  - Used to carry optional information for the Destination

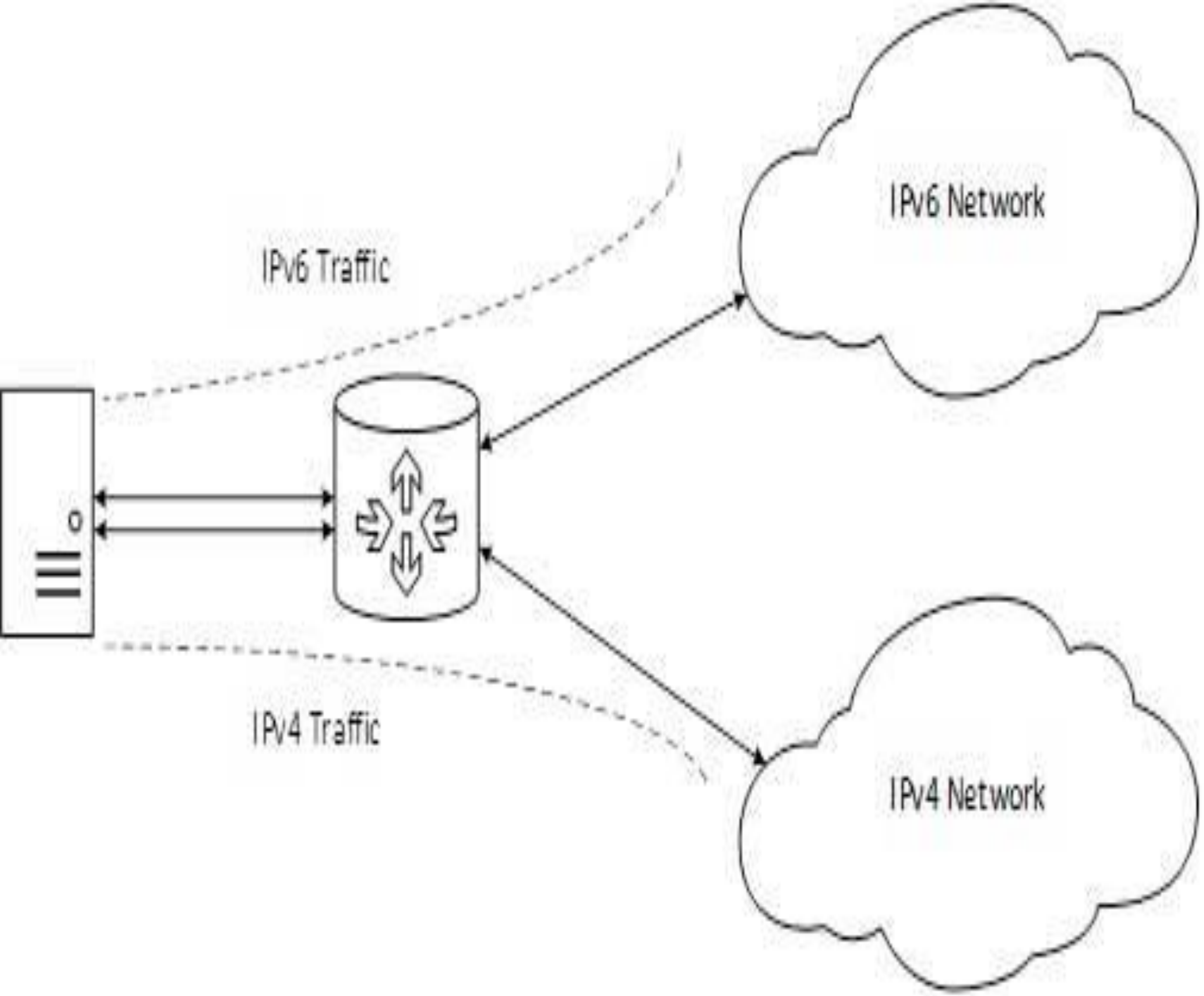
Transition from IPv4 to IPv6

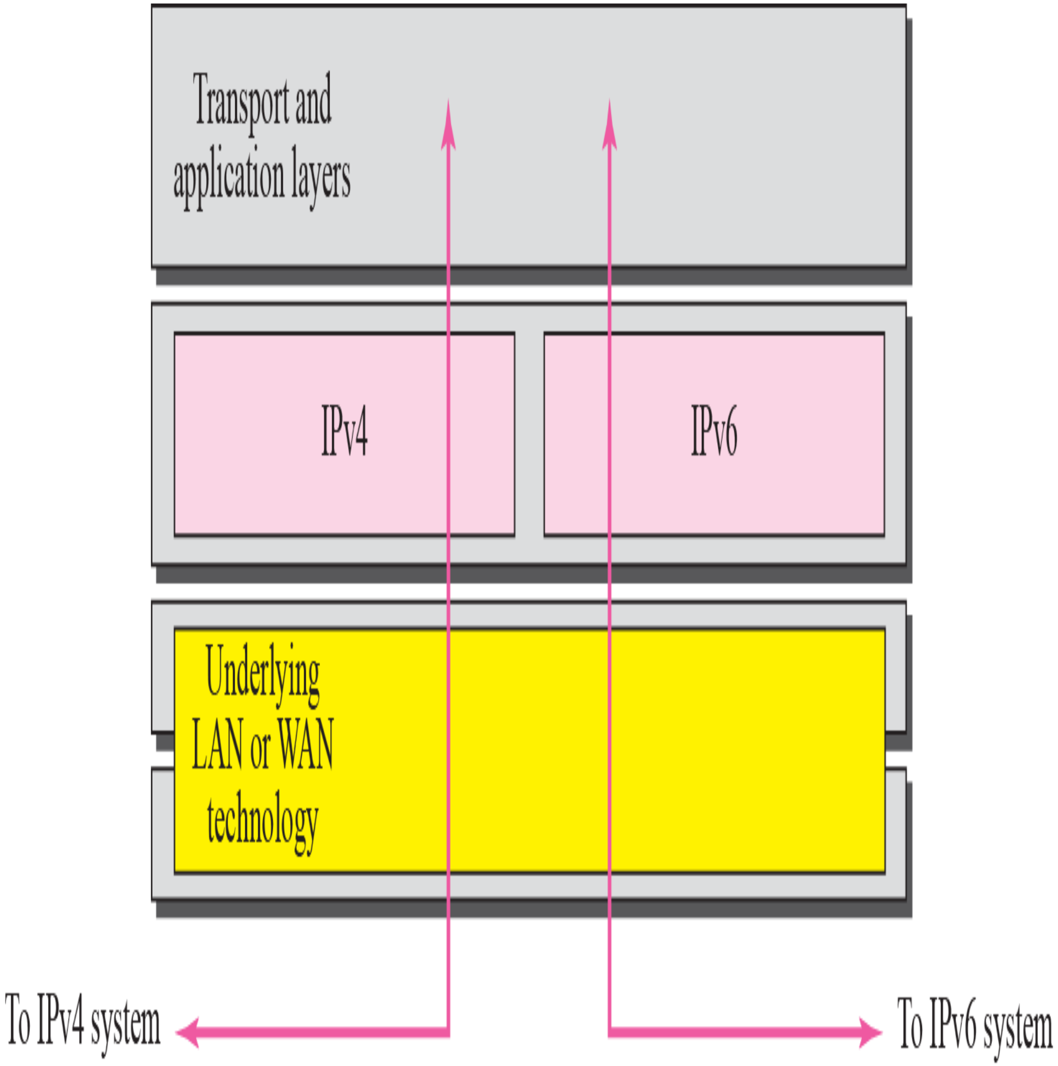


Transition from IPv4 to IPv6 : Dual Stack

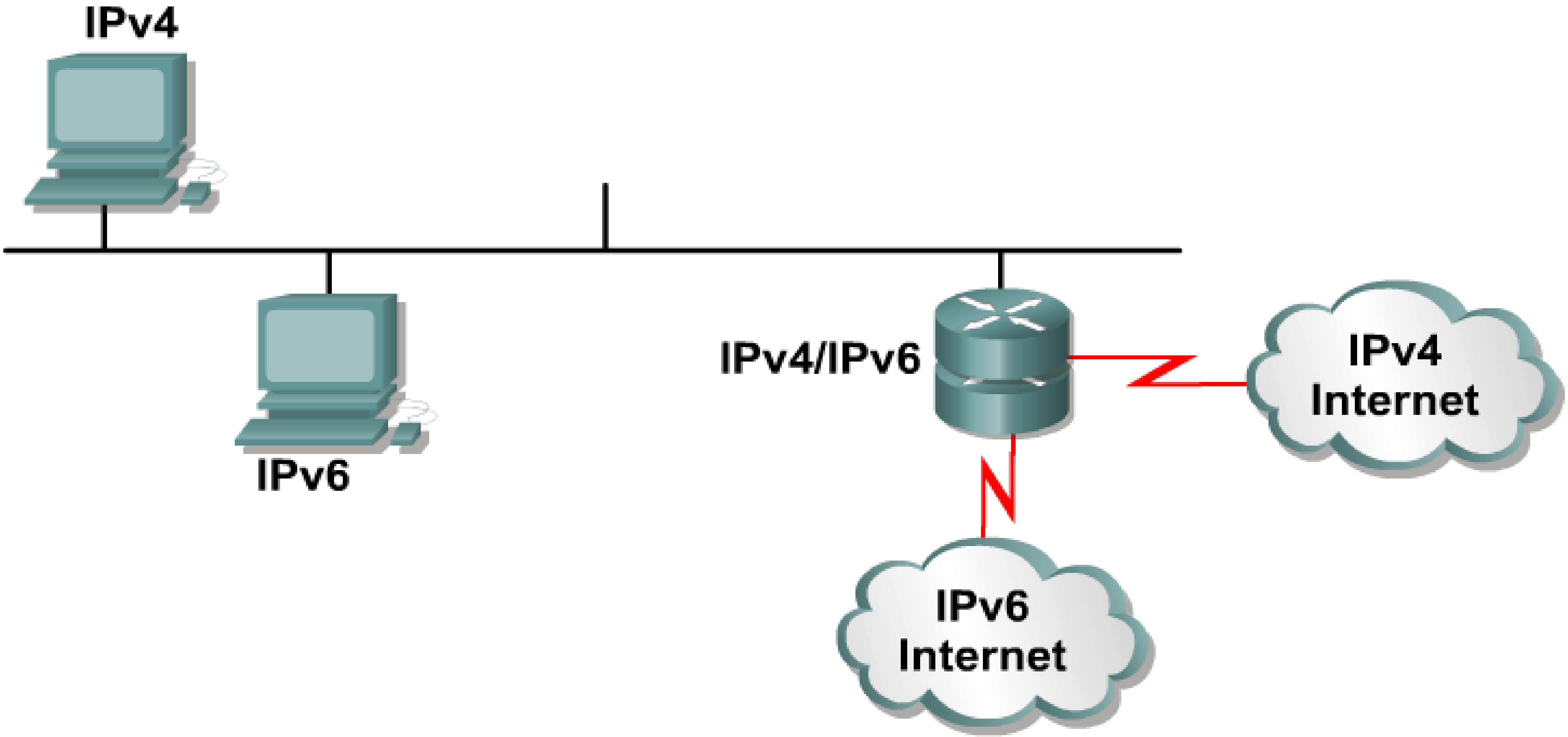
- This allows all the **end hosts and intermediate network devices** (like routers, switches, modems etc.) **to have both IPv4 and IPv6 addresses and protocol stack**.
- The **Dual Stack Router** can communicate **with both the networks**.
- If both the end stations support IPv6, they can communicate using IPv6, otherwise they will communicate using IPv4.
- This will allow both IPv4 and IPv6 **to coexist** and **slow transition from IPv4 to IPv6 can happen.**
- Equipment will prefer IPv6 from IPv4 if both are possible.
- When adding IPv6 to a system, do not delete IPv4.
  - This multi-protocol approach is familiar and well-understood
  - In most cases, IPv6 will be bundled with new OS releases

Transition from IPv4 to IPv6 : Dual Stack





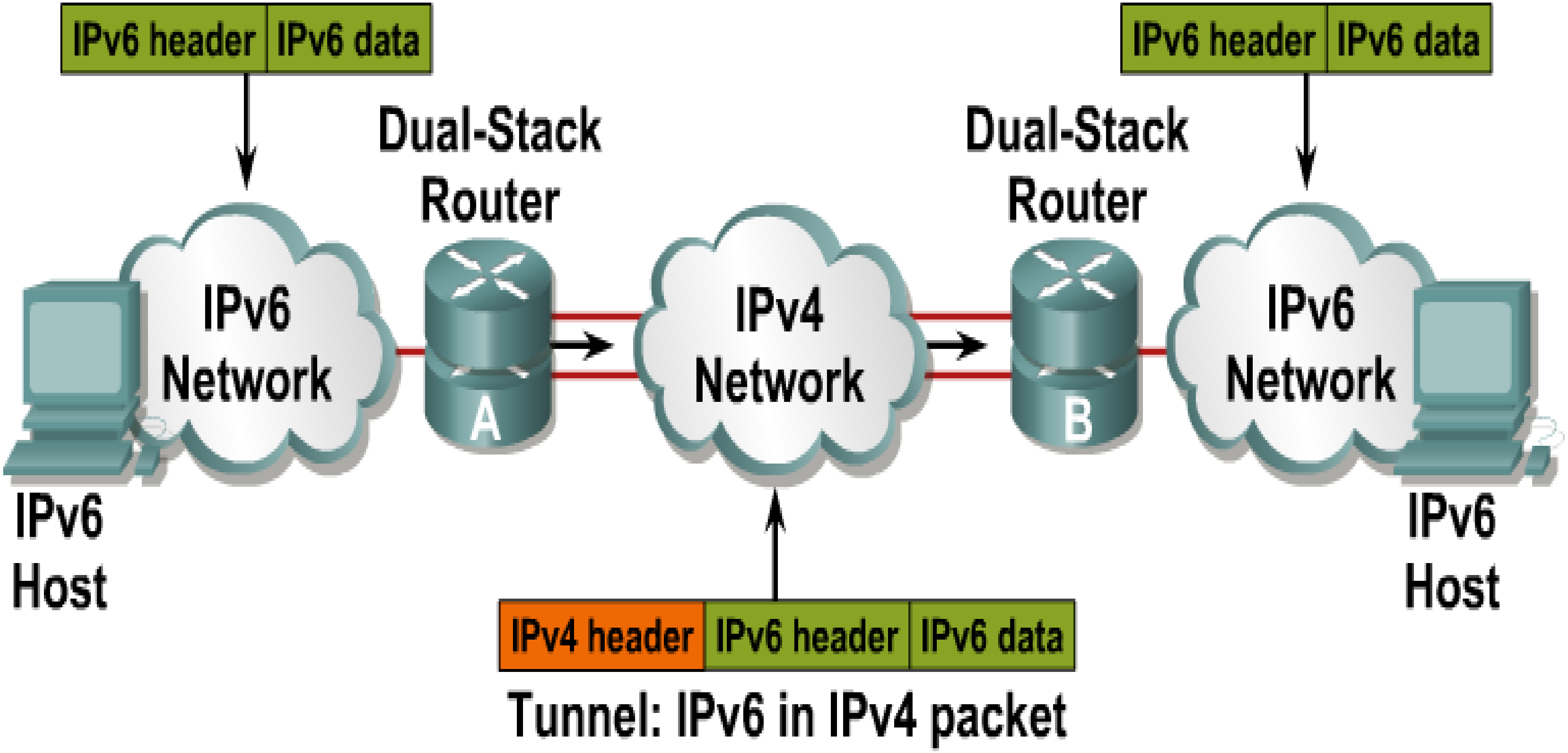
Dual Stack Hosts and Network



Transition from IPv4 to IPv6 : Tunneling

- Where different IP versions exist on intermediate path or transit networks, tunneling provides a better solution where user's data can pass through a non-supported IP version.
- This allows encapsulating IPv6 packets in IPv4 packets for transport over IPv4 only network.
- This will allow IPv6 only end stations to communicate over IPv4 only networks.
- **Tunneling Mechanism: How they work:**
  - Encapsulation of IPv6 packets within IPv4 packets and vice versa. Which means it can also be used for IPv4 connections over IPv6 native networks

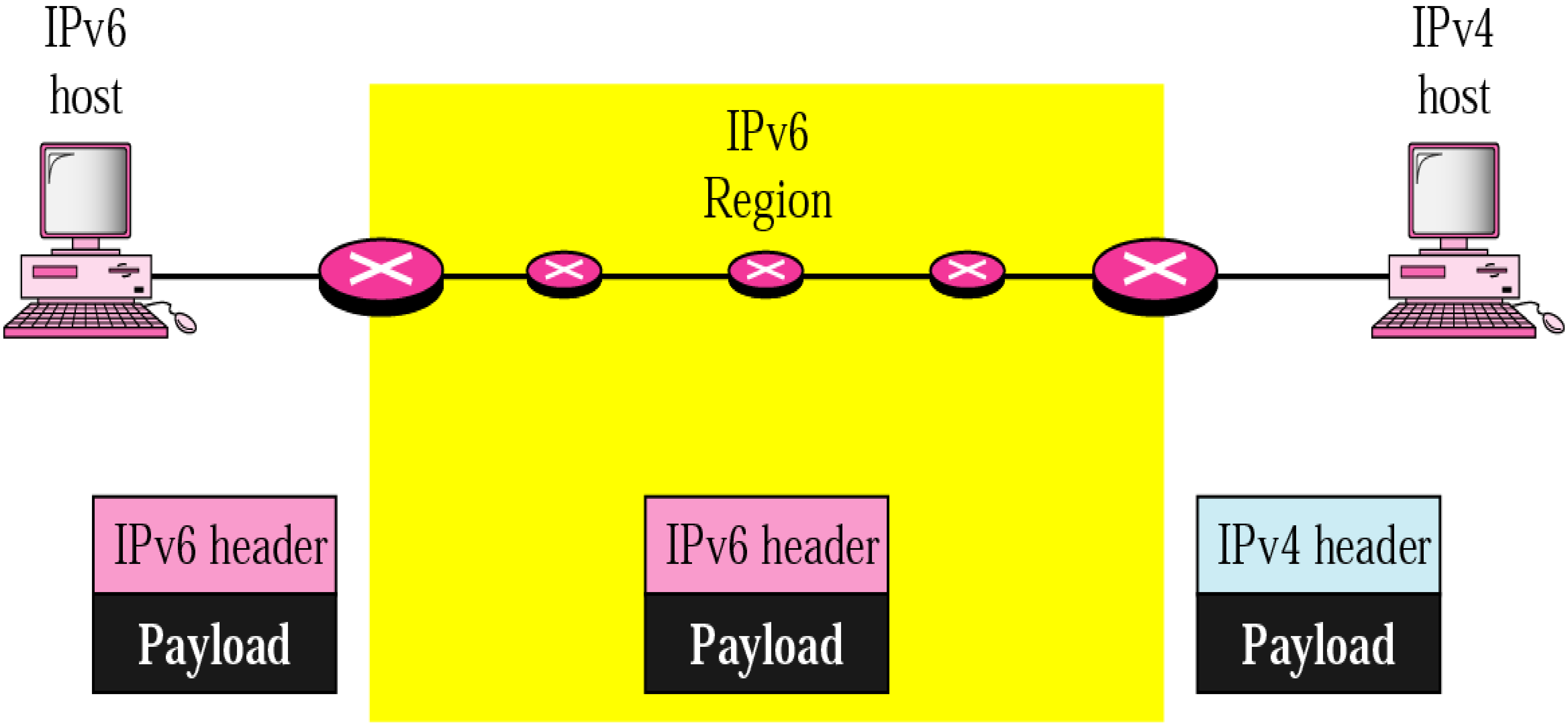
Transition from IPv4 to IPv6 : Tunneling



Automatic Tunneling Mechanisms: 6to4 Overview

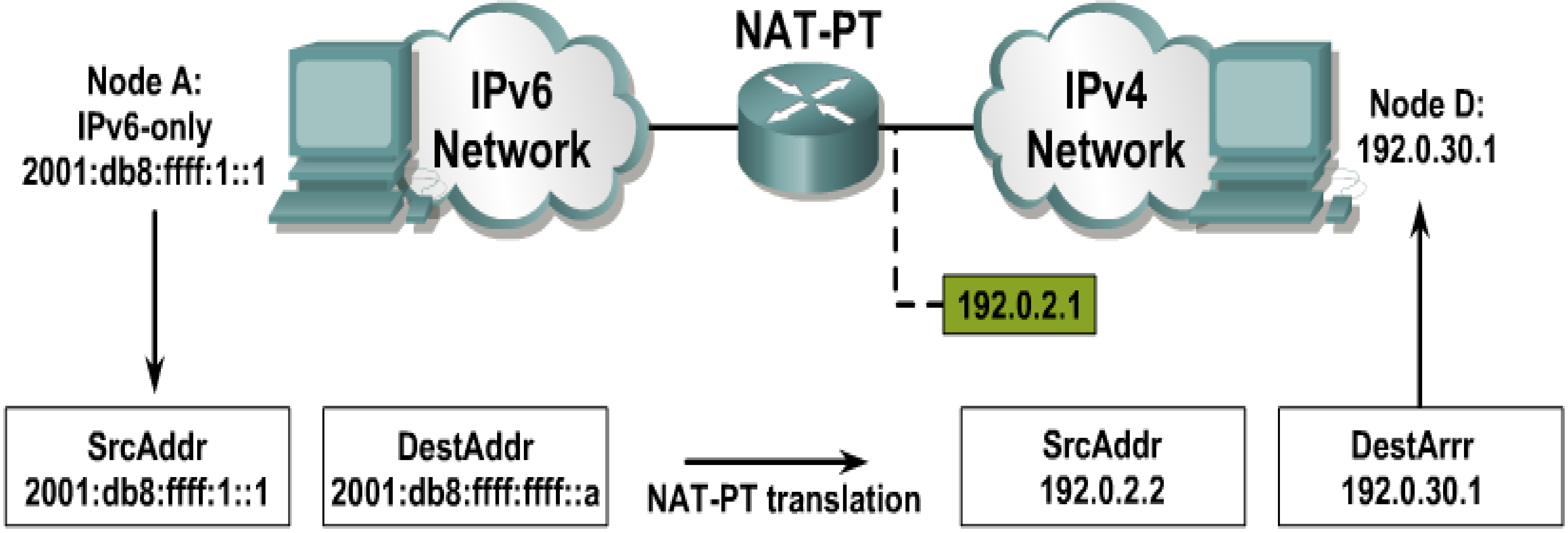
- The **most widely used mechanism .**
- In its basic configuration, **6to4** is used to connect **two IPv6 islands across an IPv4 network**
- Uses special ‘trick’ for the **2002::/16 IPv6 prefix** that is **reserved for 6to4 use**.
  - Next 32 bits of the prefix are the 32 bits of the IPv4 address of the 6to4 router.
  - For example, a 6to4 router on 192.0.1.1 would use an IPv6 prefix of 2002:c000:0101::/48 for its site network.
  - When a 6to4 router sees a packet with destination prefix 2002::/16, it knows to tunnel the packet in IPv4 towards the IPv4 address indicated in the next 32 bits.
  - Any site with single unicast IPv4 address can transmit to the IPv6 network using the 2002::/16 prefix

Header Translation



Header Translation

- This allows communication between IPv4 only and IPv6 only end stations.
- The job of the translator is to translate IPv6 packets into IPv4 packets by doing address and port translation and vice versa.



Multicasting

- Multicast is communication between a single sender and multiple receivers on a network.
- **Generic Multicast Group Addresses**

11111111	Flags	Scope	Group ID
8 bits	4 bits	4 bits	112 bits

- IPv6 multicast addresses are in the range of **FF00::/8**
- Flag field:
- 000T values
  - T = 0, for permanent addresses defined by IANA
  - T = 1, for transient addresses
- Scope field: Allows limiting the scope of the multicasting
  - 0 – Reserved
  - 1 – Node-local
  - 2 – Link-local
  - 3 – Subnet-local
  - 4 - Admin-local
  - 5 - Site-local
  - 8 - Organization-local
  - E - Global (Internet)

IPv6 Address Prefix Length Representation

- Like IPv4 classless addresses , IP v6 addresses are fundamentally divided into a number of network ID bits followed by a number of host ID bits.
- The network identifier is called the prefix, and the number of bits used is the prefix length.
- Like IPv4 address:
  - 198.10.0.0/16
- IPv6 address is represented in the same way:
  - 2001:db8:12::/40

IPv6: Special Address

IPv6 Address	Meaning
::/128	Unspecified Address
::/0	Default Route
::1/128	Loopback Address

- In IPv4, the address 0.0.0.0 with netmask 0.0.0.0 represents the default route. The same concept is also applied to IPv6, address 0:0:0:0:0:0:0:0 with netmask all 0s represents the default route. After applying IPv6 rule, this address is compressed to ::/0.
- Loopback addresses in IPv4 are represented by 127.0.0.1 to 127.255.255.255 series. But in IPv6, only 0:0:0:0:0:0:0:1/128 represents the Loopback address. After loopback address, it can be represented as ::1/128.

IPv6: Special Address

- **Reserved Multicast Address for Routing Protocols**

IPv6 Address	Routing Protocol
FF02::5	OSPFv3
FF02::6	OSPFv3 Designated Routers
FF02::9	RIPng
FF02::A	EIGRP

- **Reserved Multicast Address for Routers/Node**

IPv6 Address	Scope
FF01::1	All Nodes in interface-local
FF01::2	All Routers in interface local
FF02::1	All Nodes in link-local
FF02::2	All Routers in link-local
FF05::2	All Routers in site-local

Advantages of IPv6

- **Larger Address Space**
- **Simplified Header:** IPv6's header has been simplified by moving all unnecessary information and options (which are present in IPv4 header) to the end of the IPv6 header.
- **End-to-end Connectivity:** Every system now **has unique IP address** and can traverse through the Internet **without using NAT** or other **translating components**.
- **Faster Forwarding/Routing**
- **No Broadcast:** IPv6 does not have any broadcast support any more. It uses multicast to communicate with multiple hosts.
- **Anycast Support**
- **Extensibility:** One of the major advantages of IPv6 header is that it is extensible to add more information in the option part.
- **Internet Protocol Security (IPsec):** Initially it was decided that IPv6 must have IPSec security, making it more secure than IPv4. This feature has now been made optional.

Thank You
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References:

- Data Communications and Networking “ Behrouz A. Forouzan”
- Computer Networks “A. S. Tanenbaum” Fifth Edition
- Data and Computer Communications “William Stallings” Tenth Edition.