Network Layer:
Internet Protocol, Version 6 (IPv6)

Lecture 14 | CSE421 – Computer Networks

Department of Computer Science and Engineering
School of Data & Science

IPv6

- Initial motivation:
  - 32-bit address space soon to be completely allocated.
- Additional motivation:
  - Simpler header format helps speed processing/forwarding
  - header changes to facilitate QoS

IPv4 Allocation Authority

REGISTRY	AREA COVERED
AFRINIC	Africa Region
APNIC	Asia/Pacific Region
ARIN	Canada, USA, and some Caribbean Islands
LACNIC	Latin America and some Caribbean Islands
RIPE NCC	Europe, the Middle East, and Central Asia

IPv4 Address Exhaustion

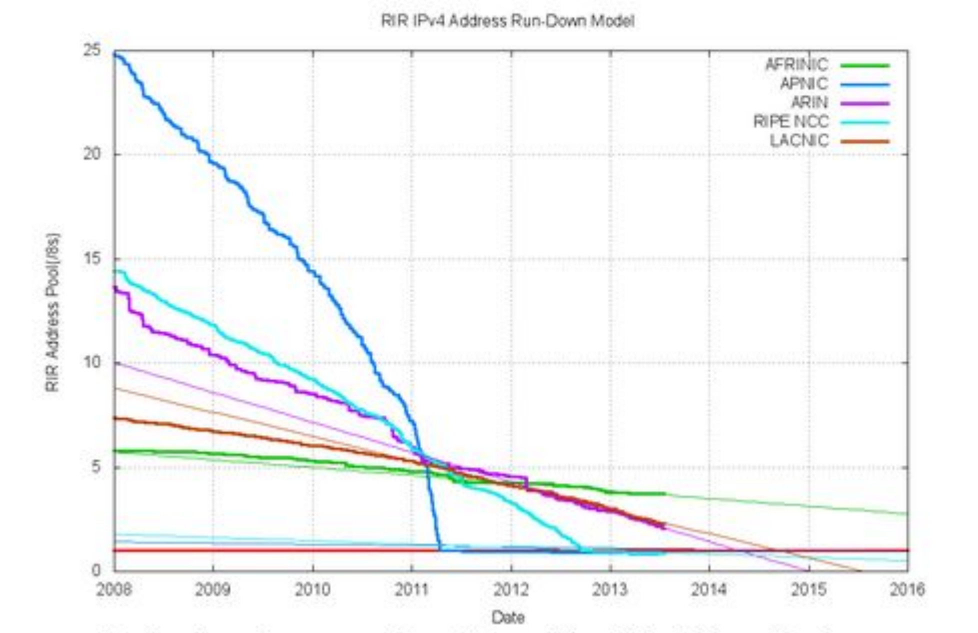
This report generated at 18-Jul-2013 08:00 UTC.

IANA Unallocated Address Pool Exhaustion:

03-Feb-2011

Projected RIR Address Pool Exhaustion Dates:

RIR	Projected Exhaustion Date	Remaining Addresses in RIR Pool (/8s)
APNIC:	**19-Apr-2011** (actual)	0.8498
RIPE NCC:	**14-Sep-2012** (actual)	0.8828
ARIN:	**12-Apr-2014**	2.0572
LACNIC:	**24-Aug-2014**	2.2882
AFRINIC:	**09-Nov-2020**	3.7184



Projection of consumption of Remaining RIR Address Pools

Reasons for using IPv6

- Address Availability:
  - IPv4: 4 octets - 32 bits
    - 2^32 or 4,294,467,295 IP Addresses.
  - IPv6: 16 octets - 128 bits
    - 3.4 x 10^38 or

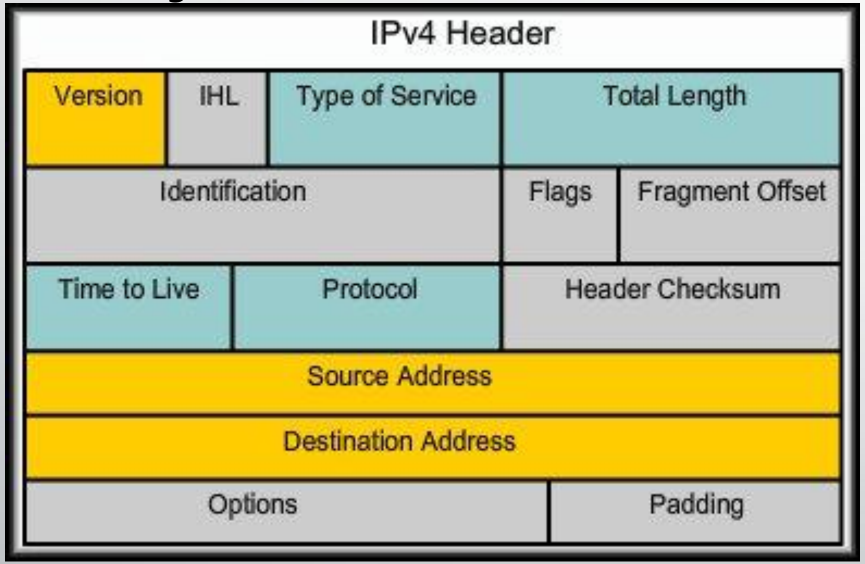
340,282,366,920,938,463,463,374,607,431,768,211,456

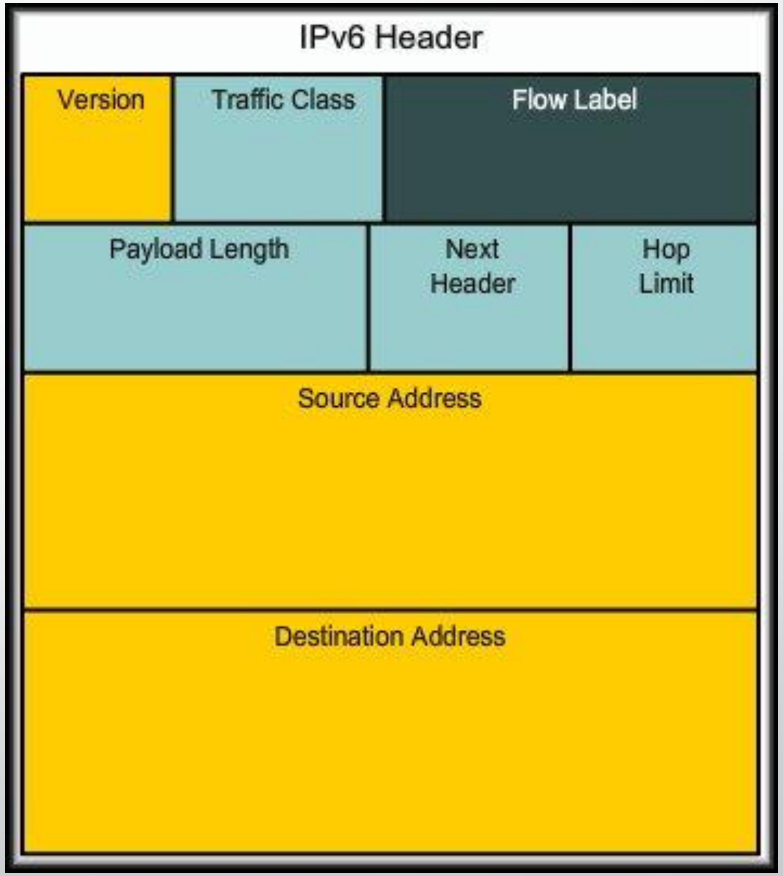
(340 undecillion) IP Addresses.

  - *Every atom of every person on Earth could be assigned 7 unique addresses with some to spare (assuming*
    7×10^{27} atoms per human x 6.5 Billion).

Reasons for Using IPv6

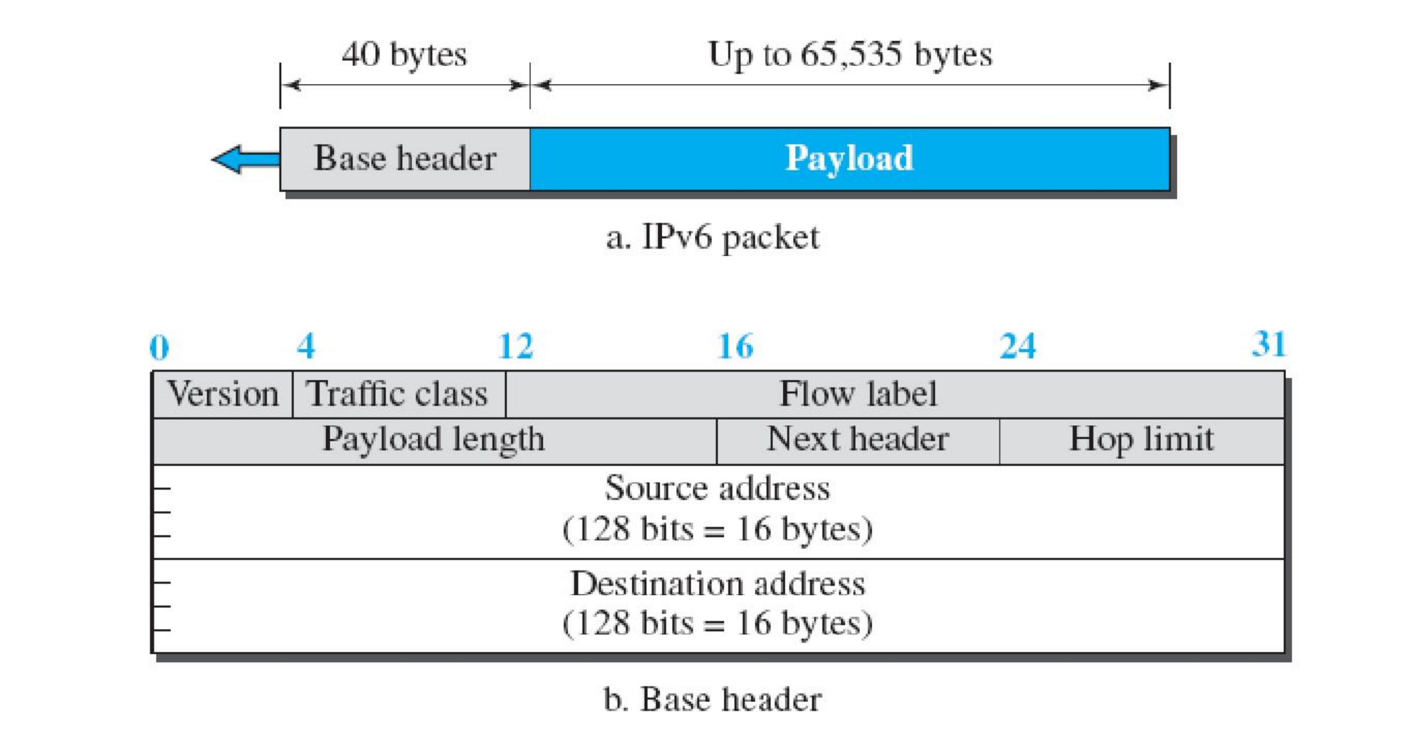
- IPv6 Features:
  - fixed-length 40 byte header
  - no fragmentation allowed



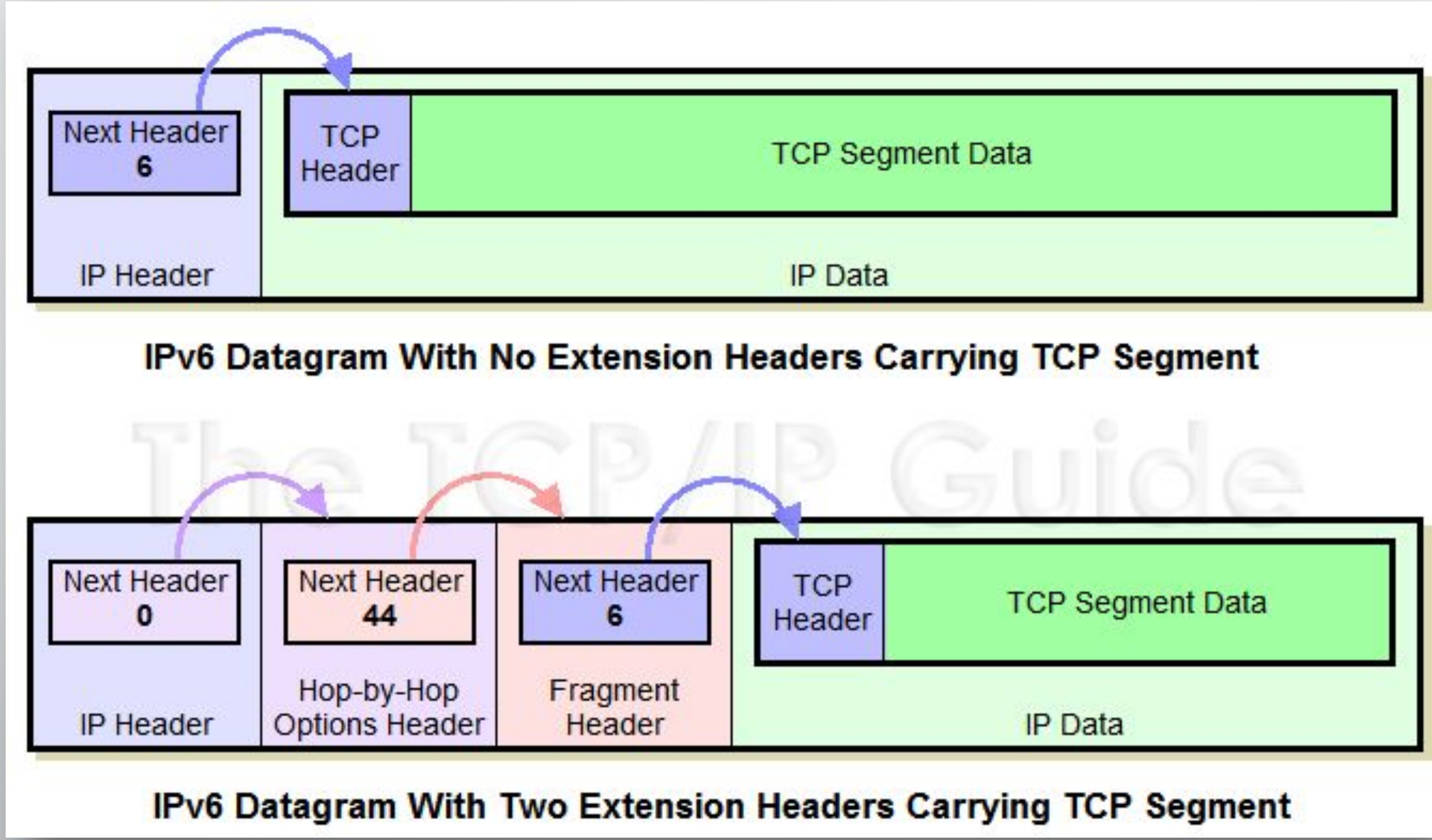


IPv6 Datagram

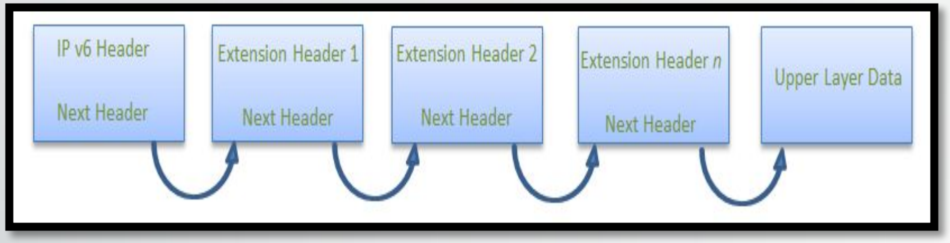
40 Octets, 8 fields

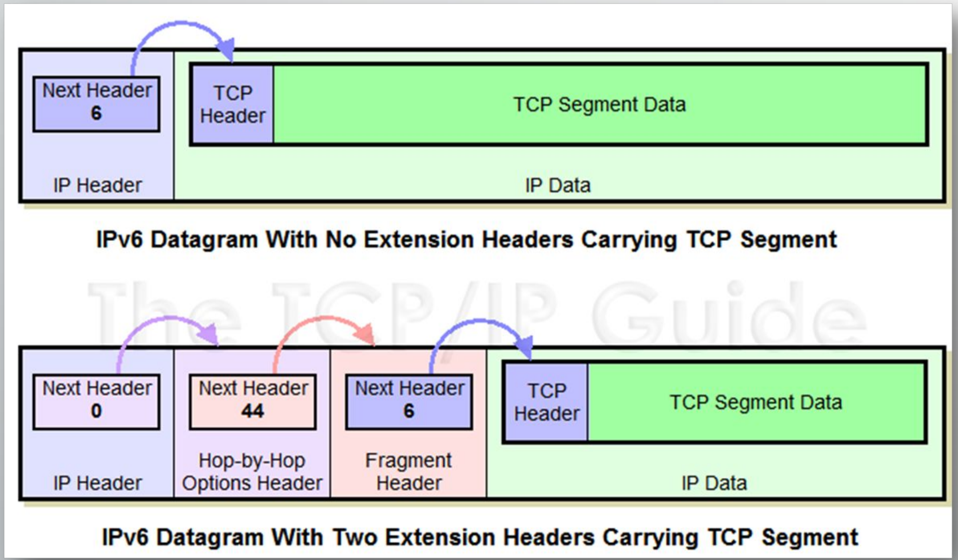


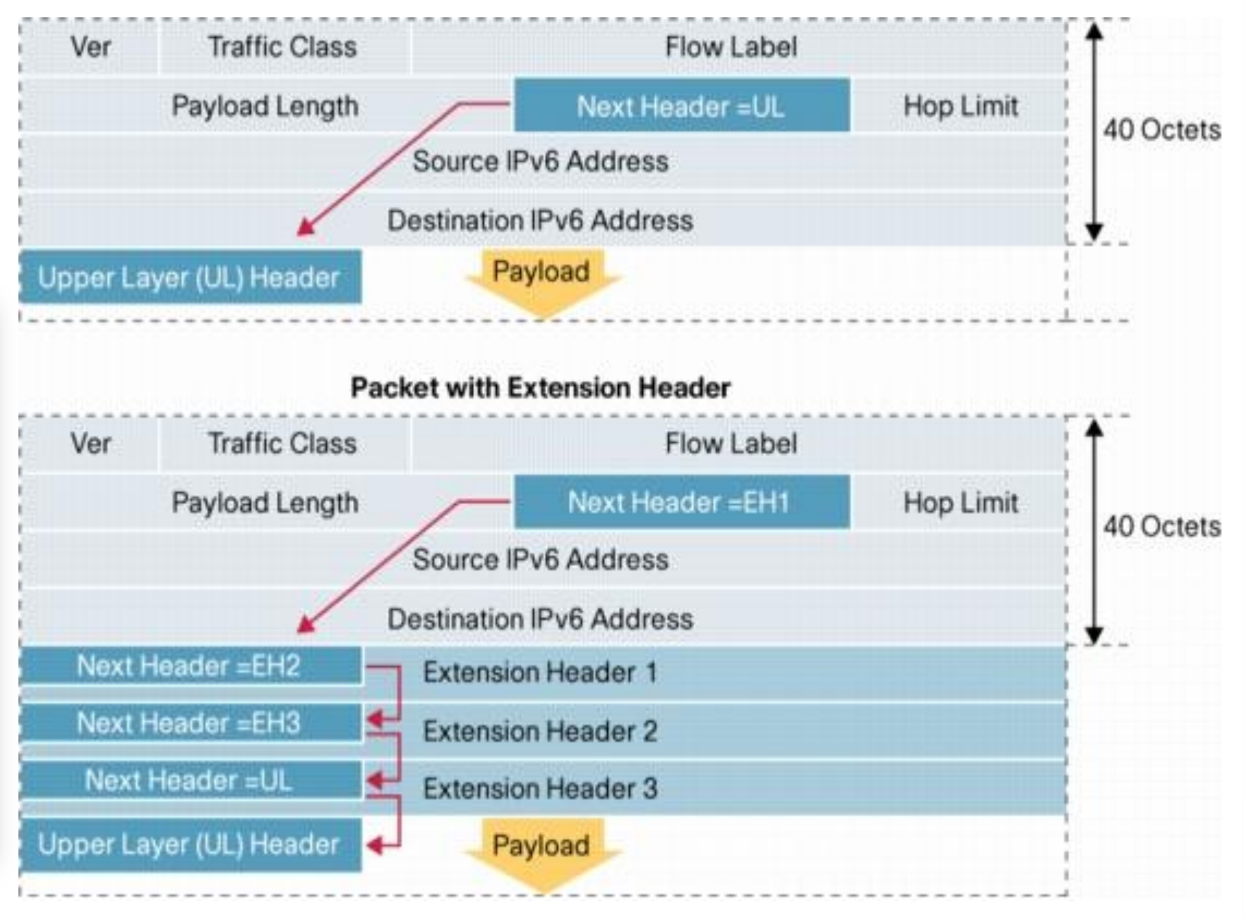
Extension Headers



Extension Headers



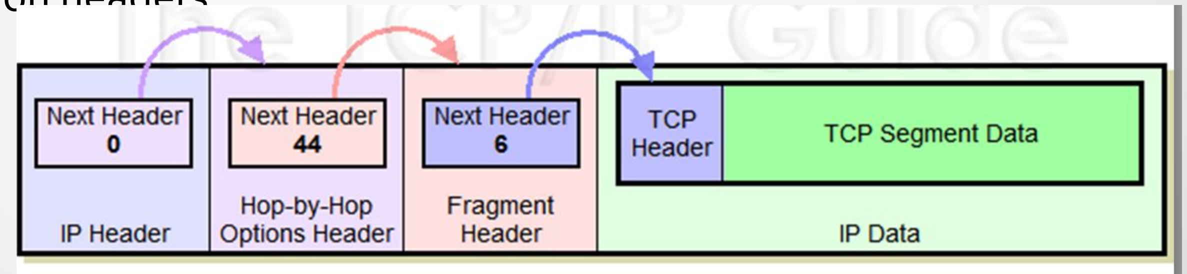




Extension Headers

- Basic header simplified for ease of processing

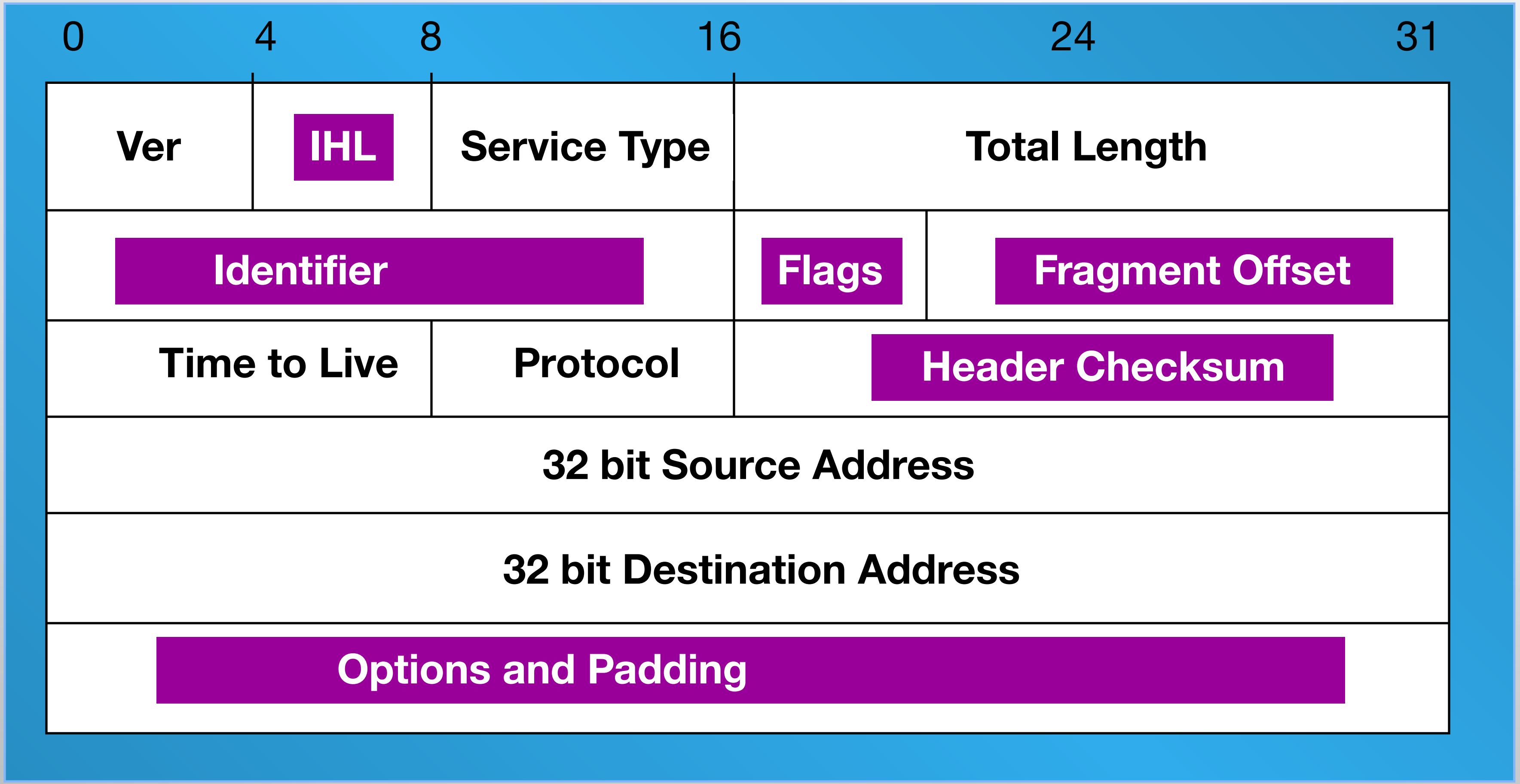
- Additional information carried in extension headers
  - Hop-by-hop options
  - Routing header
  - Fragment header
  - Destination options header
  - Authentication header (AH)
  - Encrypted security payload (ESP) header



IPv6 Datagram With Two Extension Headers Carrying TCP Segment

- Next Header field says what type of header follows
  - E.g. Fragment Header, TCP, ICMP, etc.

The IPv4 Header



shaded fields are absent from IPv6 header

Header Changes between IPv4 and IPv6

- Revised
  - Time to Live (Hop Limit)
  - Addresses increased from 32 bits to 128 bits
  - Protocol (Next Header)
  - Precedence & TOS (Traffic Class)
- Extended
  - Flow Label field added

End of Part1

IPv6 Address

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0010000000000001 0000000000000000 0011001000111000 110111111110000
0000000001100011 0000000000000000 0000000000000000 1111111011111110

- given below is a 128 bit IPv6 address represented in binary format and divided into eight 16-bits blocks

001:0000:3238:DFE1:0063:0000:0000:FEF

- Called **string notation**

IPv6 Addressing

- IPv6 Representation – Rule 1:
  - The leading zeroes in any 16-bit segment do not have to be written. If any 16-bit segment has fewer than four hexadecimal digits, it is assumed that the missing digits are leading zeroes.

2031 :	0000 :	130F :	0000 :	0000 :	09C0 :	876A :	130B
2031 :	0 :	130F :	0 :	0 :	9C0 :	876A :	130B
8105 :	0000 :	0000 :	4B10 :	1000 :	0000 :	0000 :	0005
8105 :	0 :	0 :	4B10 :	1000 :	0 :	0 :	5
0000 :	0000 :	0000 :	0000 :	0000 :	0000 :	0000 :	0000
0 :	0 :	0 :	0 :	0 :	0 :	0 :	0

IPv6 Addressing

- IPv6 Representation – Rule 2:
  - Any single, contiguous string of one or more 16-bit segments consisting of all zeroes can be represented once with a double colon

1080:0:0:0:8:800:200C:417A	=
FF01:0:0:0:0:0:0:101	=
0:0:0:0:0:0:0:1	=
0:0:0:0:0:0:0:0	=

IPv6 Addressing

- IPv6 Representation – Rule 2:
  - *Any single, contiguous string of one or more 16-bit segments consisting of all zeroes can be represented $\boxed{\text{once}}$ with a double colon.*

Example: **`1843:f01::22::fa`**

  - Illegal because the length of the two all-zero strings is ambiguous.

`1843:00f0:0000:0000:0022:0000:0000:00fa`

or

`1843:00f0:0000:0000:0000:0022:0000:00fa`

or

`1843:00f0:0000:0022:0000:0000:0000:00fa`

Representing IPv6 addresses

- No more net masks
  - Represented by a "/prefixlen" appended to the end of an address where prefixlen indicates the number of bits in the address that make up the network address
    - Similar to classless address representation in IPv4
    - For example:

2001:db8:abcd:0012::0/64 specifies a subnet with a range of IP addresses from:

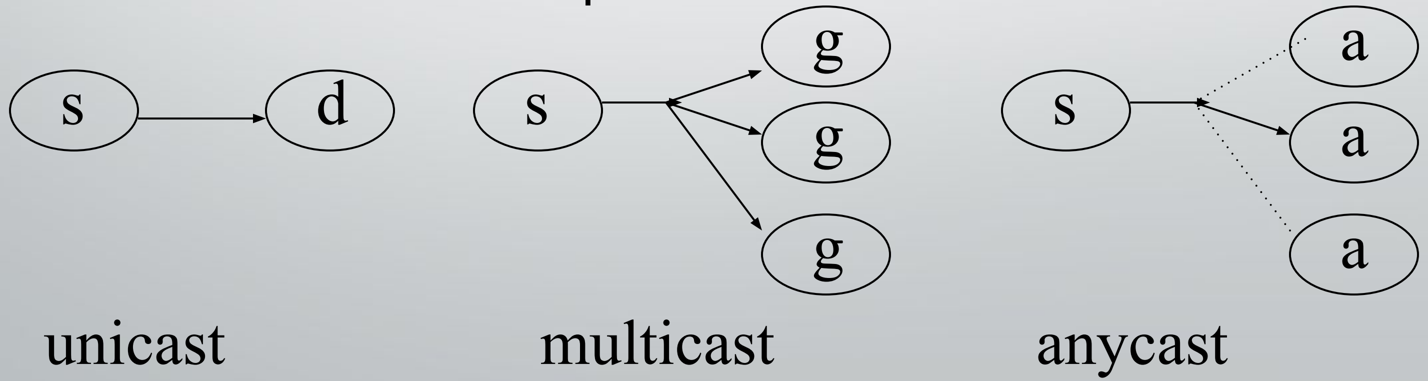
2001:db8:abcd:0012:0000:0000:0000:0000 to
2001:db8:abcd:0012:ffff:ffff:ffff:ffff.

Network part : 2001:db8:abcd:0012

Host part : ::0

Types of IPv6 addresses

- **unicast**
  - communicate specified 1 computer
- **multicast**
  - communicate group of computers
- **anycast**
  - send group address that can receive multiple computers, but receive 1 computer



Types of IPv6 addresses

- Unlike IPv4, there is no broadcast address.
- There is an “all nodes multicast” which serves the same purpose.

Unicast Global Addresses

- These are assigned by the IANA and used on public networks.
- They are equivalent to IPv4 global (sometimes called public) addresses.
- Typically they start at 2000::/3

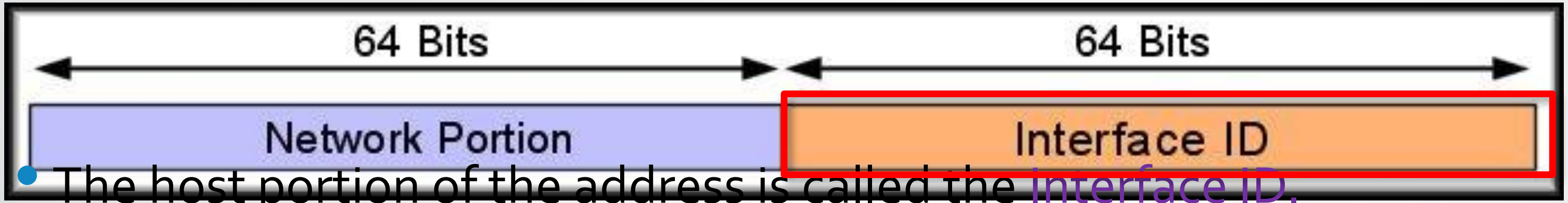
Unicast addresses

- A unicast address is an address that identifies a single device.

- Types of Unicast Addresses:

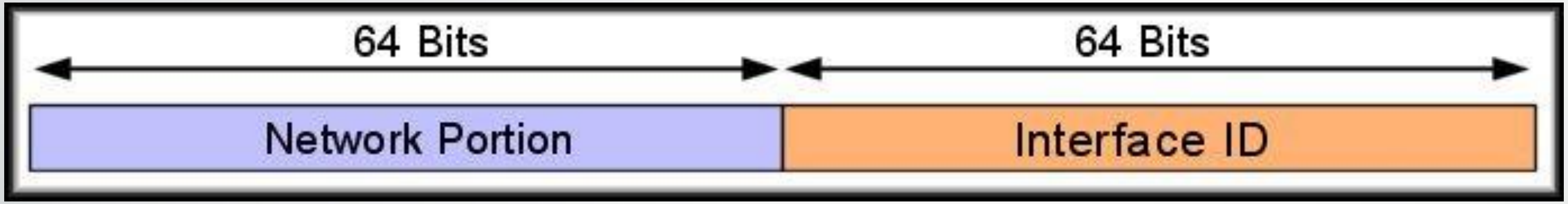
Block prefix	*CIDR*	*Block assignment*	*Fraction*
0000 0000	0000::/8	Special addresses	1/256
001	**2000::/3**	**Global unicast**	**1/8**
1111 110	FC00::/7	Unique local unicast	1/128
1111 1110 10	FE80::/10	Link local addresses	1/1024
1111 1111	FF00::/8	Multicast addresses	1/256

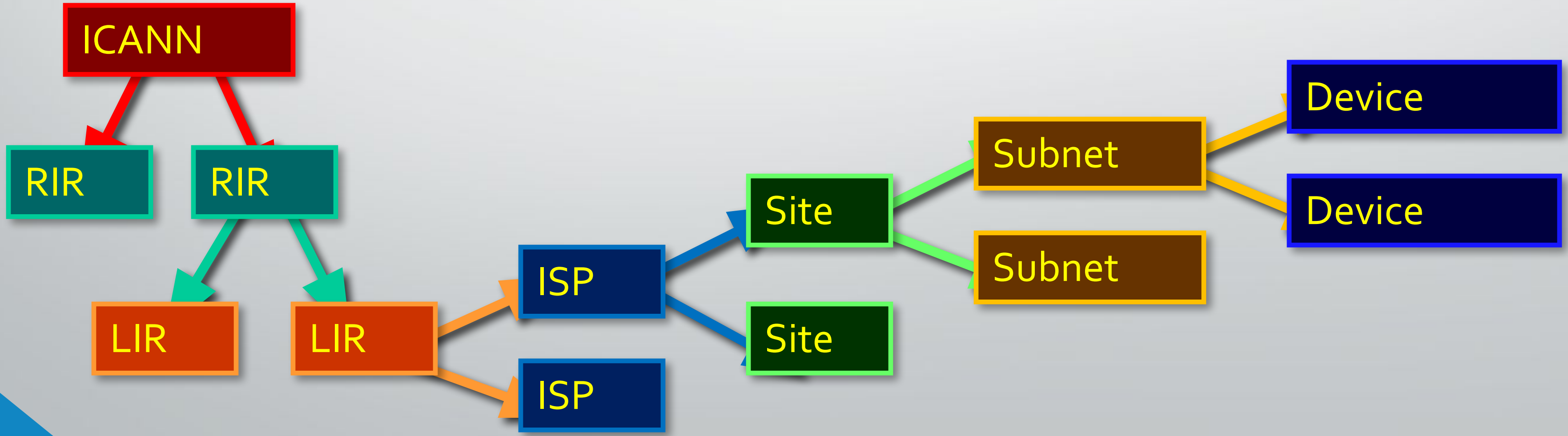
Unicast Global Addresses



- The host portion of the address is called the interface ID.
  - Can contain:
    - The interface's 48-bit MAC Address.
    - An identifier derived from the EUI-64 Address (more later).
    - A manually configured address.

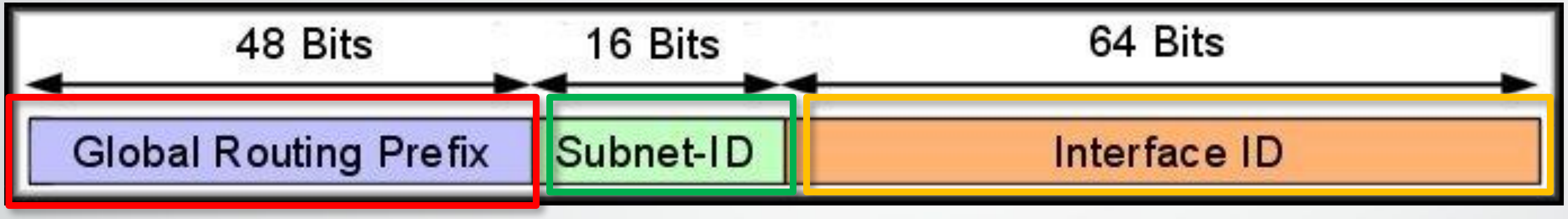
Unicast Global Addresses

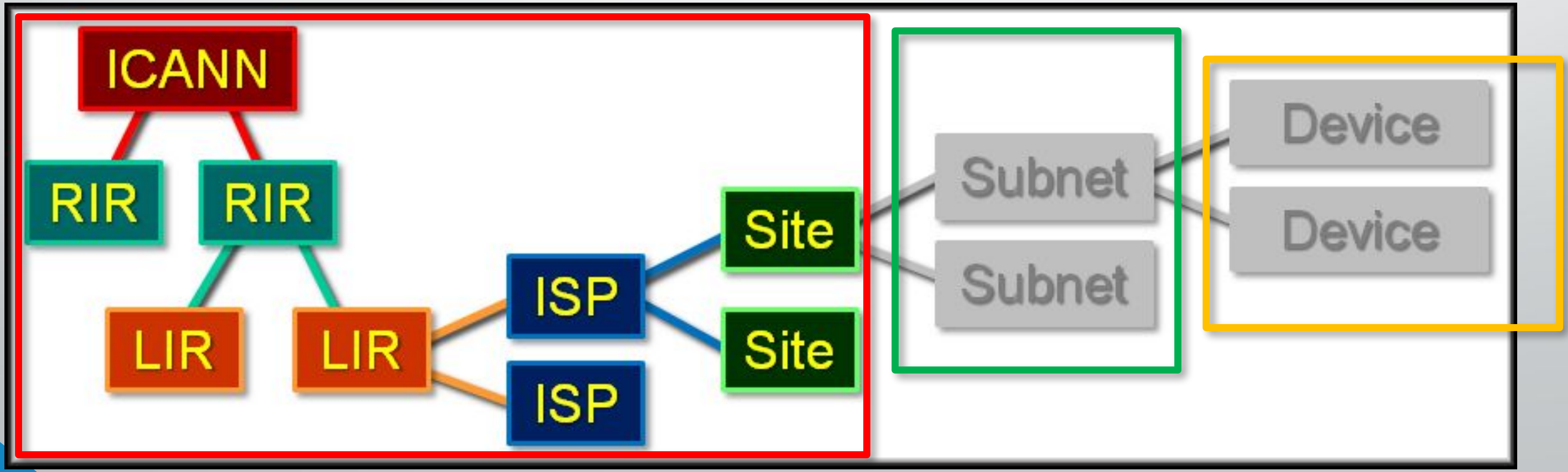




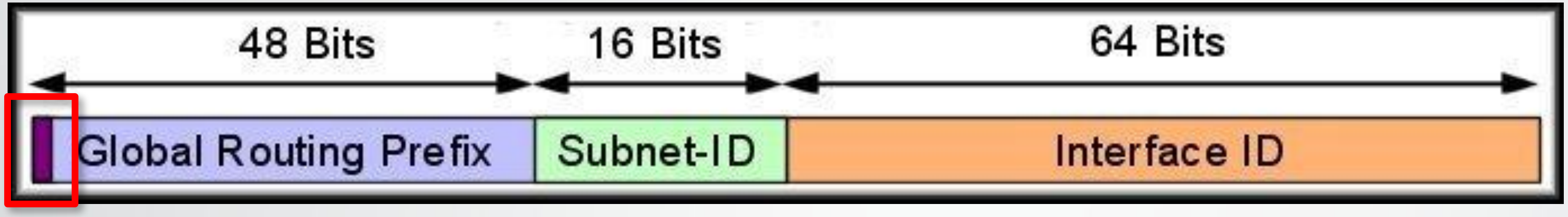
Unicast Global Addresses

- Network Portion:





Unicast Global Addresses

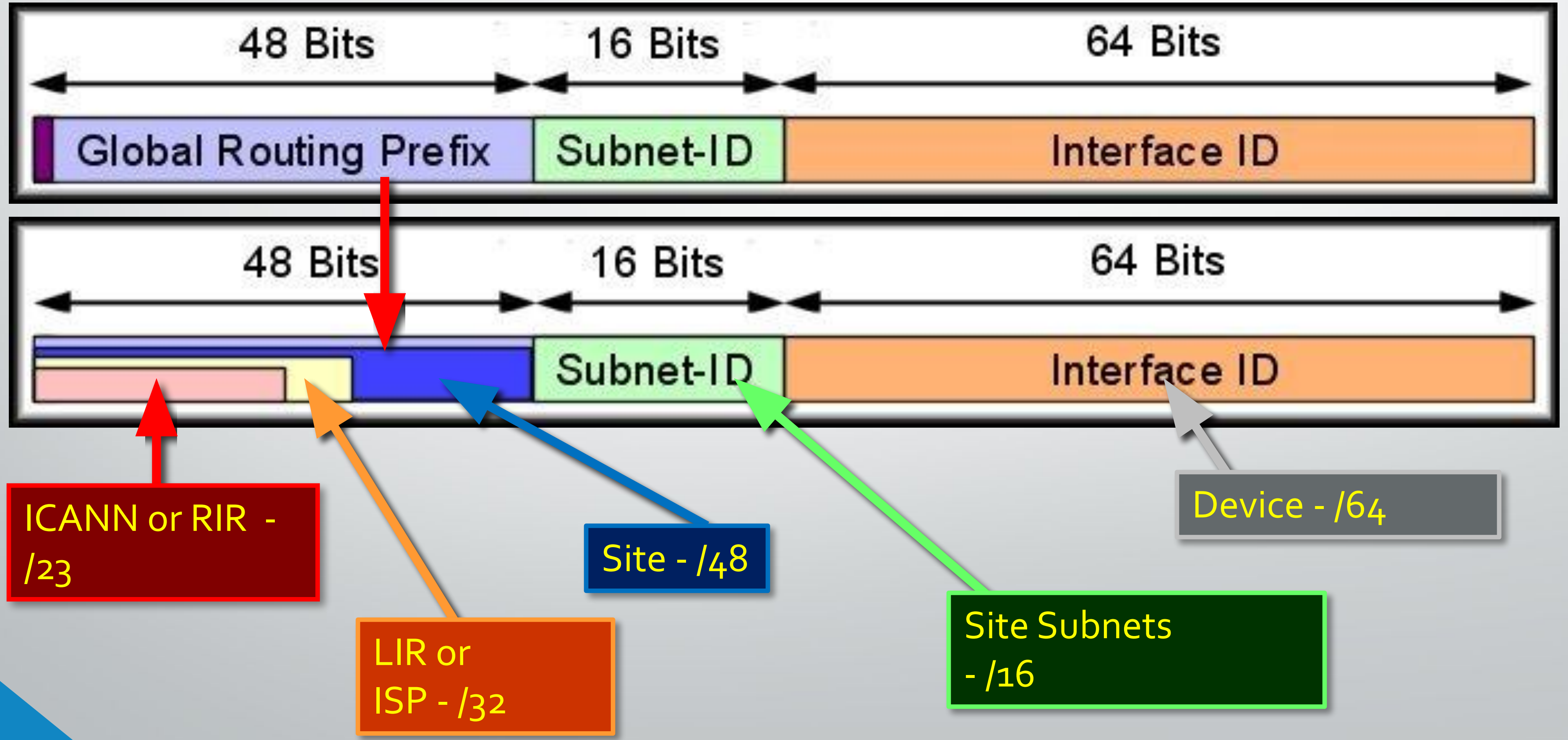


- Begins with binary 001.
- More easily recognized as beginning with a hexadecimal 2 or 3.

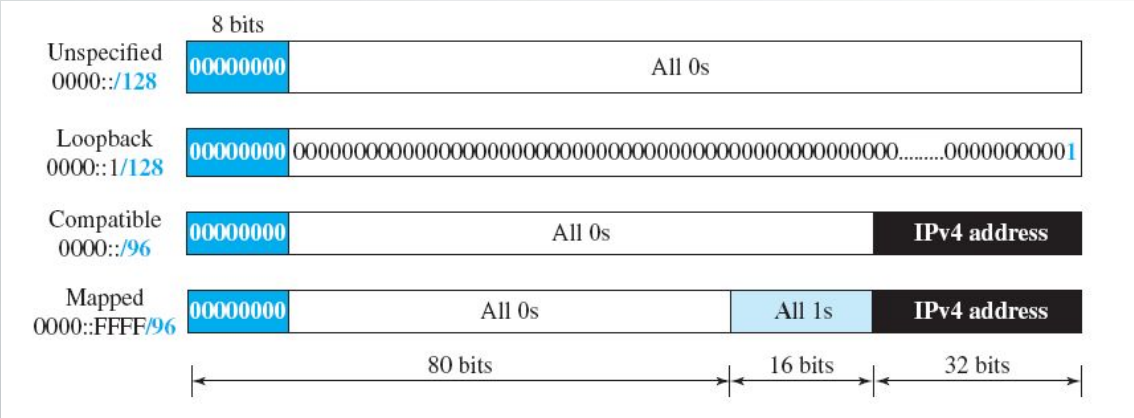
  0010 xxxx or 0011 xxxx

- ICANN assigns global unicast IPv6 addresses as public and globally-unique IPv6 addresses.
- *No need for NAT..*

Unicast Global Addresses



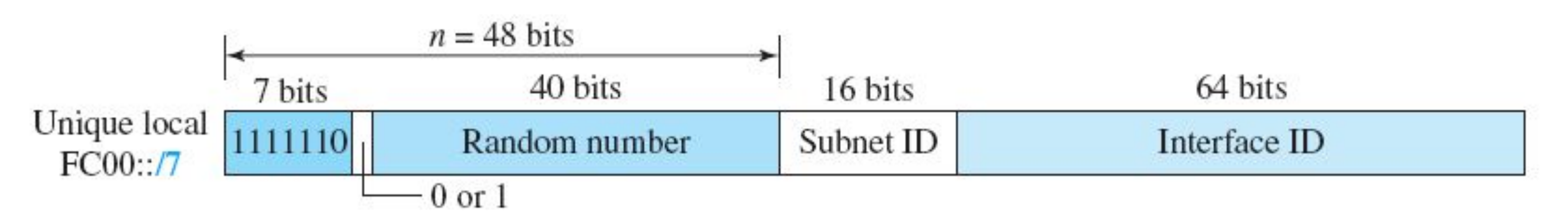
Special Addresses



- **Unspecified Address:**
  - ::/128
  - In a host, it refers to the host itself, and is used when a device does not know its own address
  - For addressing purposes within a software. .
- **Loopback Address**
  - ::1/128
  - loopback (same as 127.0.0.1 in many IPv4 implementations)
  - In IPv6 there is just one address, not a whole block, for this function.

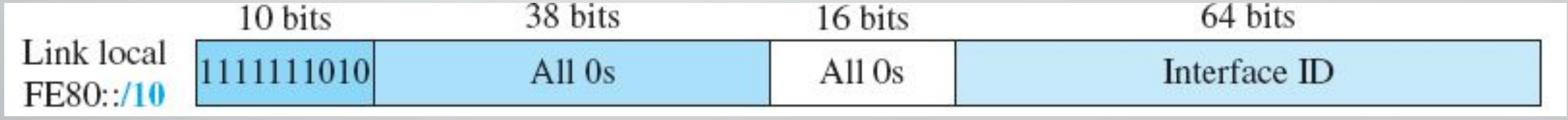
Unique Local Unicast Address

- FC00::/7
- Globally unique,
- But it should be used in local communication.

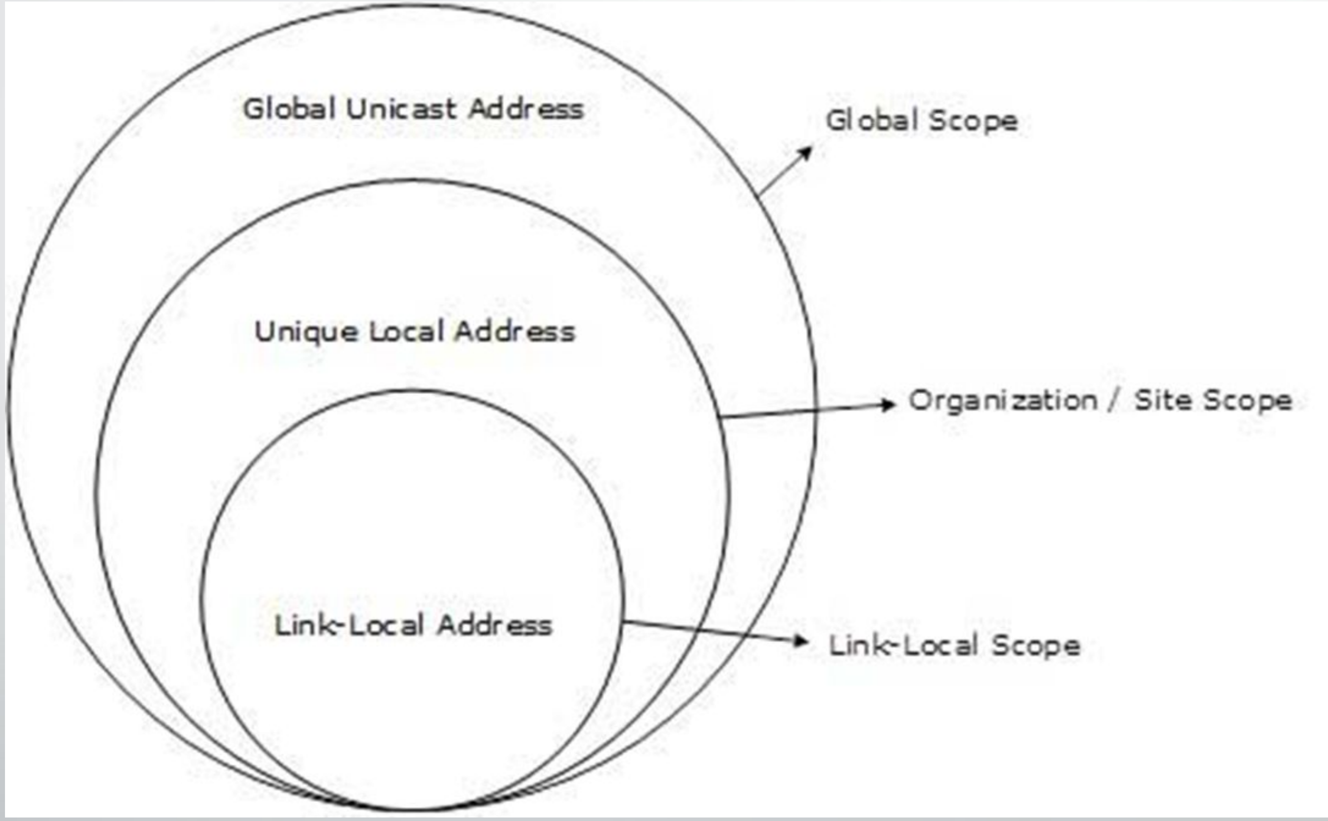


Link Local Unicast Address

- **FE80::/10**
  - These addresses refer only to a particular physical network.
  - Routers do not forward datagrams using link-local addresses.
  - They are only for local communication on a particular physical network segment.
    - Automatic address configuration.
    - Neighbor discovery.

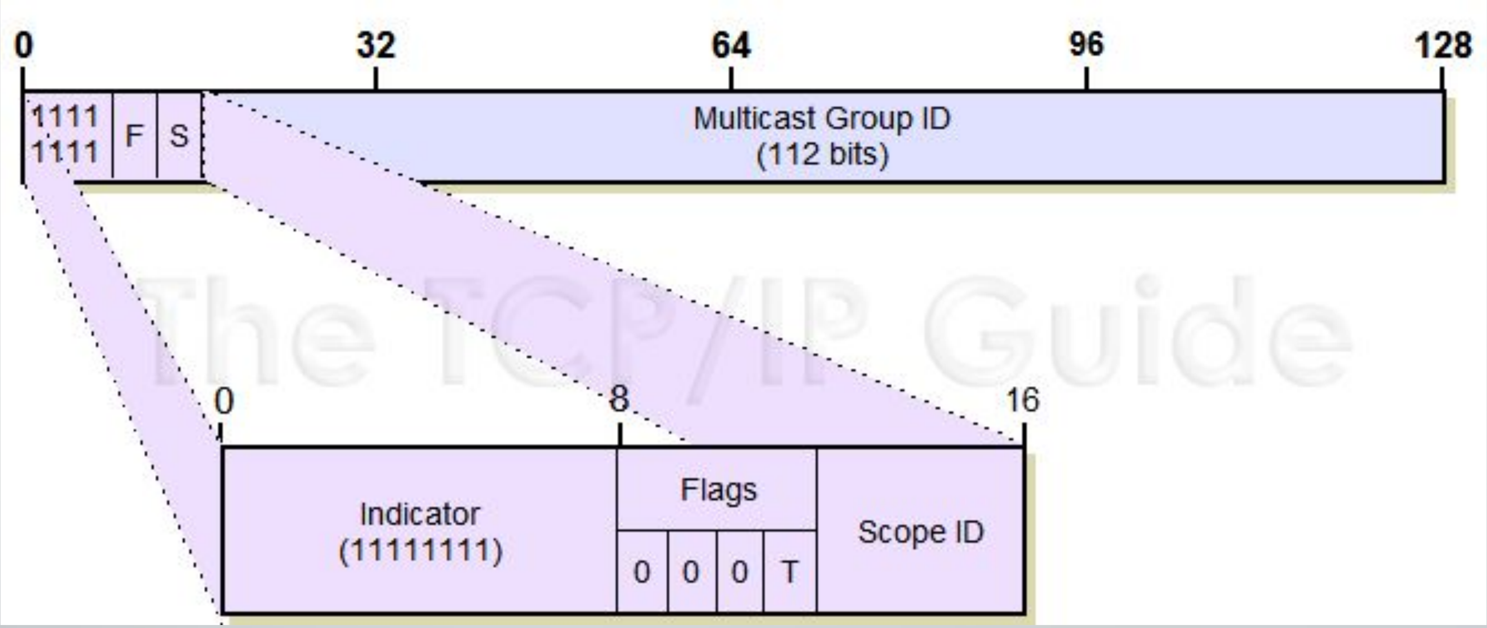


Scope of IPv6 Unicast Addresses



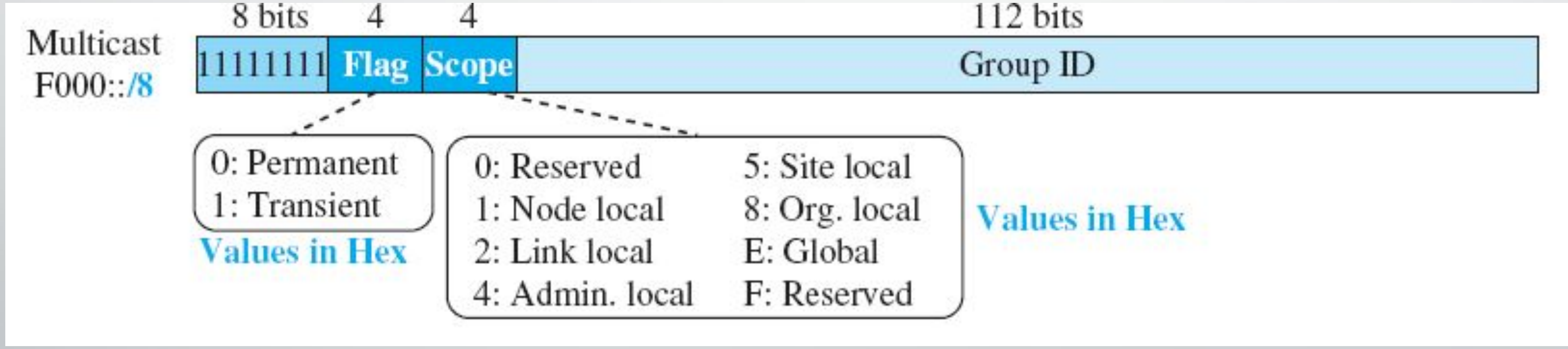
Multicast Addresses

- Consisting of all addresses that begin with "1111 1111" i.e "FF"

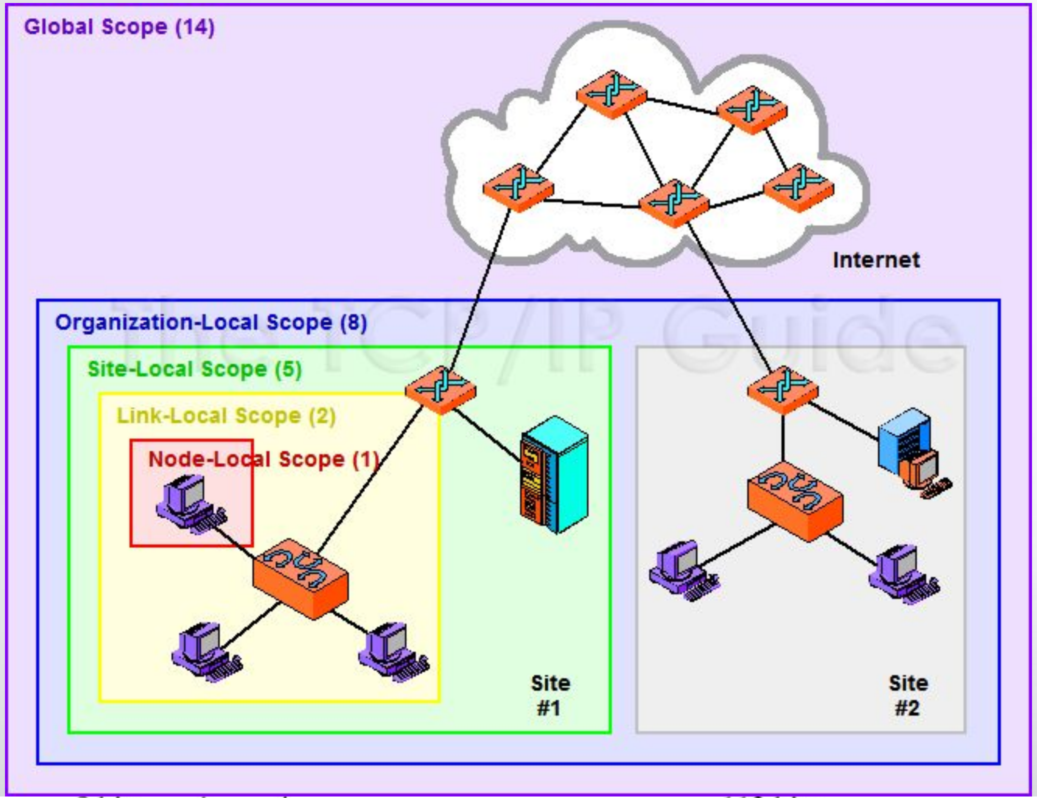


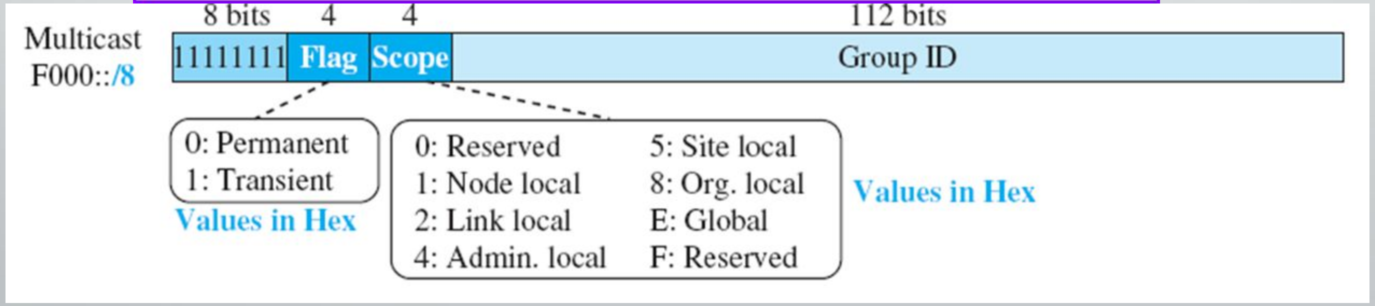
Multicast Addresses

- Multicast addresses are used to send data to a number of devices on an internetwork simultaneously.
- Each multicast address can be specified for a variety of different *scopes*
  - allowing a transmission to be targeted to either a wide or narrow audience of recipient devices.



Multicast Scopes





Anycast Addresses

- To provide flexibility in situations where we need a service that is provided by a number of different servers or routers but don't really care which one provides it.
- In routing, anycast allows datagrams to be sent to whichever router in a group of equivalent routers is closest

Anycast Addresses

- There is no special anycast addressing scheme: anycast addresses are the same as unicast addresses.
- An anycast address is created “automatically” when a unicast address is assigned to more than one interface.

Anycast Addresses

- Like multicast, anycast creates more work for routers; it is more complicated than unicast addressing.

- Due to the relative inexperience of the Internet community in using anycast,
  - for the present time anycast addresses are used only by routers and not individual hosts.

IPv6 Address Management

- IPv6 addresses use Interface Identifiers to identify interfaces on a link.
  - Think of them as the host portion of an IPv6 address.
- Four methods of address assignment:
  - Static assignment using a manual interface ID.
  - Static assignment using an EUI-64 interface ID.
  - Stateless Address Auto configuration (SLAAC)
  - Stateless/Stateful DHCP for IPv6 (DHCPv6)

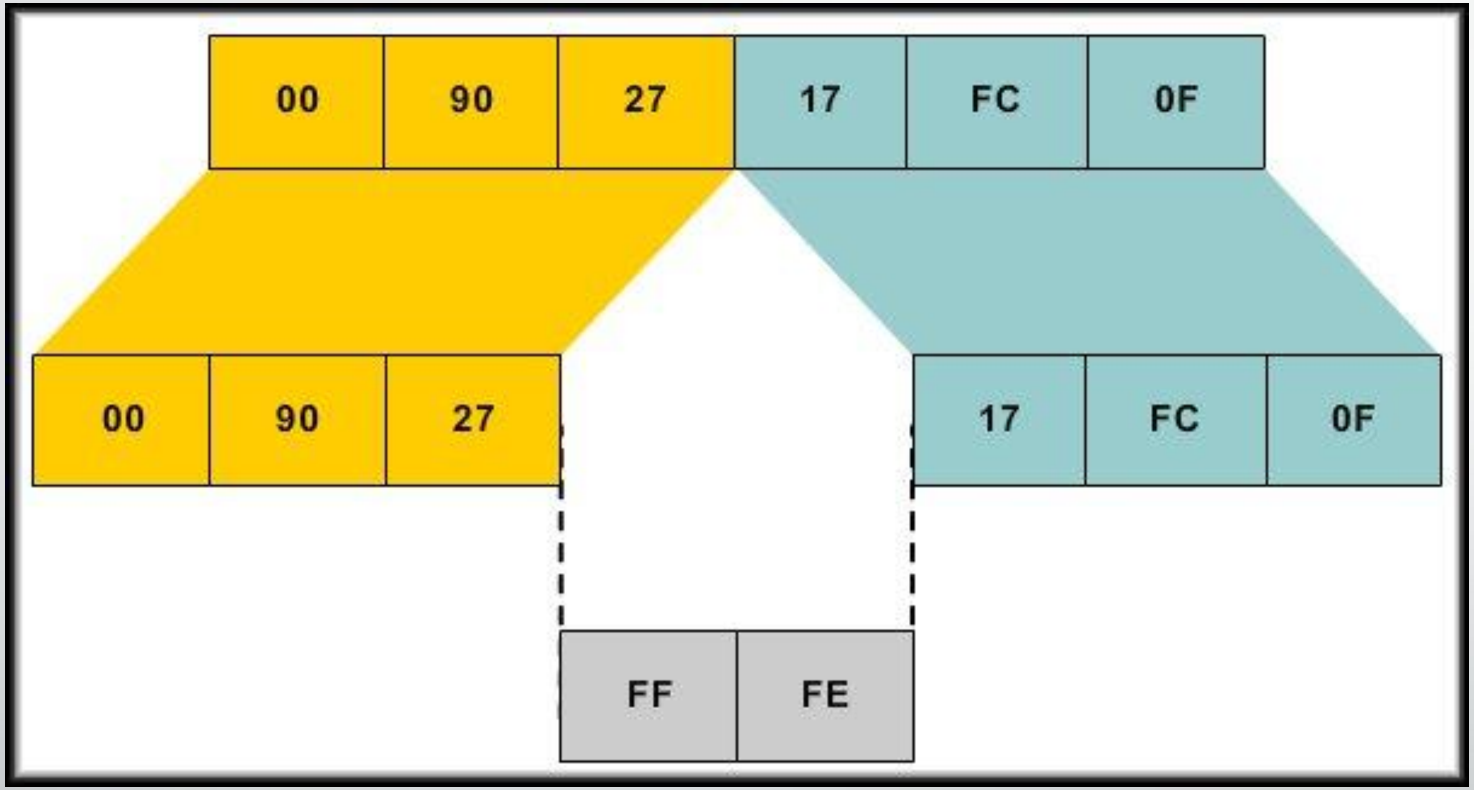
Static Address Management

- In order to enable IPv6 on a router
  - Corp(config)#ipv6 unicast-routing
- IPv6 isn't enabled by default
  - `After going to the interface`
  - `Corp(config-if)#ipv6 address 2001:DB8:2222:7272::72/64`
- To configure a router so that it uses only link-local addresses
  - Corp(config-if)#ipv6 enable

Using an **EUI-64**

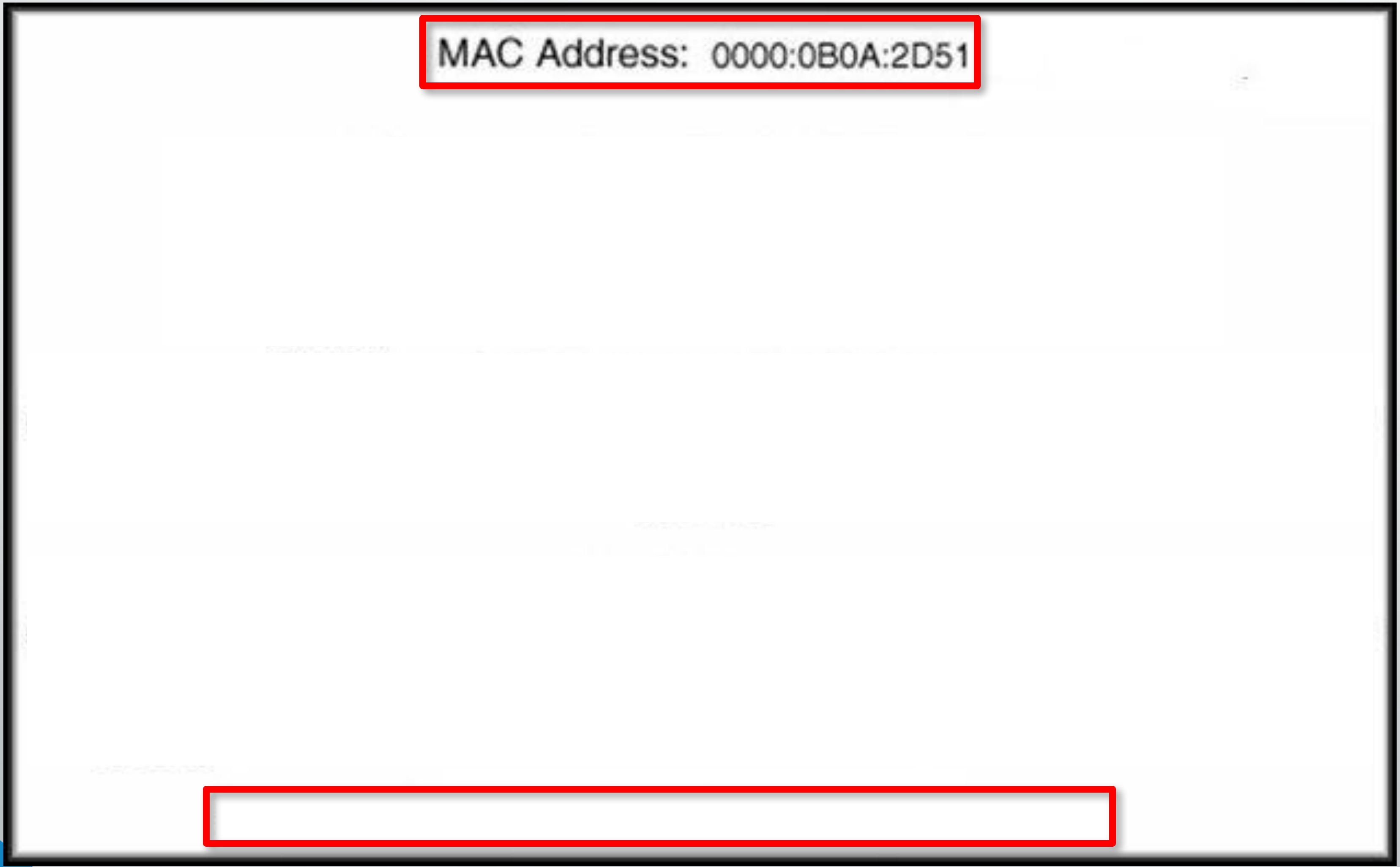
- **EUI-64(extended unique identifier)**
  - How to stretch IEEE 802 MAC addresses from 48 to 64 bits
  - Done by inserting the 16-bit 0xFFFE in the middle at the 24th bit of the MAC address
  - To create a 64-bit, unique interface identifier.
    - **Corp(config-if)#ipv6 address 2001:db8:3c4d:1::/64 eui-64**

Using an **EUI-64**



Using an **EUI-64**

- Using EUI-64.



End of Part2

ICMPv6

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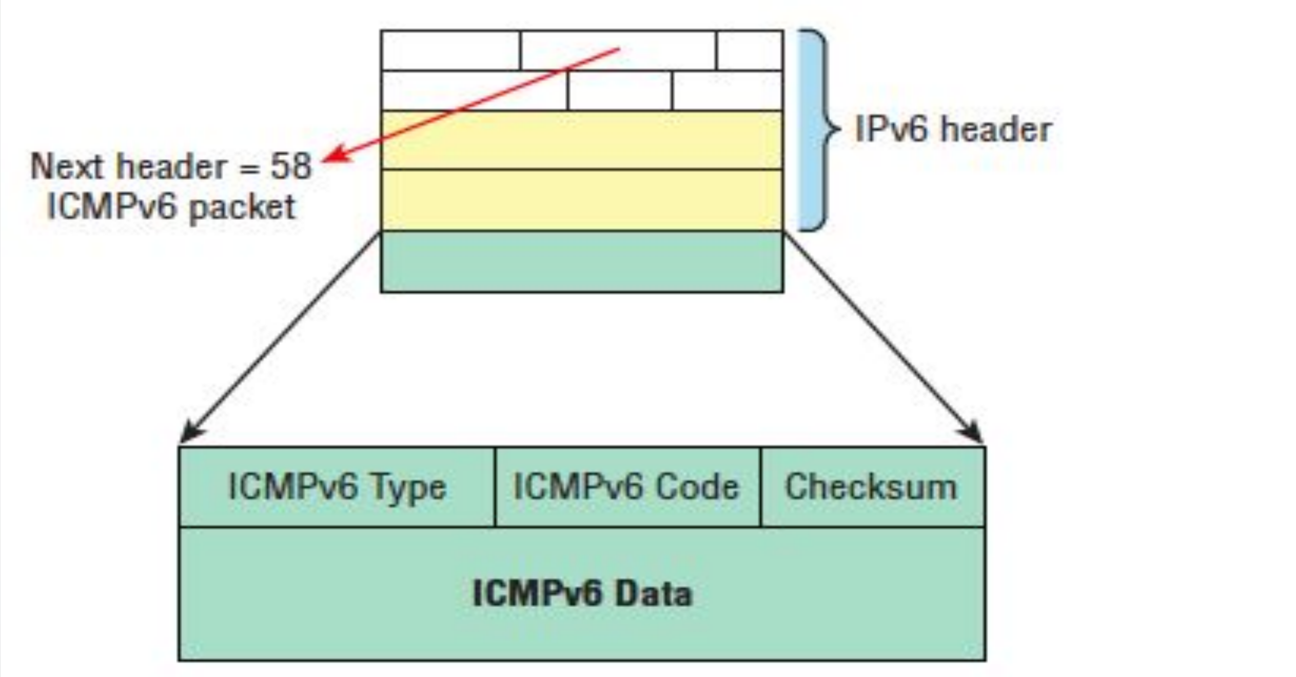
ICMPv6



- it's an integrated part of IPv6, not like IPv4
- Is carried after the basic IPv6 header information as an extension header.

ICMP v6

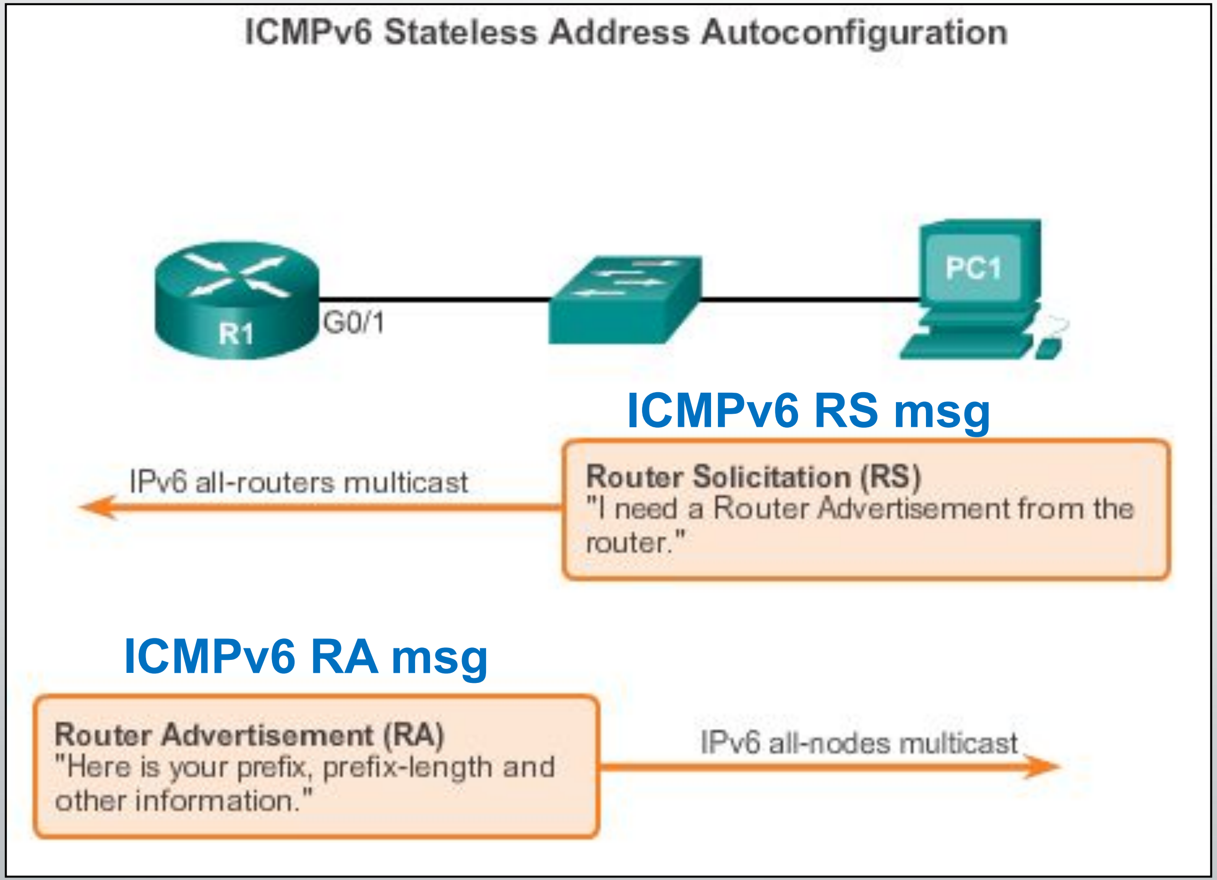
- By default, it prevents IPv6 from doing any fragmentation through an ICMPv6 process called path MTU discovery
- The Address Resolution Protocol is used to perform this function for IPv4, but that's been renamed neighbor discovery (ND) in ICMPv6.

ICMPv6

- Neighbor discovery enables these functions:
  - Determining the MAC address of neighbors
  - Router solicitation (RS) FF02::2
  - Router advertisements (RA) FF02::1
  - Neighbor solicitation (NS)
  - Neighbor advertisement (NA)
  - Duplicate address detection (DAD)

Stateless Address Auto configuration

Stateless Address Auto configuration (SLAAC) is a method in which a device can obtain an IPv6 global unicast address without the services of a DHCPv6 server.

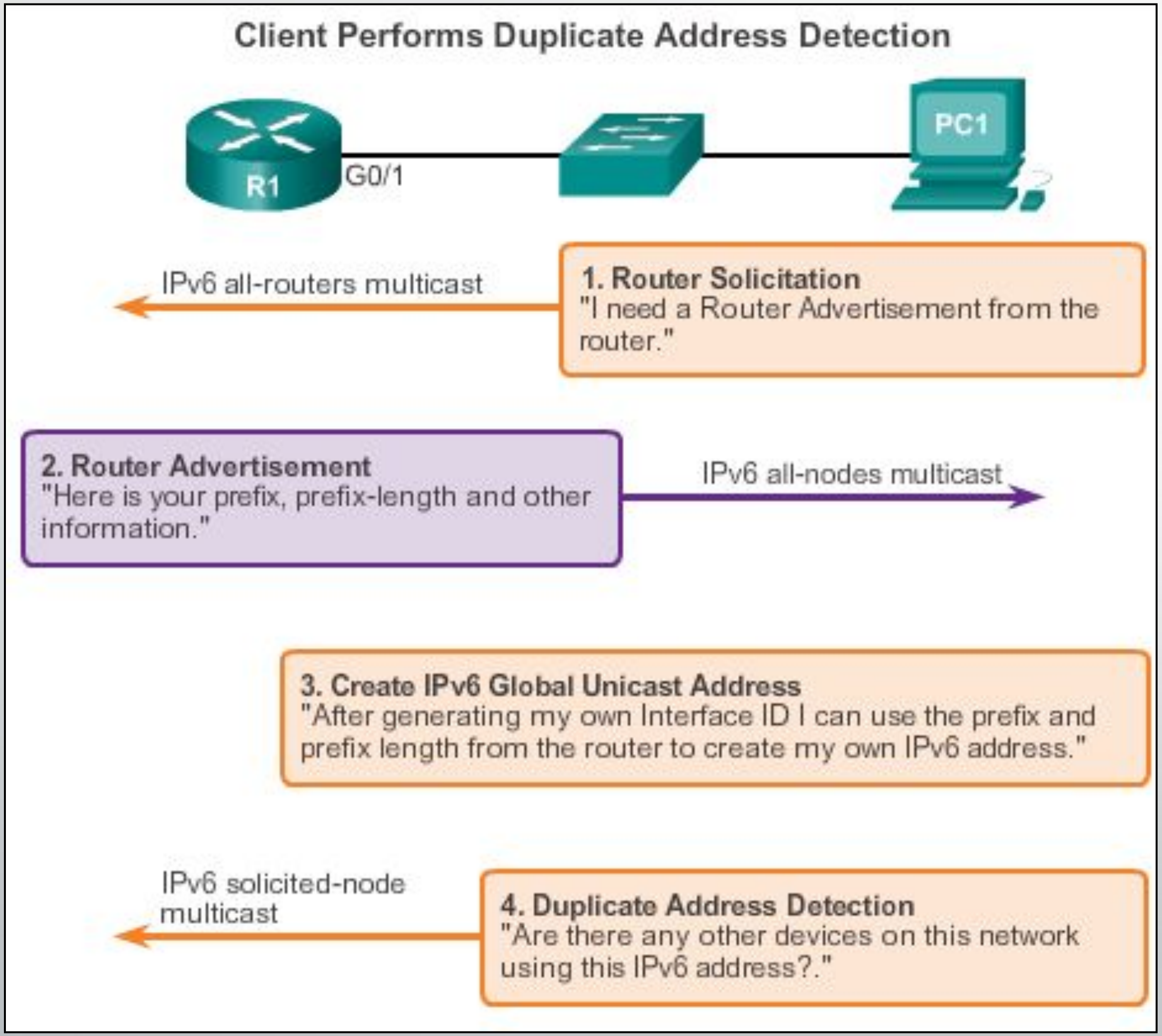


- **Stateless as no server maintains network address information.**

The RS message is ICMP type 133.

Using multicast address of FF02::2

SLAAC Operation



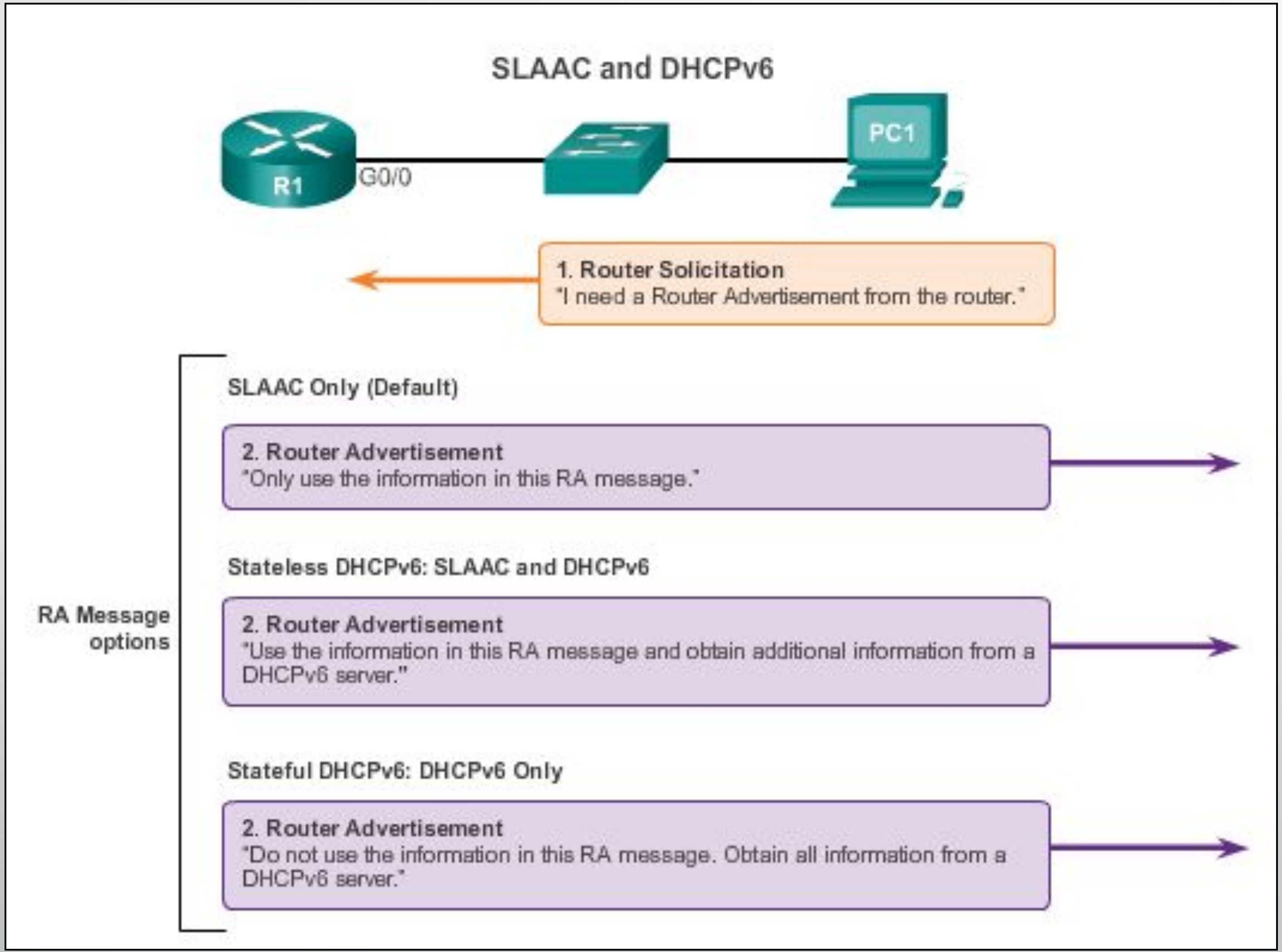
Using either

- **EUI-64**
- **Randomly Generated**

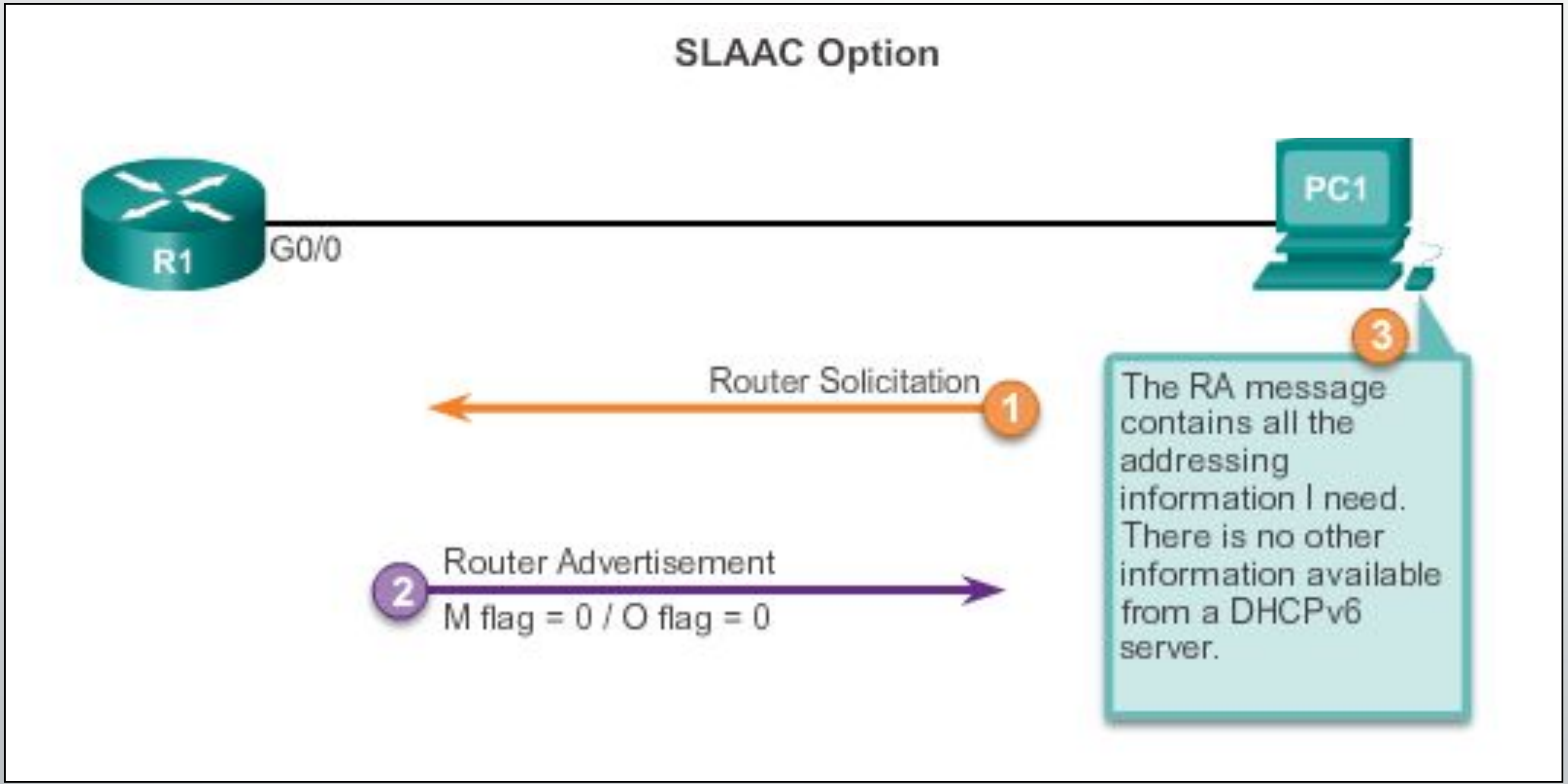
Using ICMPv6 neighbor solicitation msg with the target address of its own.

Duplicate address detection (DAD)

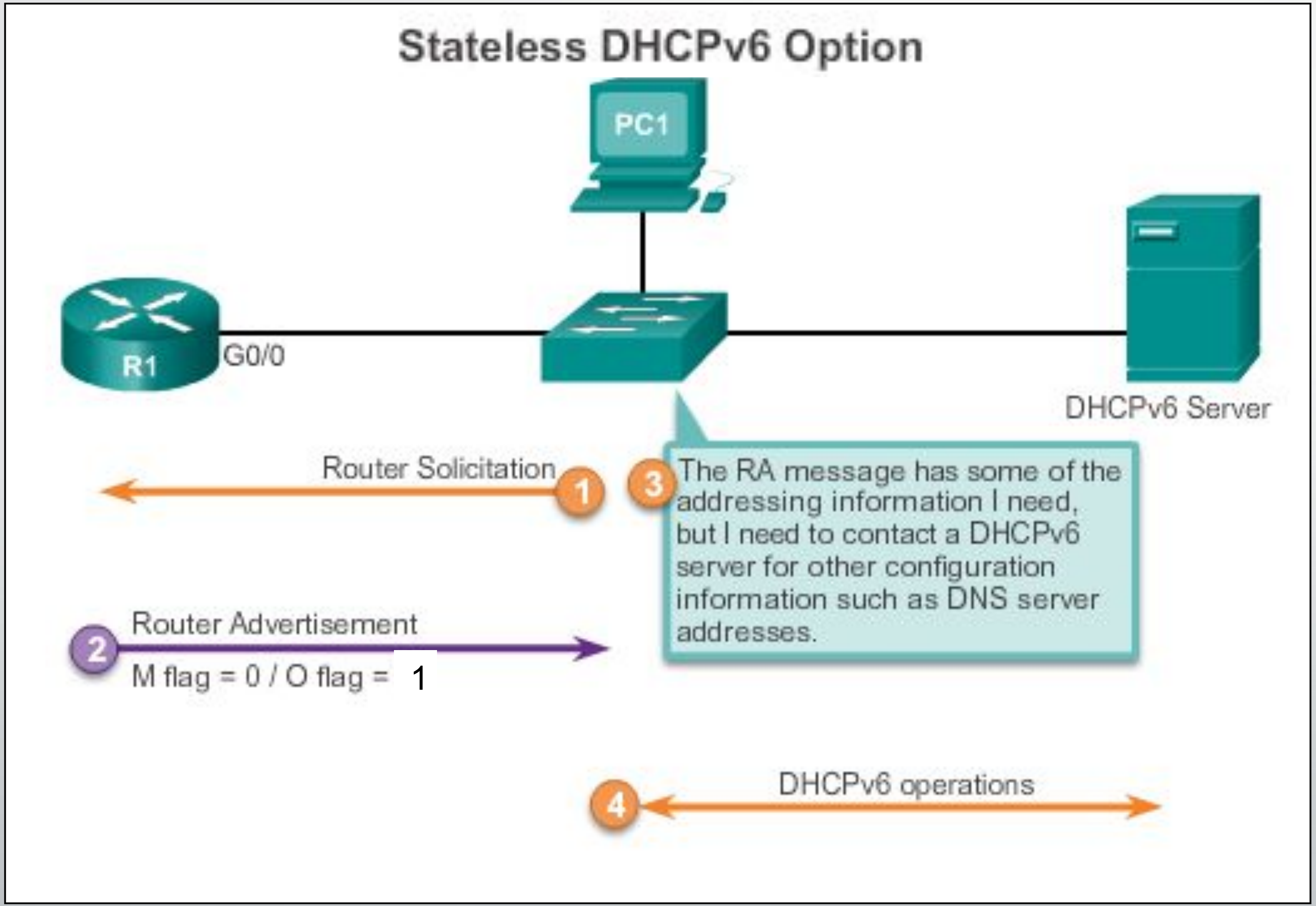
SLAAC and DHCPv6



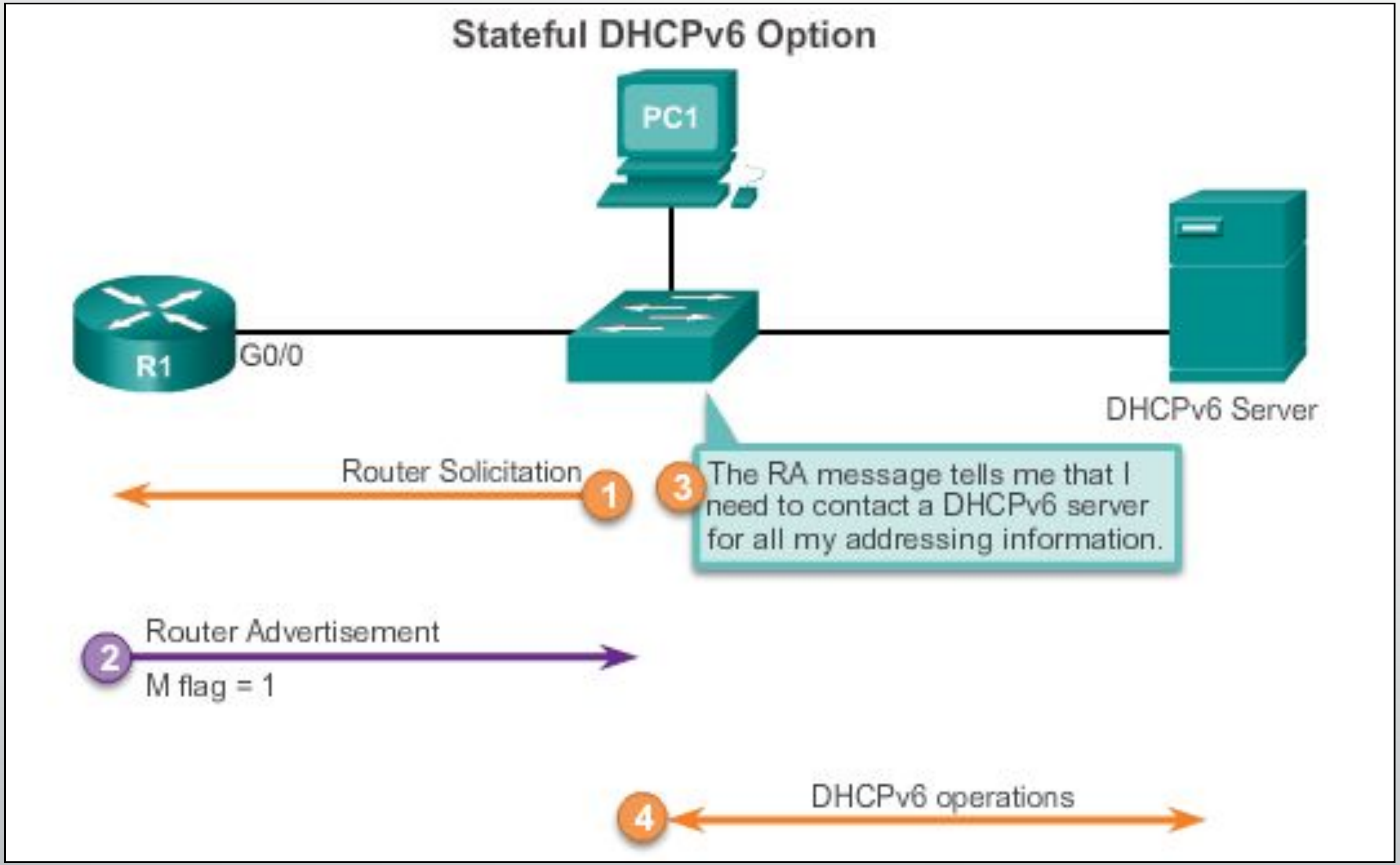
SLAAC Option



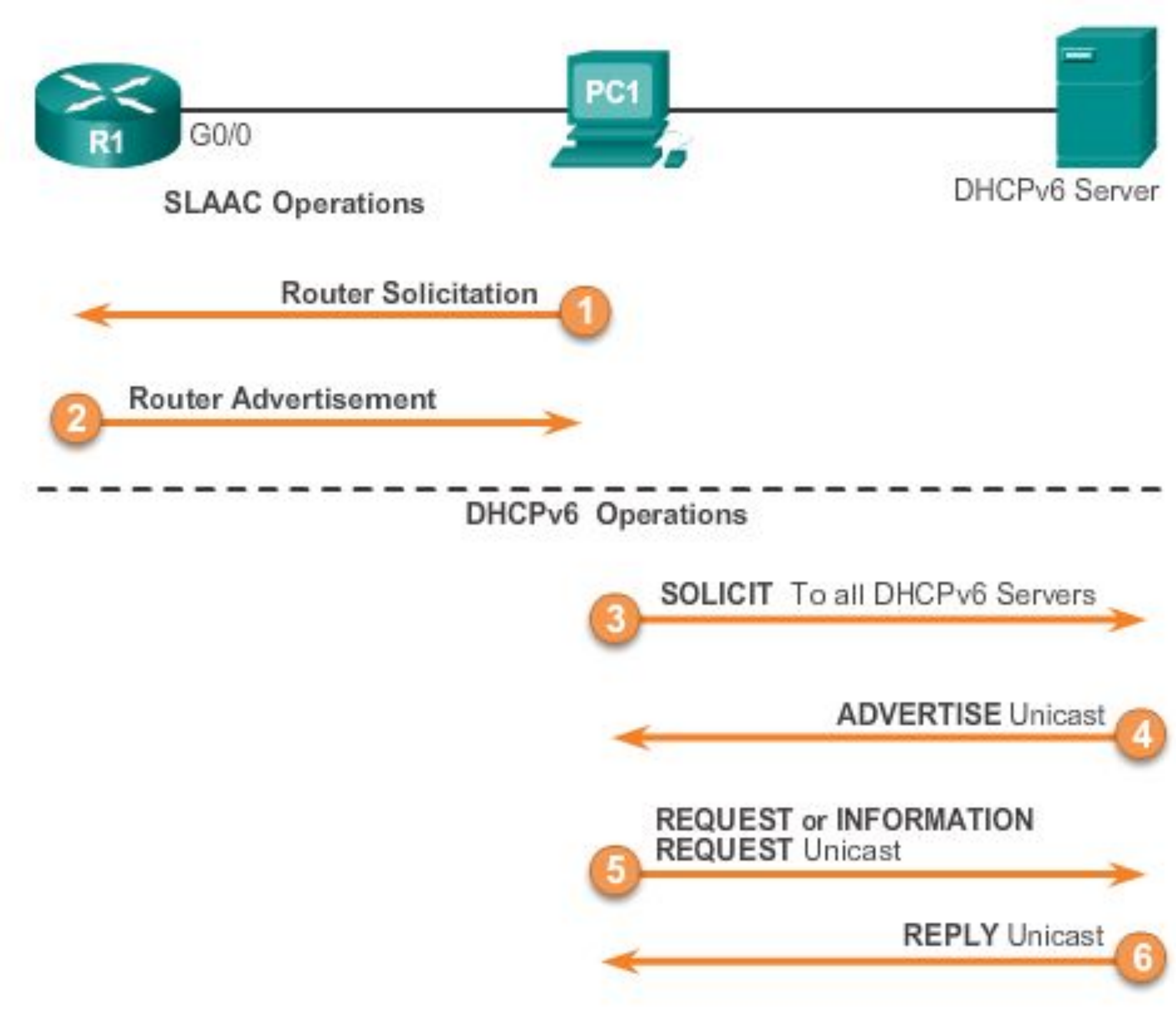
Stateless DHCP Option



Stateful DHCP Option



DHCPv6 Operations



Using reserved IPv6 multicast all-DHCP-servers-address FF02::1:2 Port 547

Server available for service

Stateless- INFORMATION REQUEST
Stateful - REQUEST

End of Part3

Transition from IPv4 to IPv6

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IPv4 to IPv6 Transition

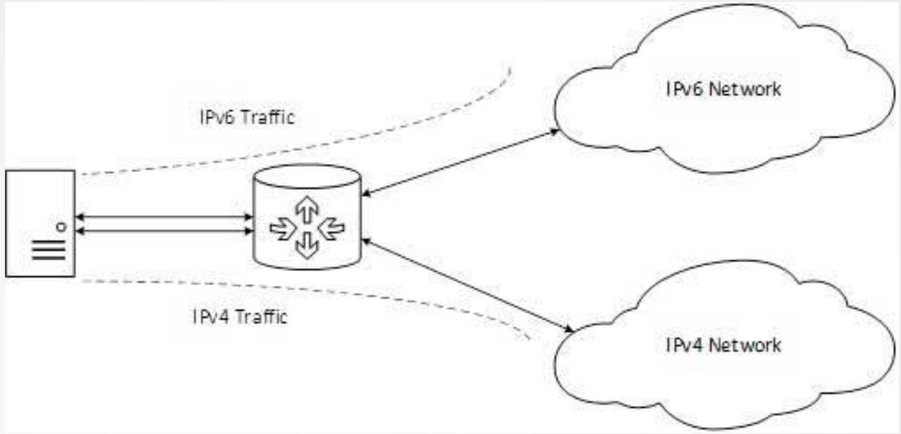
Strategies and mechanisms:

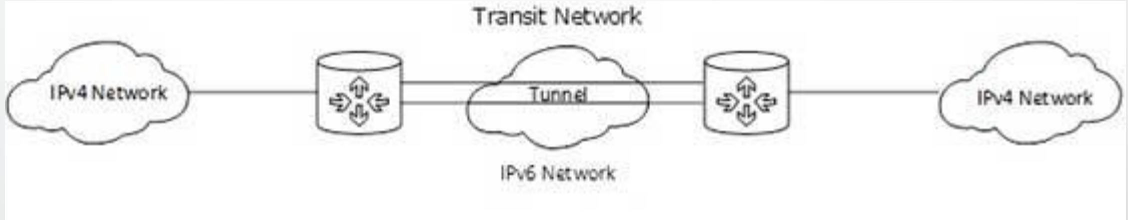
- IPv4 to IPv6 transition is gradual
- IPv6 devices need to communicate to IPv4
- IPv6 needs to communicate over IPv4 links

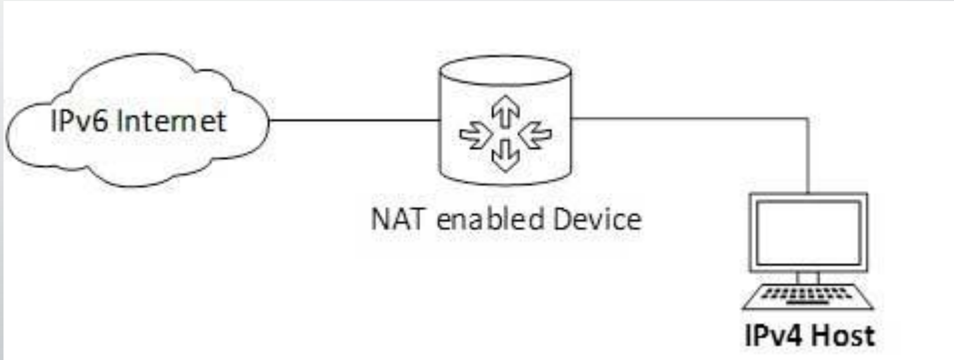
Transition Techniques

Three categories:

- **Dual-stack techniques**
- **Tunneling Techniques**
- **Translation techniques**

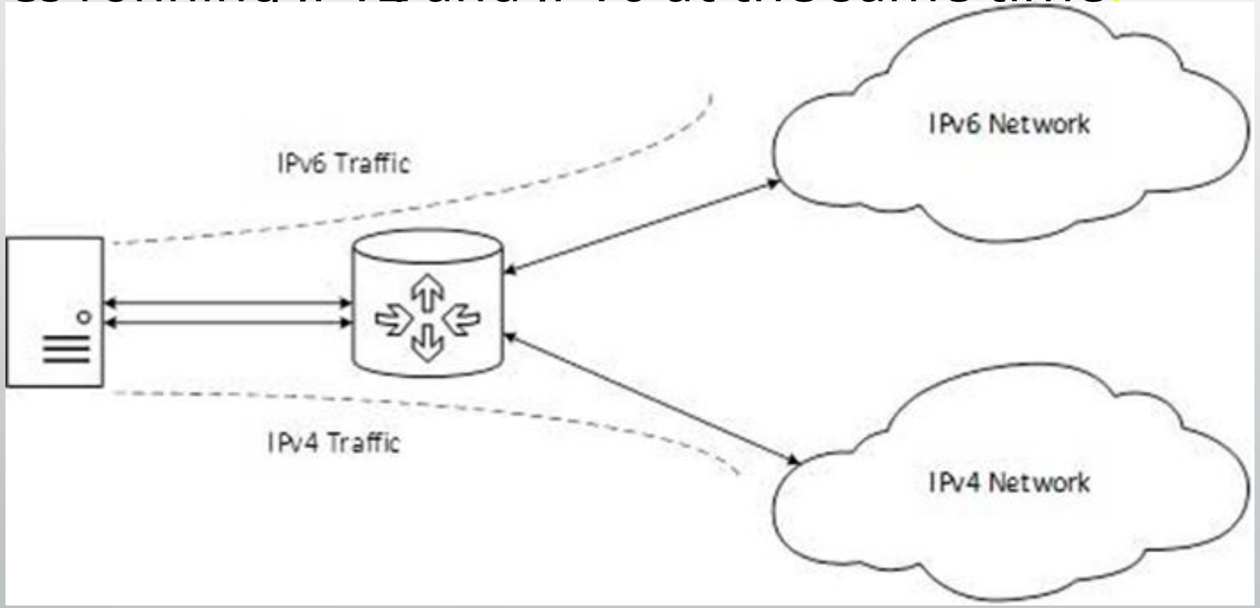






Dual Stack

- Method in which a node has implementation and connectivity to both an IPv4 and IPv6 network.
- The recommended option.
- Involves running IPv4 and IPv6 at the same time.



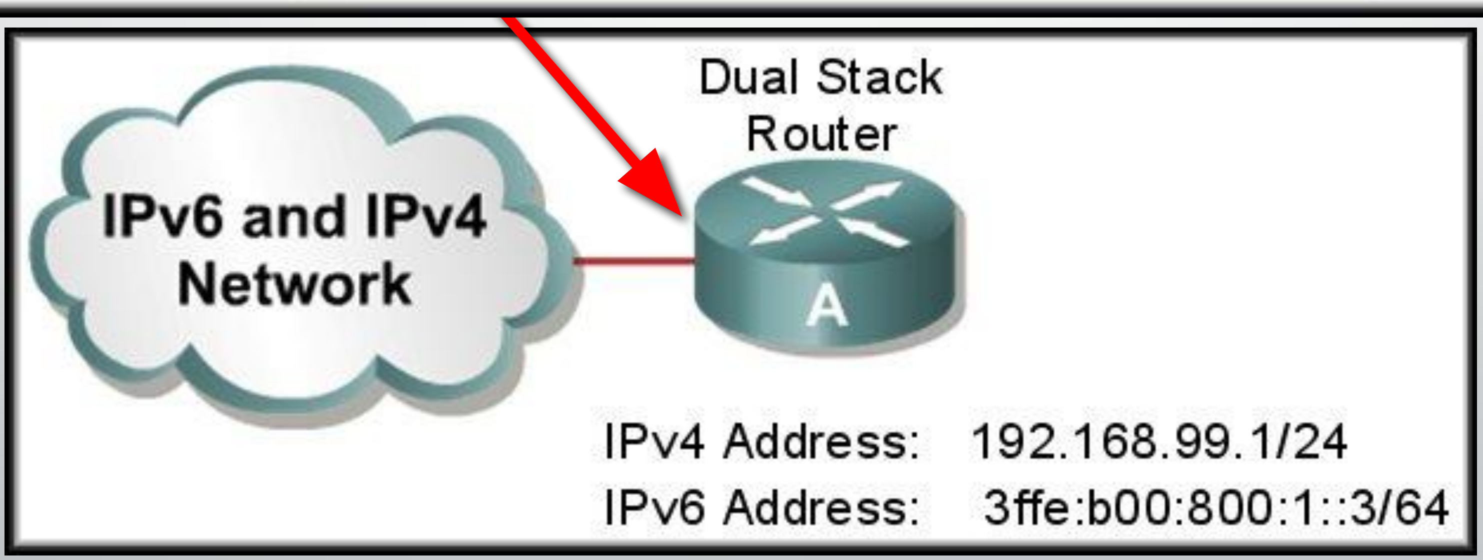
Dual Stack

- **Applications on dual stack hosts:**
  - For applications that only support IPv4 - use IPv4 only
  - For applications that support IPv6:
    - If DNS lookup of destination resolves address to IPv4 destination, use IPv4
    - If DNS resolves address to IPv6 destination use IPv6
- Routers – send traffic based on IP type, and routing rules

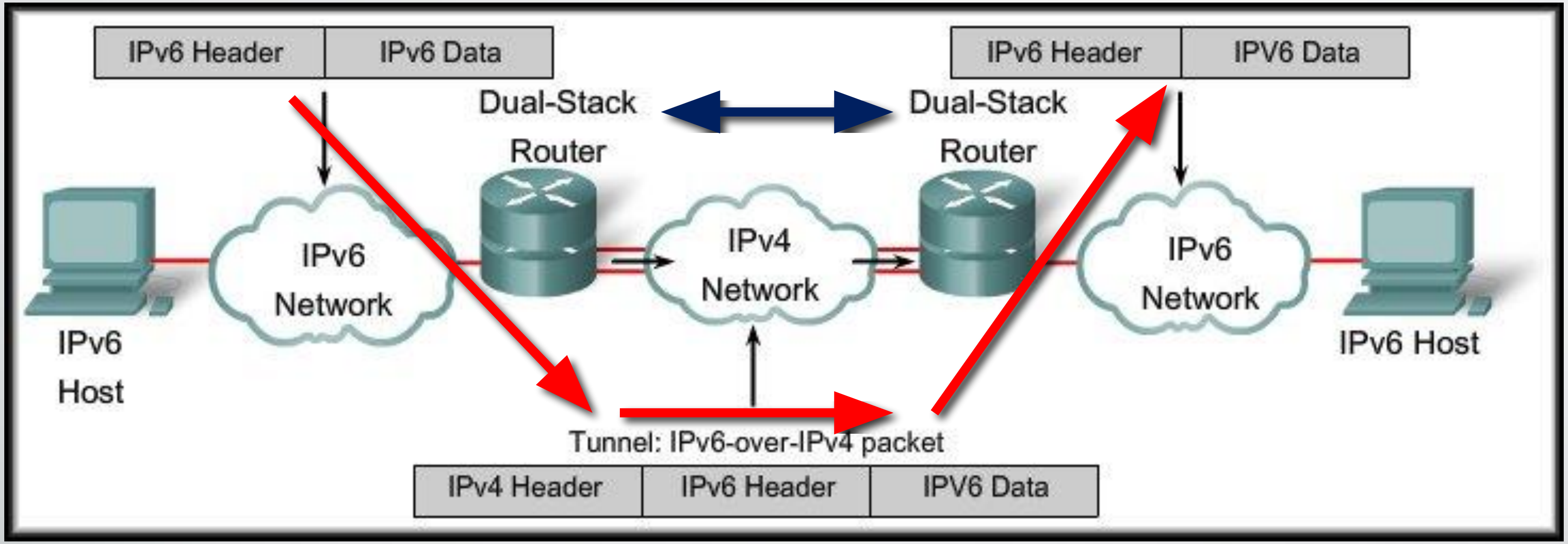
Cisco IOS Dual Stack

- If both IPv4 and IPv6 addresses are configured on an interface, the interface is considered dual stacked.

```
RTA(config)#interface fa0/0
RTA(config-if)#ip address 192.168.99.1 255.255.255.0
RTA(config-if)#ipv6 address 3ffe:b00:800:1::3/64
```

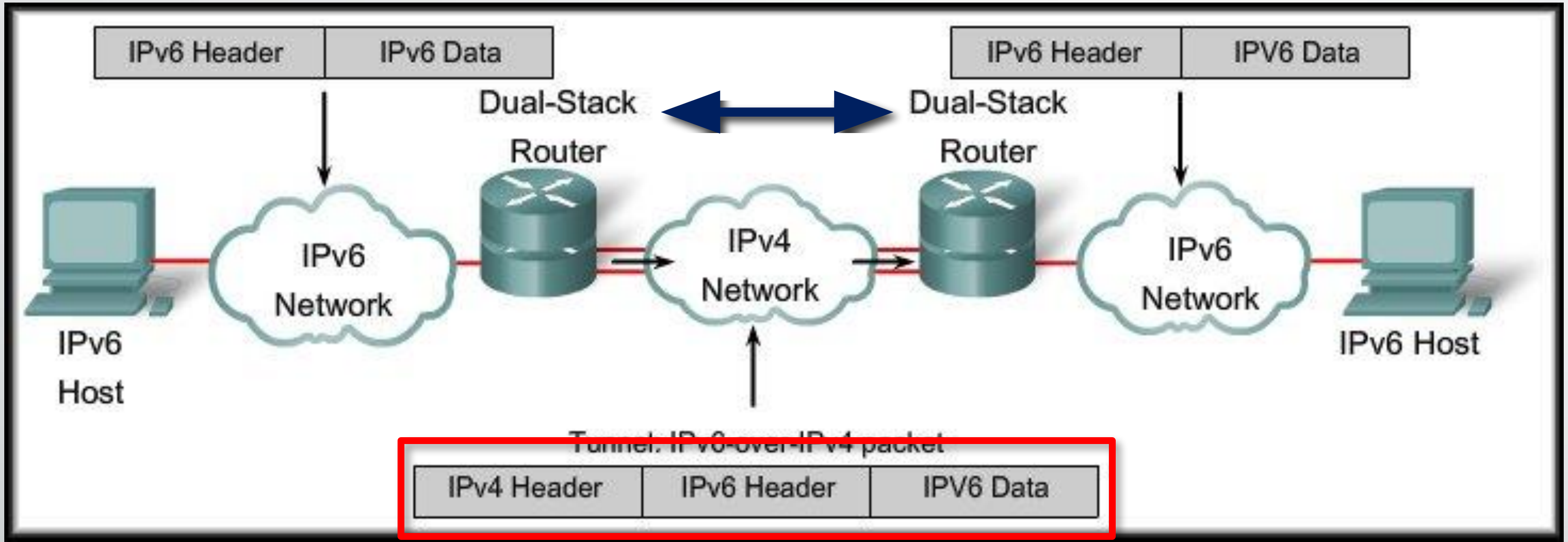


IPv6 Tunneling



- Tunneling is an integration method where an IPv6 packet is encapsulated within another protocol.
- Tunneling encapsulates the IPv6 packet in the IPv4 packet.

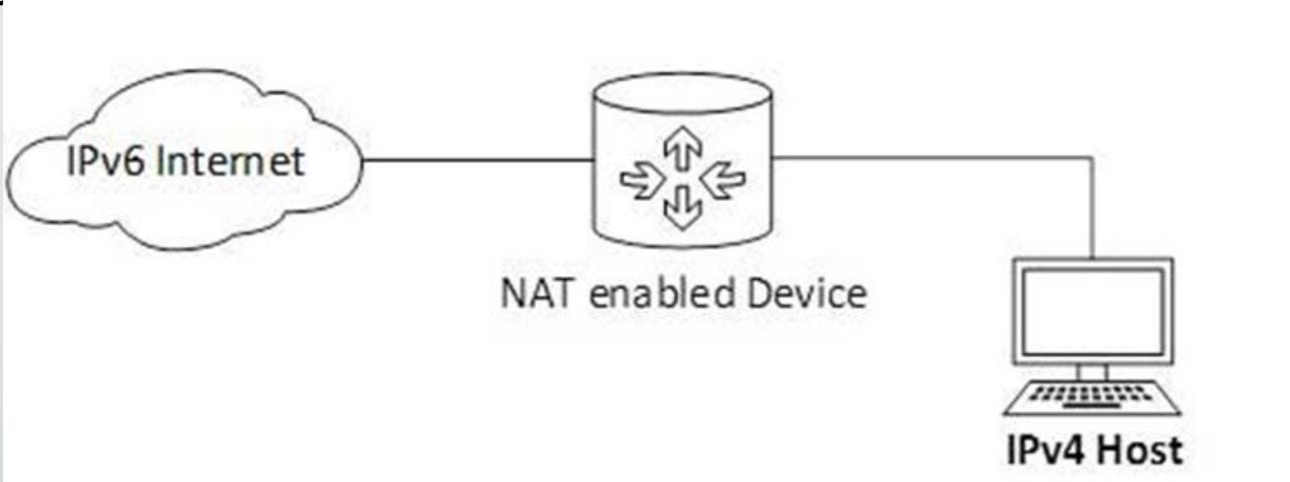
IPv6 Tunneling



- When IPv4 is used to encapsulate the IPv6 packet:
  - Protocol type of 41.
  - 20-byte IPv4 header with no options.
  - IPv6 header and payload.
  - Requires dual stacked routers.

NAT Protocol Translation

- Important method of transition to IPv6 by means of a NAT-PT (Network Address Translation – Protocol Translation) enabled device.



When the IPv4 host sends a request packet to the IPv6 server, the NAT-PT device/router strips down the IPv4 packet, removes IPv4 header, and adds IPv6 header and passes it through the Internet. When a response from the IPv6 server comes for the IPv4 host, the router does vice versa.

THE END