IPv6

Introduction to Networks &

Routing and Switching Essentials

The Need for IPv6

- IPv6 is designed to be the successor to IPv4.

- Depletion of IPv4 address space has been the motivating factor for moving to IPv6.

- Projections show that all five RIRs will run out of IPv4 addresses between 2015 and 2020.

- With an increasing Internet population, a limited IPv4 address space, issues with NAT and an Internet of things, the time has come to begin the transition to IPv6!

- IPv4 has a theoretical maximum of 4.3 billion addresses, plus private addresses in combination with NAT.

- IPv6 larger 128-bit address space provides for 340 undecillion addresses.

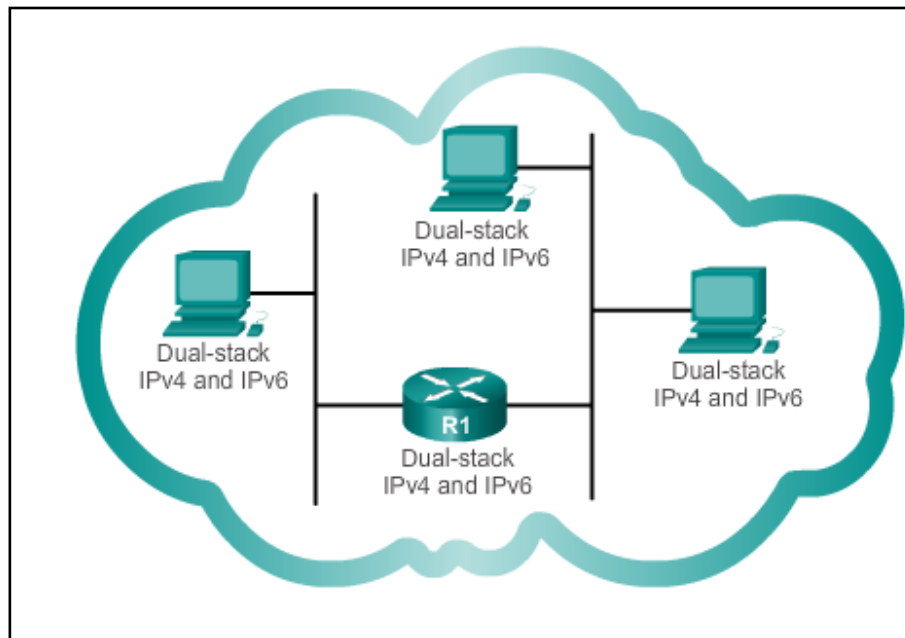- IPv6 fixes the limitations of IPv4 and includes additional enhancements, such as ICMPv6.

IPv4 and IPv6 Coexistence

The migration techniques can be divided into three categories: Dual-stack, Tunnelling, and Translation.

Dual-stack
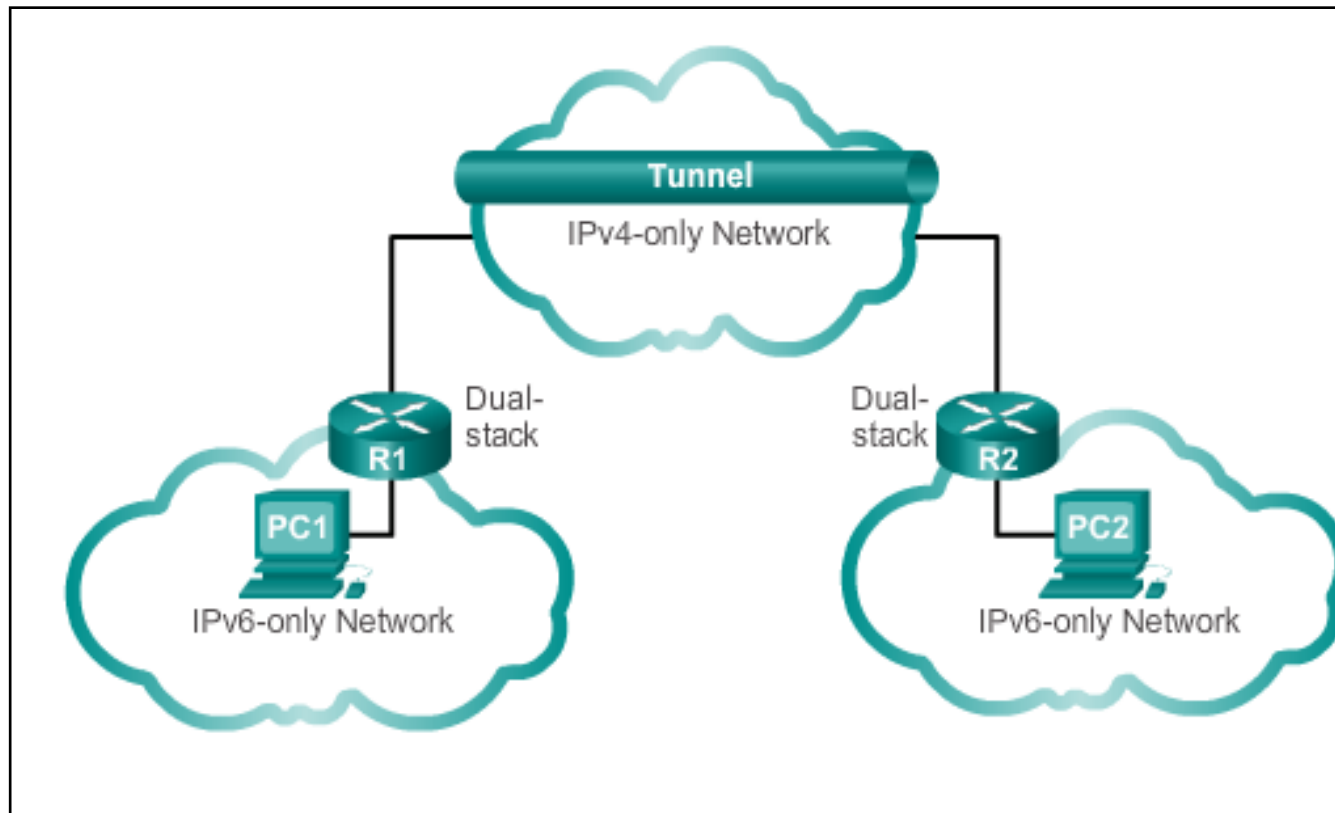

Dual-stack: Allows IPv4 and IPv6 to coexist on the same network. Devices run both IPv4 and IPv6 protocol stacks simultaneously.
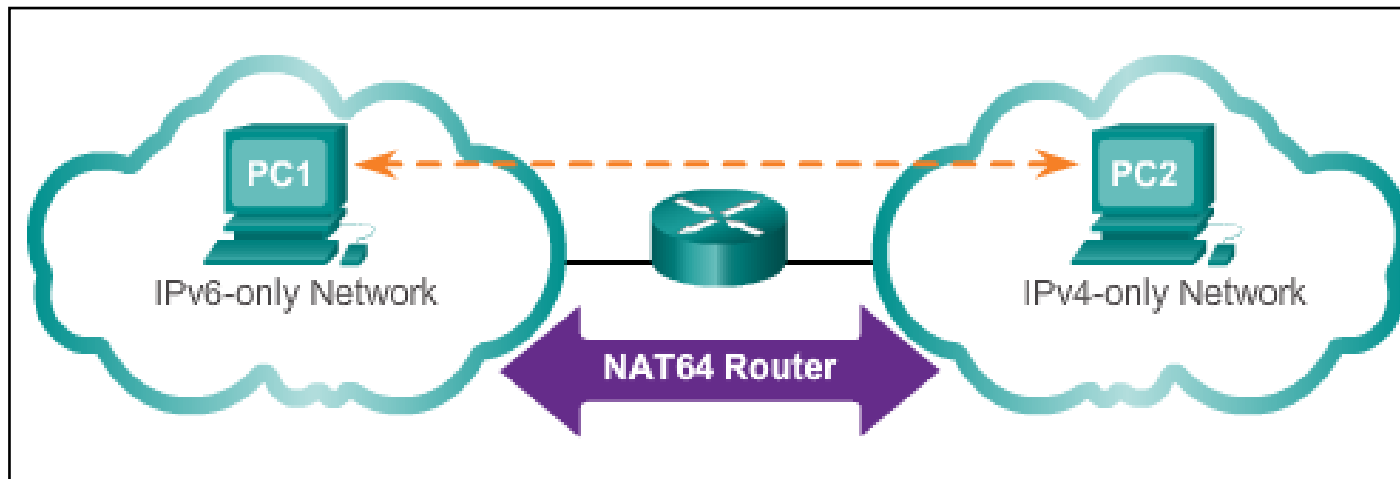
 3

IPv4 and IPv6 Coexistence (cont.)

Tunnelling

Tunnelling: A method of transporting an IPv6 packet over an IPv4 network. The IPv6 packet is encapsulated inside an IPv4 packet.

IPv4 and IPv6 Coexistence (cont.)

Translation

Translation: The Network Address Translation 64 (NAT64) allows IPv6-enabled devices to communicate with IPv4-enabled devices using a translation technique similar to NAT for IPv4. An IPv6 packet is translated to an IPv4 packet, and vice versa.

Hexadecimal Number System

- Hexadecimal is a base sixteen system.

- Base 16 numbering system uses the numbers 0 to 9 and the letters A to F.

- Four bits (half of a byte) can be represented with a single hexadecimal value.

Hexadecimal	Decimal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111

IPv6 Address Representation

- 128 bits in length and written as a string of hexadecimal values

- In IPv6, 4 bits represents a single hexadecimal digit, 32 hexadecimal value = IPv6 address

```
2001:0DB8:0000:1111:0000:0000:0000:0200

FE80:0000:0000:0000:0123:4567:89AB:CDEF
```
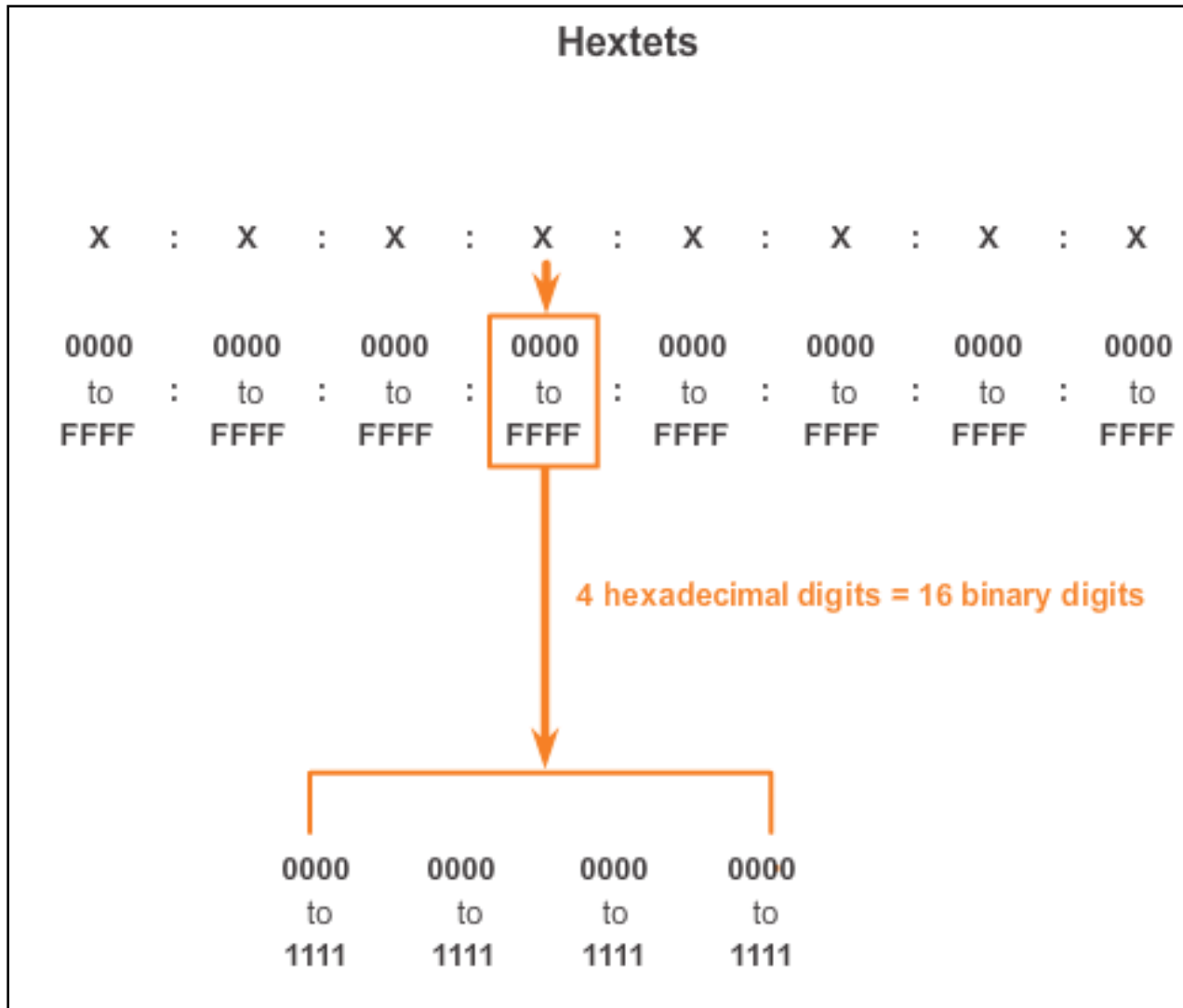
- Hextet used to refer to a segment of 16 bits or four hexadecimals

- Can be written in either lowercase or uppercase

IPv6 Address Representation (cont.)

Rule 1- Omitting Leading 0s

- The first rule to help reduce the notation of IPv6 addresses is any leading 0s (zeros) in any 16-bit section or hextet can be omitted.

- 01AB can be represented as 1AB.

- 09F0 can be represented as 9F0.

- 0A00 can be represented as A00.

- 00AB can be represented as AB.

Preferred	2001:0DB8:000A:1000:0000:0000:0000:0100
No leading 0s	2001: DB8: A:1000: 0: 0: 0: 100
Compressed	2001:DB8:A:1000:0:0:0:100

Rule 2 - Omitting All 0 Segments

- A double colon (::) can replace any single, contiguous string of one or more 16-bit segments (hextets) consisting of all 0's.

- Double colon (::) can only be used once within an address otherwise the address will be ambiguous.

- Known as the *compressed format.*

- Incorrect address - 2001:0DB8::ABCD::1234.

Rule 2 - Omitting All 0 Segments (cont.)

Example #1

Preferred	2001:0DB8:0000:0000:ABCD:0000:0000:0100
Omit leading 0s	2001: DB8: 0: 0:ABCD: 0: 0: 100
Compressed	2001:DB8::ABCD:0:0:100
OR	
Compressed	2001:DB8:0:0:ABCD::100

Only one : : may be used.

Example #2

| Preferred	FE80:0000:0000:0000:0123:4567:89AB:CDEF
Omit leading 0s	FE80: 0: 0: 0: 123:4567:89AB:CDEF
Compressed	FE80::123:4567:89AB:CDEF

IPv6 Prefix Length

- IPv6 does not use the dotted-decimal subnet mask notation

- Prefix length indicates the network portion of an IPv6 address using the following format:

  - IPv6 address/prefix length

  - Prefix length can range from 0 to 128

  - Typical prefix length is /64

/64 Prefix

64 bits	64 bits
Prefix	Interface ID

Example: 2001:0DB8:000A::/64

2001:0DB8:000A:0000	0000:0000:0000:0000
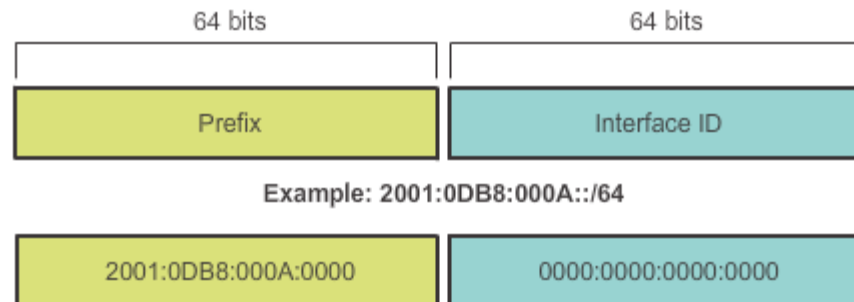
IPv6 Address Types

There are three types of IPv6 addresses:

- Unicast
- Multicast
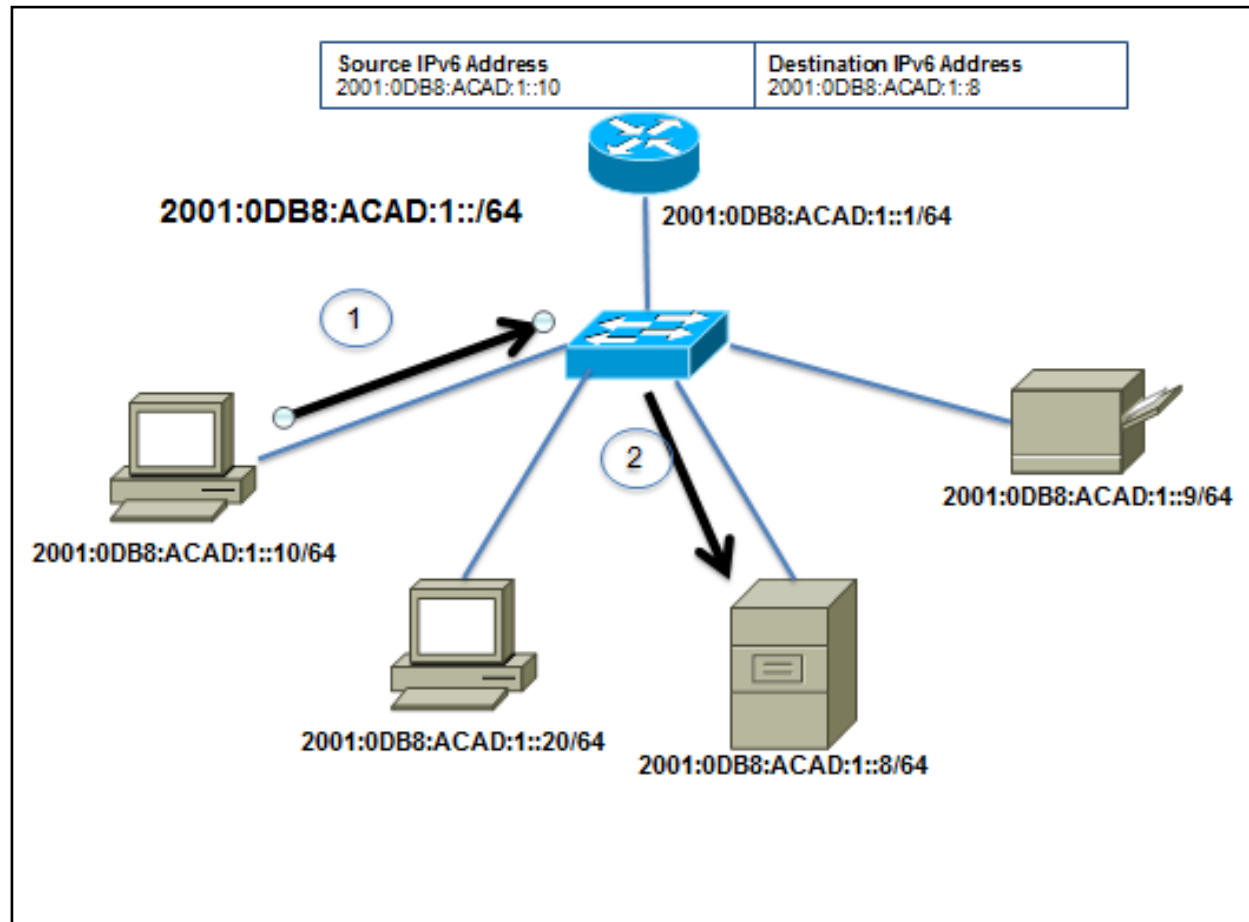- Anycast.

Note: IPv6 does not have broadcast addresses.
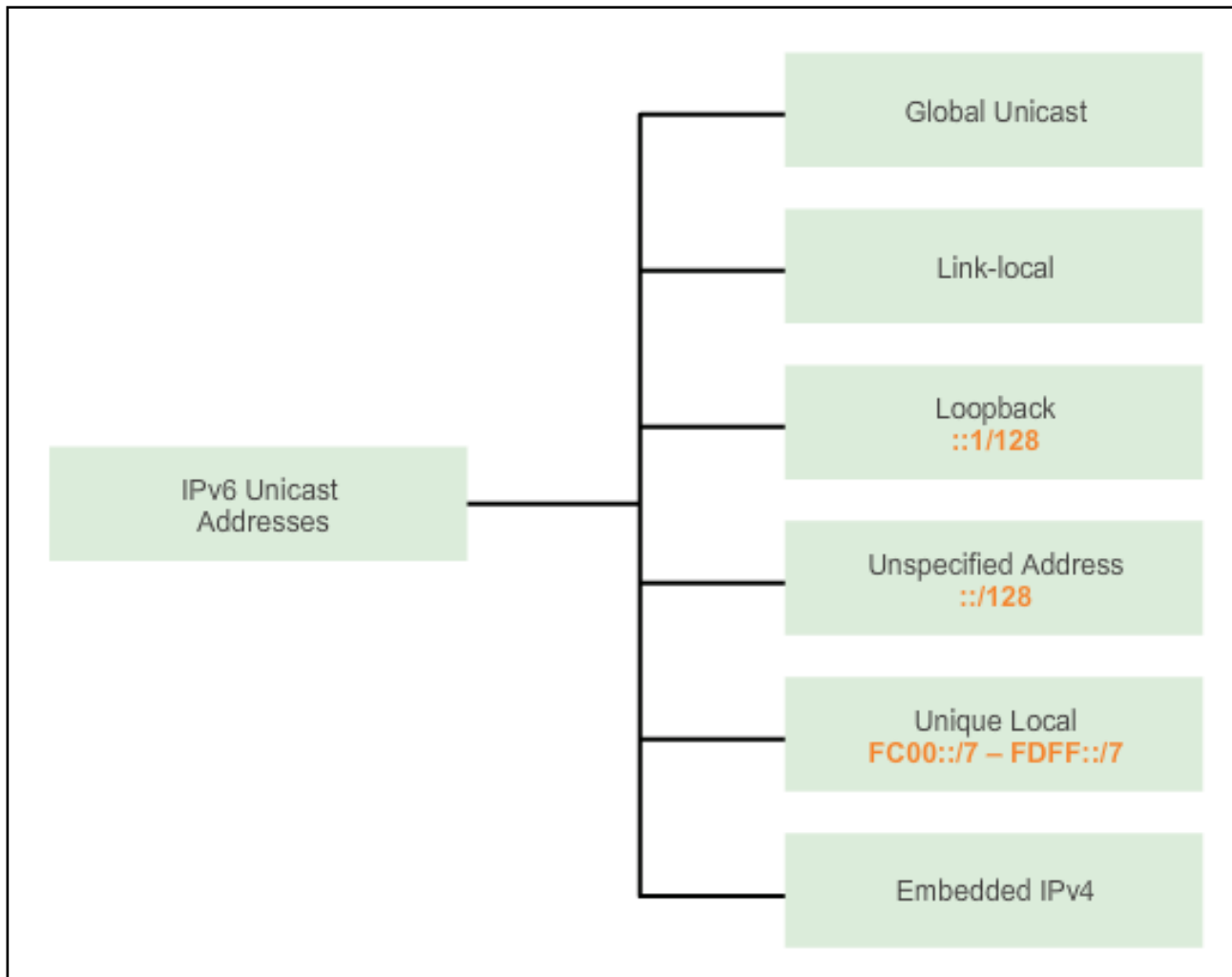
IPv6 Unicast Addresses

Unicast

- Uniquely identifies an interface on an IPv6-enabled device.

- A packet sent to a unicast address is received by the interface that is assigned that address.

IPv6 Unicast Addresses (cont.)

IPv6 Unicast Addresses (cont.)

Global Unicast

- Similar to a public IPv4 address

- Globally unique

- Internet routable addresses

- Can be configured statically or assigned dynamically

Link-local

- Used to communicate with other devices on the same local link

- Confined to a single link; not routable beyond the link

IPv6 Unicast Addresses (cont.)

Loopback

- Used by a host to send a packet to itself and cannot be assigned to a physical interface.

- Ping an IPv6 loopback address to test the configuration of TCP/IP on the local host.

- All-0s except for the last bit, represented as ::1/128 or just ::1.

Unspecified Address

- All-0's address represented as ::/128 or just ::

- Cannot be assigned to an interface and is only used as a source address.

- An unspecified address is used as a source address when the device does not yet have a permanent IPv6 address or when the source of the packet is irrelevant to the destination.

IPv6 Unicast Addresses (cont.)

Unique Local

- Similar to private addresses for IPv4.

- Used for local addressing within a site or between a limited number of sites.

- In the range of FC00::/7 to FDFF::/7.

IPv4 Embedded (not covered in this course)

- Used to help transition from IPv4 to IPv6.

IPv6 Link-Local Unicast Addresses

- Every IPv6-enabled network interface is REQUIRED to have a link-local address

- Enables a device to communicate with other IPv6-enabled devices on the same link and only on that link (subnet)

- FE80::/10 range, first 10 bits are 1111 1110 10xx xxxx

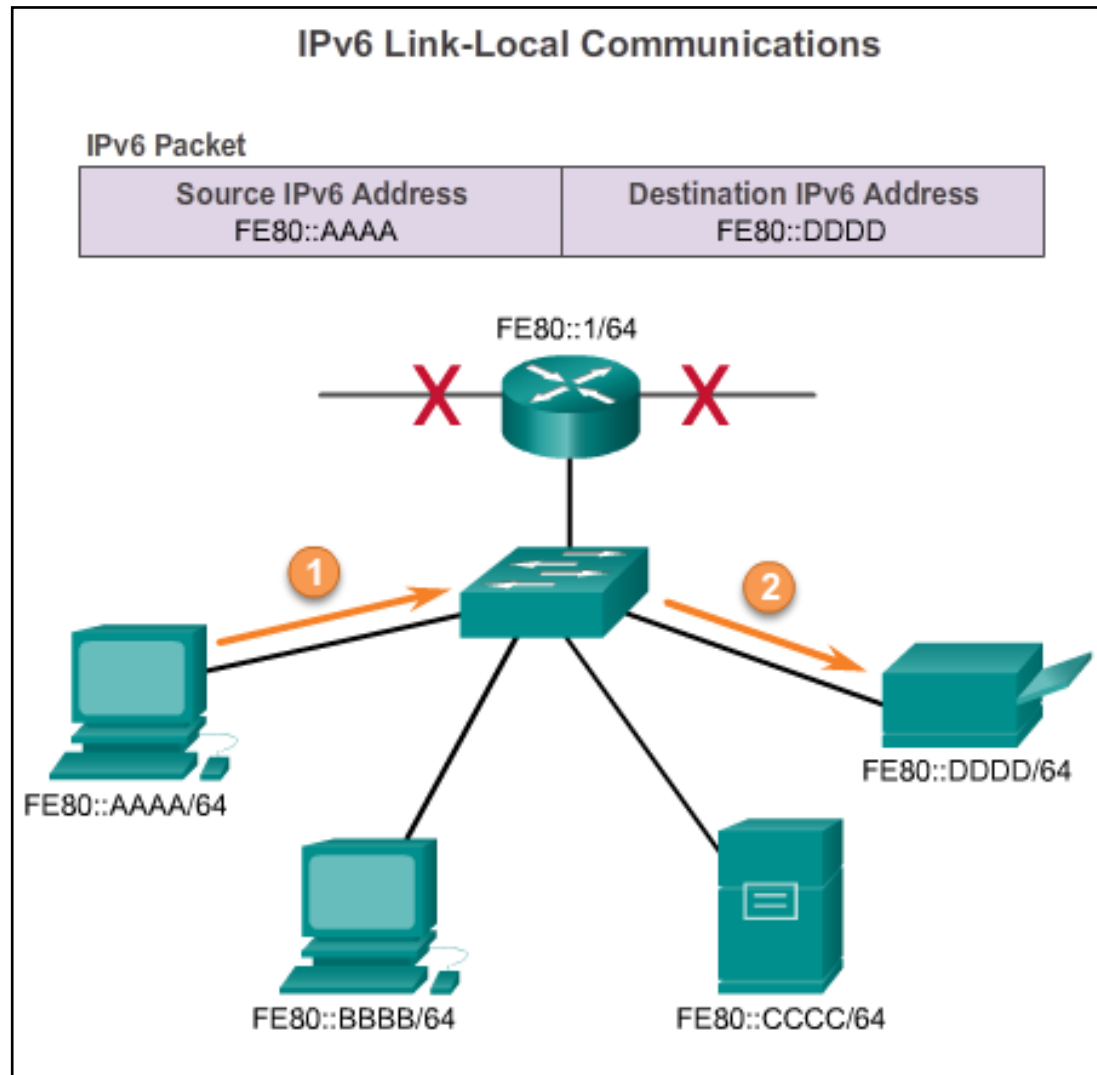- 1111 1110 10**00 0000** (FE80) - 1111 1110 10**11 1111** (FEBF)
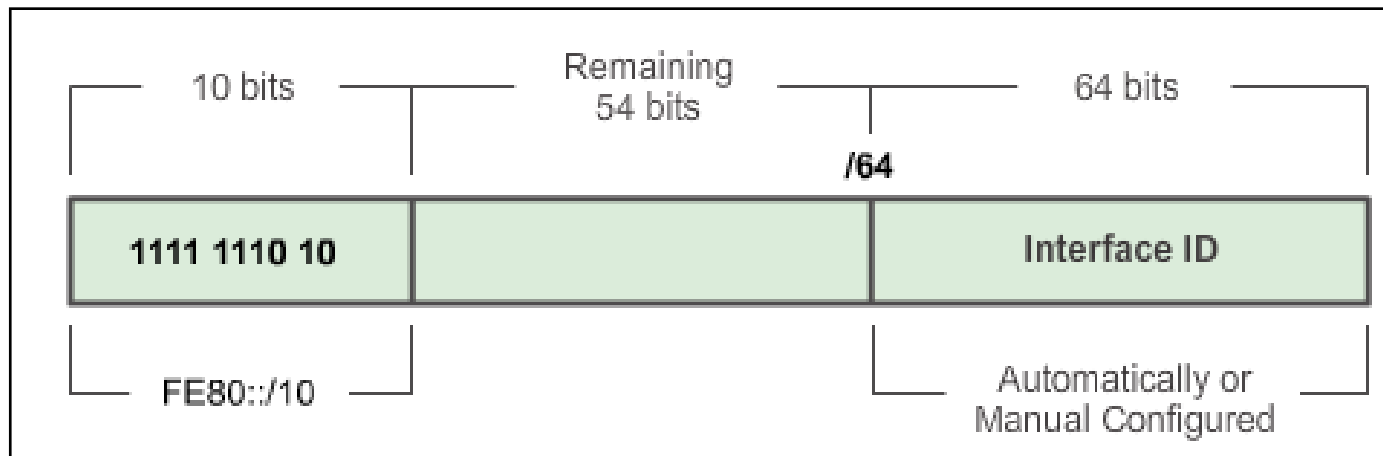
IPv6 Link-Local Unicast Addresses (cont.)

Packets with a source or destination link-local address cannot be routed beyond the link from where the packet originated.
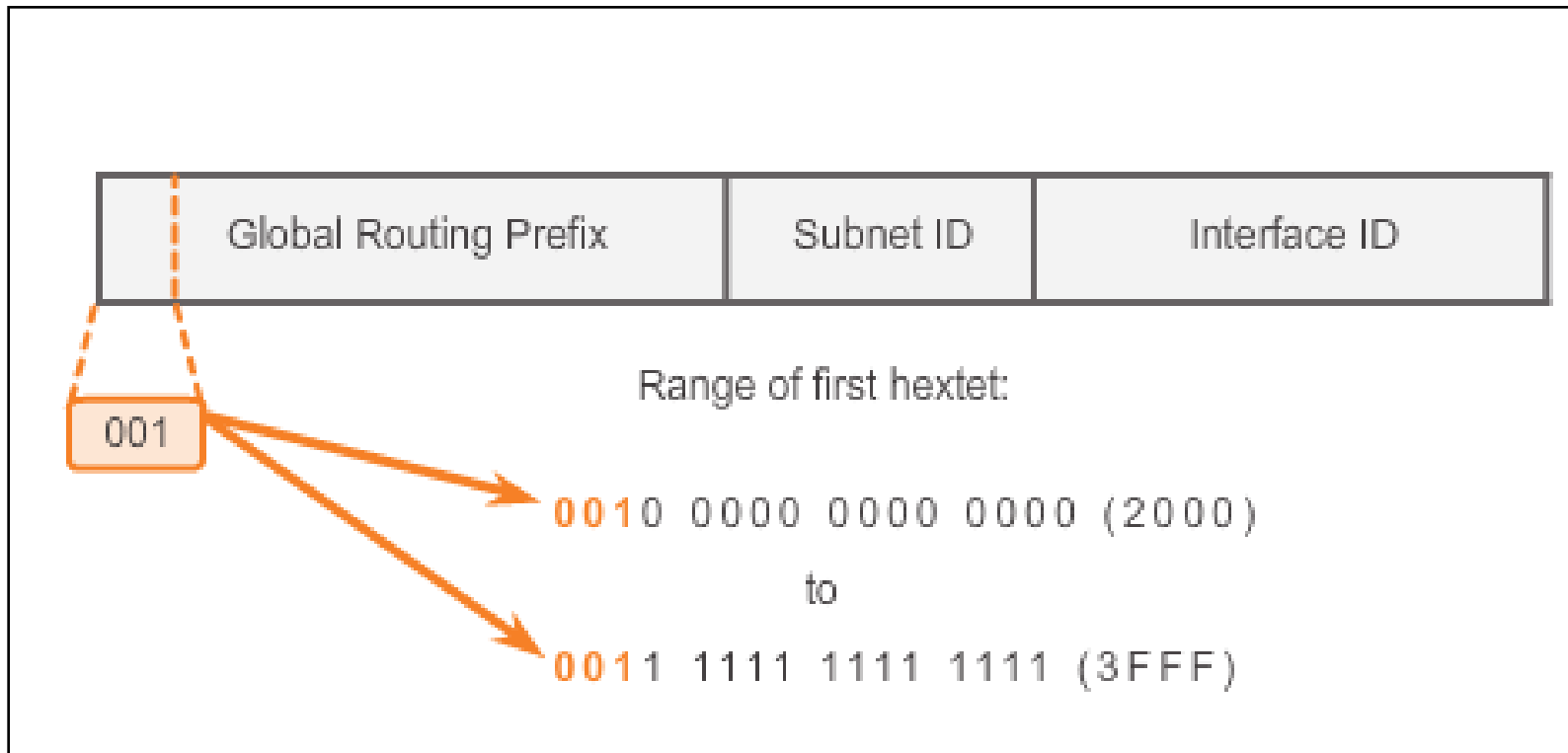
Structure of an IPv6 Global Unicast Address

- IPv6 global unicast addresses are globally unique and routable on the IPv6 Internet

- Equivalent to public IPv4 addresses

- ICANN allocates IPv6 address blocks to the five RIRs

Structure of an IPv6 Global Unicast Address (cont.)

Currently, only global unicast addresses with the first three bits of 001 or 2000::/3 are being assigned
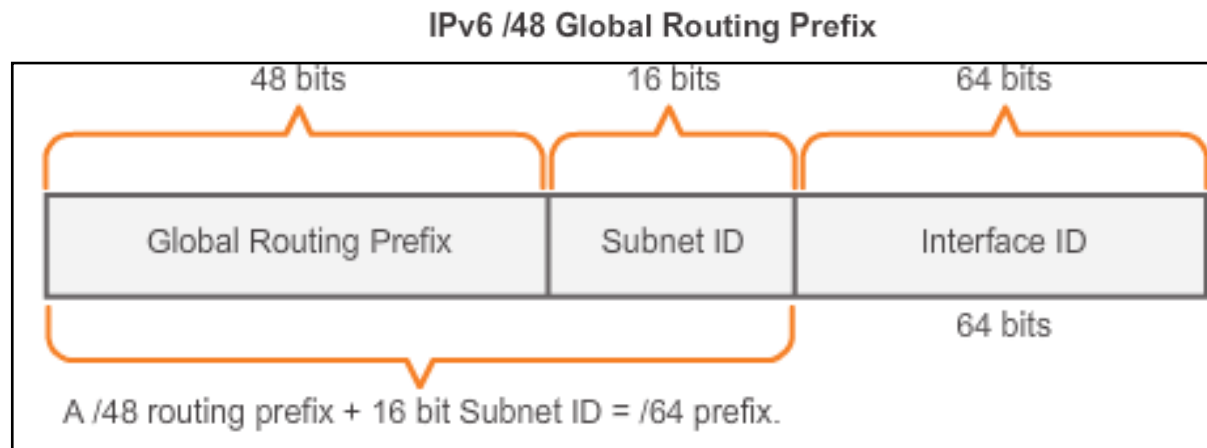
Structure of an IPv6 Global Unicast Address (cont.)

A global unicast address has three parts: Global Routing Prefix, Subnet ID, and Interface ID.

- **Global Routing Prefix** is the prefix or network portion of the address assigned by the provider, such as an ISP, to a customer or site, currently, RIR's assign a /48 global routing prefix to customers.

- 2001:0DB8:ACAD::/48 has a prefix that indicates that the first 48 bits (2001:0DB8:ACAD) is the prefix or network portion.
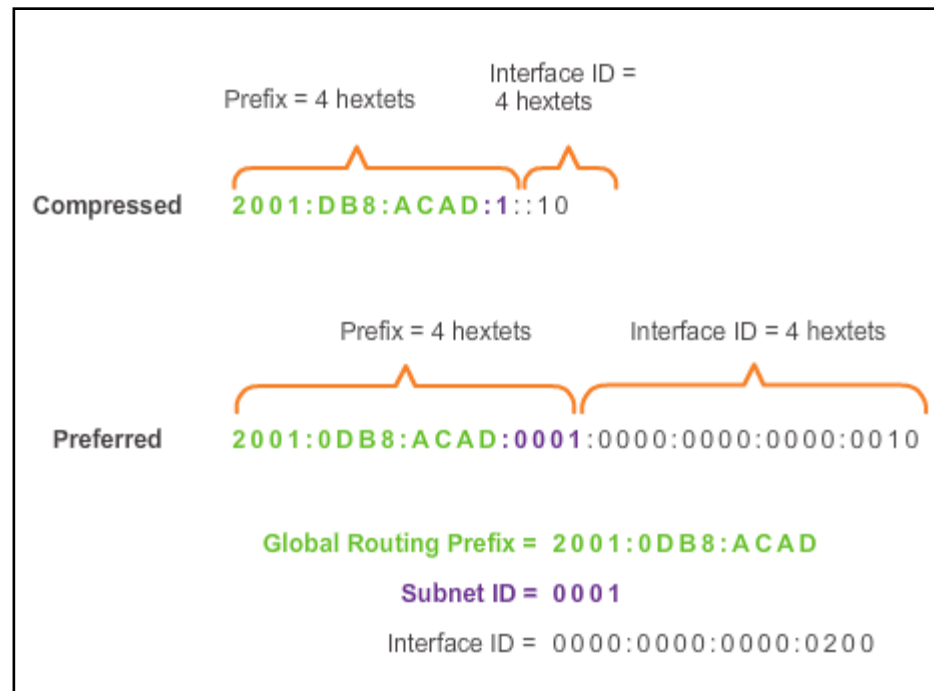

IPv6 /48 Global Routing Prefix

48 bits	16 bits	64 bits
Global Routing Prefix	Subnet ID	Interface ID

64 bits

A /48 routing prefix + 16 bit Subnet ID = /64 prefix.

Structure of an IPv6 Global Unicast Address (cont.)

- **Subnet ID** is used by an organization to identify subnets within its site

- **Interface ID**

  - Equivalent to the host portion of an IPv4 address.

  - Used because a single host may have multiple interfaces, each having one or more IPv6 addresses.
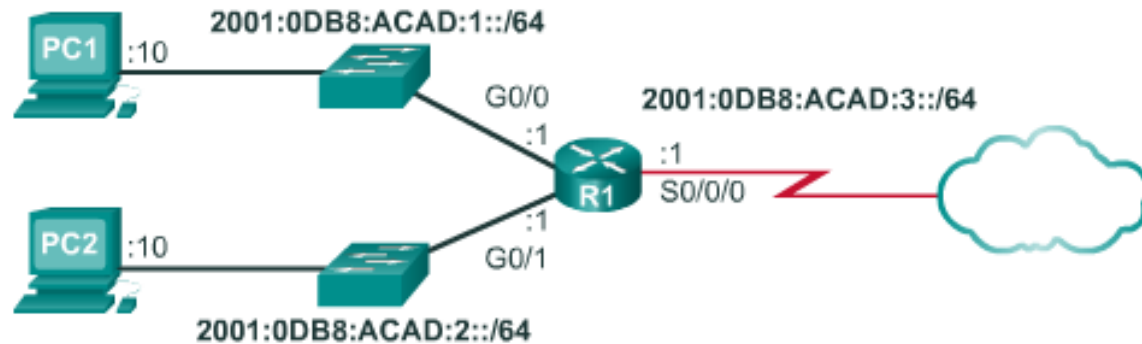

Reading a Global Unicast Address

Static Configuration of a Global Unicast Address

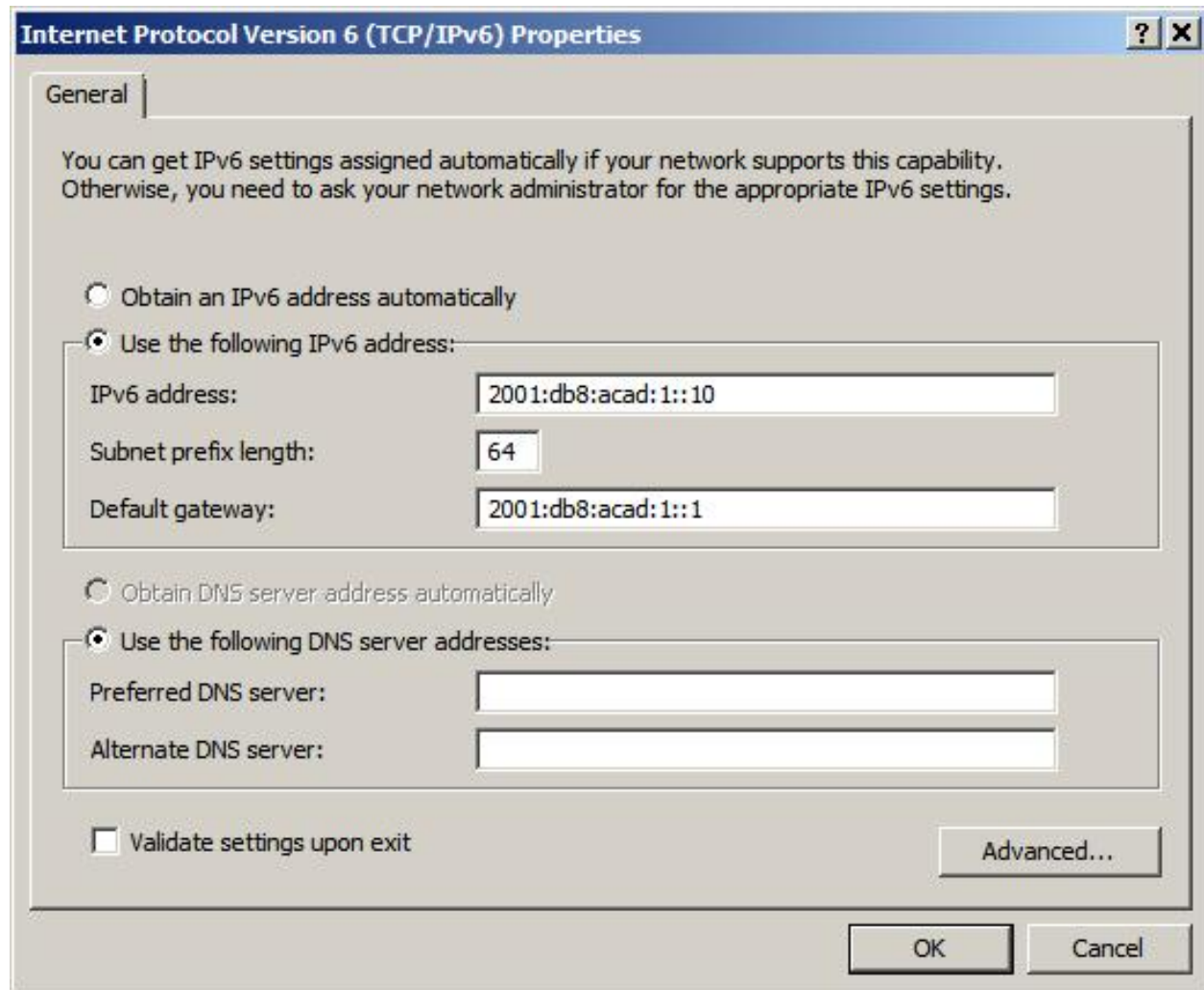# Static Configuration of an IPv6 Global Unicast Address (cont.)

Windows
IPv6
Setup

Dynamic Configuration of a Global Unicast Address using SLAAC

Stateless Address Autoconfiguraton (SLAAC)

- A method that allows a device to obtain its prefix, prefix length and default gateway from an IPv6 router

- No DHCPv6 server needed

- Rely on ICMPv6 Router Advertisement (RA) messages

IPv6 routers

- Forwards IPv6 packets between networks

- Can be configured with static routes or a dynamic IPv6 routing protocol

- Sends ICMPv6 RA messages

Dynamic Configuration of a Global Unicast Address using SLAAC (cont.)

- The **`IPv6 unicast-routing`** command enables IPv6 routing.

- RA message can contain one of the following three options:

  - SLAAC Only – Uses the information contained in the RA message.

  - SLAAC and DHCPv6 – Uses the information contained in the RA message and get other information from the DHCPv6 server, stateless DHCPv6 (for example, DNS).

  - DHCPv6 only – The device should not use the information in the RA, stateful DHCPv6.

- Routers send ICMPv6 RA messages using the link-local address as the source IPv6 address

Dynamic Configuration of a Global Unicast Address using SLAAC (cont.)

Router Solicitation and Router Advertisement Messages

① **Router Solicitation – To all IPv6 routers**
"I need addressing information from the router."

② **Router Advertisement – To all IPv6 nodes**
Option 1 (SLAAC Only) – "Here is your Prefix, Prefix-length, Default Gateway information."

DHCPv6 Server

Router Advertisement Options

Option 1 (SLAAC Only) – "I'm everything you need (Prefix, Prefix-length, Default Gateway)"
Option 2 (SLAAC and DHCPv6) – "Here is my information but you need to get other information such as DNS addresses from a DHCPv6 server."
Option 3 (DHCPv6 Only) – "I can't help you. Ask a DHCPv6 server for all your information."

# Dynamic Configuration of a Global Unicast Address using DHCPv6 (cont.)

Dynamic Host Configuration Protocol for IPv6 (DHCPv6)

- Similar to IPv4

- Automatically receives addressing information, including a global unicast address, prefix length, default gateway address and the addresses of DNS servers using the services of a DHCPv6 server.

- Device may receive all or some of its IPv6 addressing information from a DHCPv6 server depending upon whether option 2 (SLAAC and DHCPv6) or option 3 (DHCPv6 only) is specified in the ICMPv6 RA message.

- Host may choose to ignore whatever is in the router's RA message and obtain its IPv6 address and other information directly from a DHCPv6 server.

Dynamic Configuration of a Global Unicast Address using DHCPv6 (cont.)
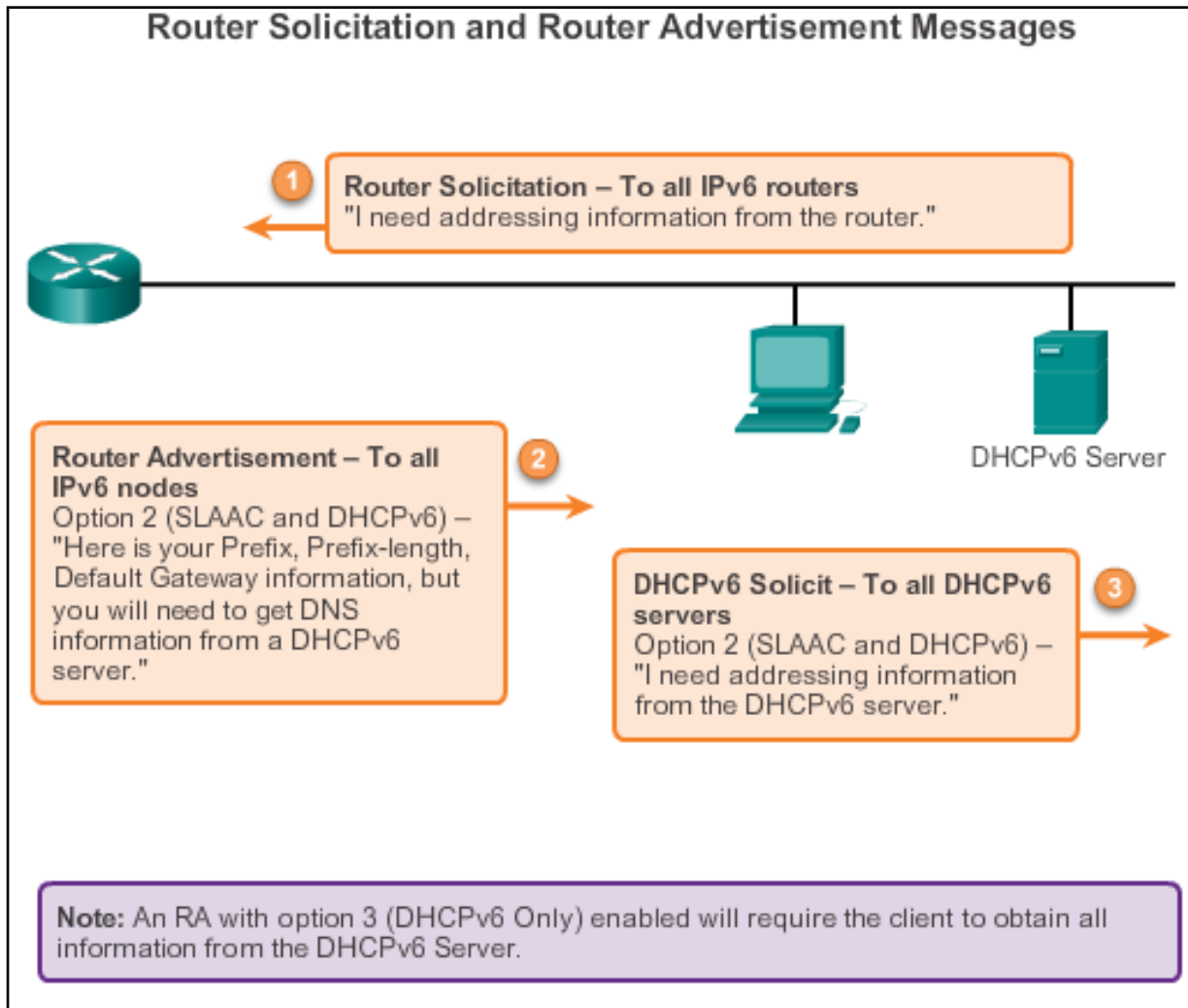
EUI-64 Process or Randomly Generated

EUI-64 Process

- Uses a client's 48-bit Ethernet MAC address and inserts another 16 bits in the middle of the 46-bit MAC address to create a 64-bit Interface ID.

- Advantage is that the Ethernet MAC address can be used to determine the interface; is easily tracked.
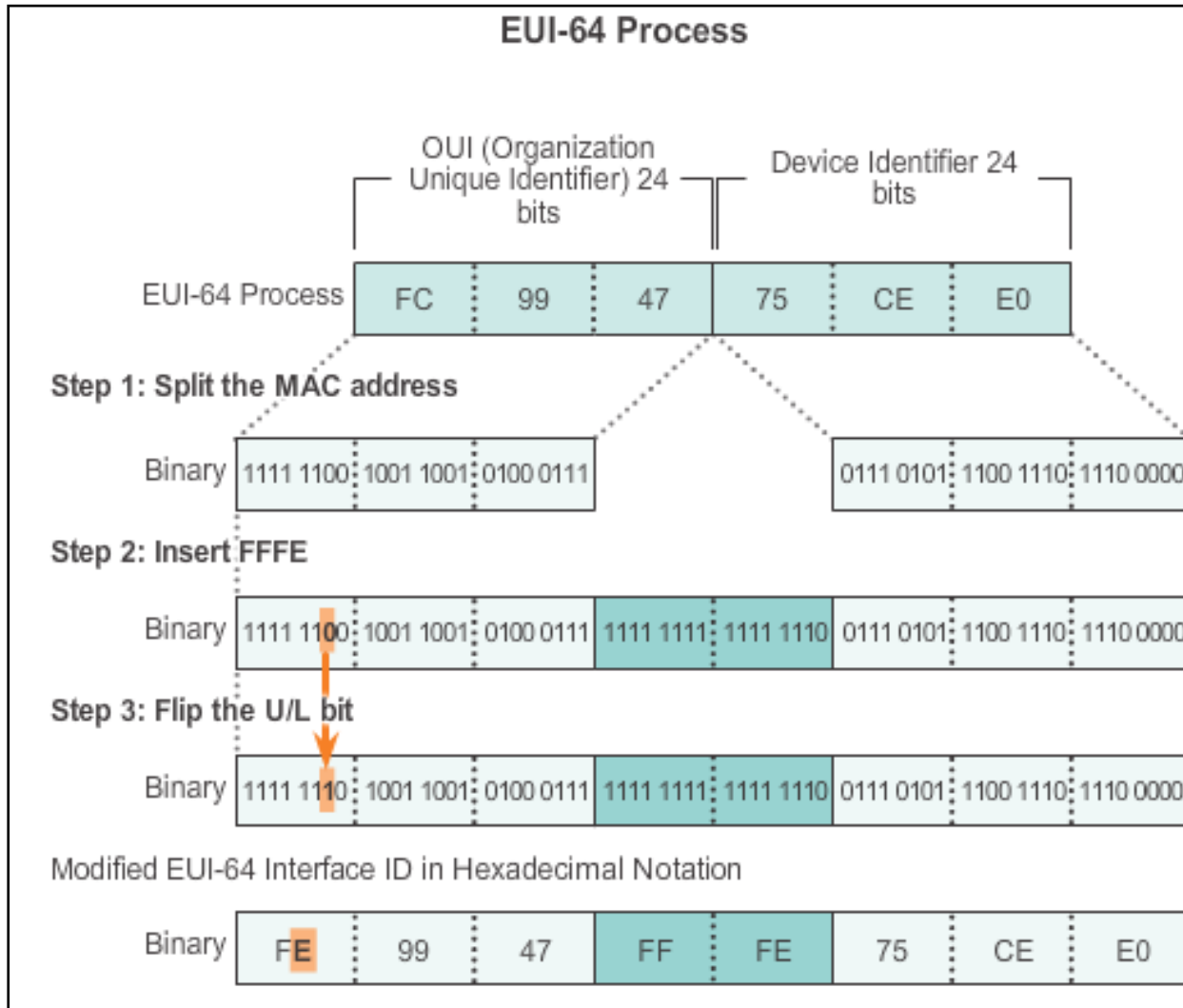
EUI-64 Interface ID is represented in binary and comprises three parts:

- 24-bit OUI from the client MAC address, but the 7th bit (the Universally/Locally bit) is reversed (0 becomes a 1).

- Inserted as a 16-bit value FFFE.

- 24-bit device identifier from the client MAC address.

EUI-64 Process or Randomly Generated (cont.)

EUI-64 Process or Randomly Generated (cont.)

```
R1#show interface gigabitethernet 0/0
GigabitEthernet0/0 is up, line protocol is up
  Hardware is CN Gigabit Ethernet, address is fc99.4775.c3e0
(bia fc99.4775.c3e0)
<Output Omitted>

R1#show ipv6 interface brief
GigabitEthernet0/0        [up/up]
    FE80::FE99:47FF:FE75:C3E0
    2001:DB8:ACAD:1::1
GigabitEthernet0/1        [up/up]
    FE80::FE99:47FF:FE75:C3E1
    2001:DB8:ACAD:2::1
Serial0/0/0               [up/up]
    FE80::FE99:47FF:FE75:C3E0
    2001:DB8:ACAD:3::1
Serial0/0/1               [administratively down/down]
    unassigned
R1#
```

Link-local addresses using EUI-64

EUI-64 Process or Randomly Generated (cont.)

Randomly Generated Interface IDs

- Depending upon the operating system, a device can use a randomly generated Interface ID instead of using the MAC address and the EUI-64 process.

- Beginning with Windows Vista, Windows uses a randomly generated Interface ID instead of one created with EUI-64.

- Windows XP (and previous Windows operating systems) used EUI-64.

Dynamic Link-local Addresses

Link-Local Address

- After a global unicast address is assigned to an interface, an IPv6-enabled device automatically generates its link-local address.

- Must have a link-local address that enables a device to communicate with other IPv6-enabled devices on the same subnet.

- Uses the link-local address of the local router for its default gateway IPv6 address.

- Routers exchange dynamic routing protocol messages using link-local addresses.

- Routers' routing tables use the link-local address to identify the next-hop router when forwarding IPv6 packets.
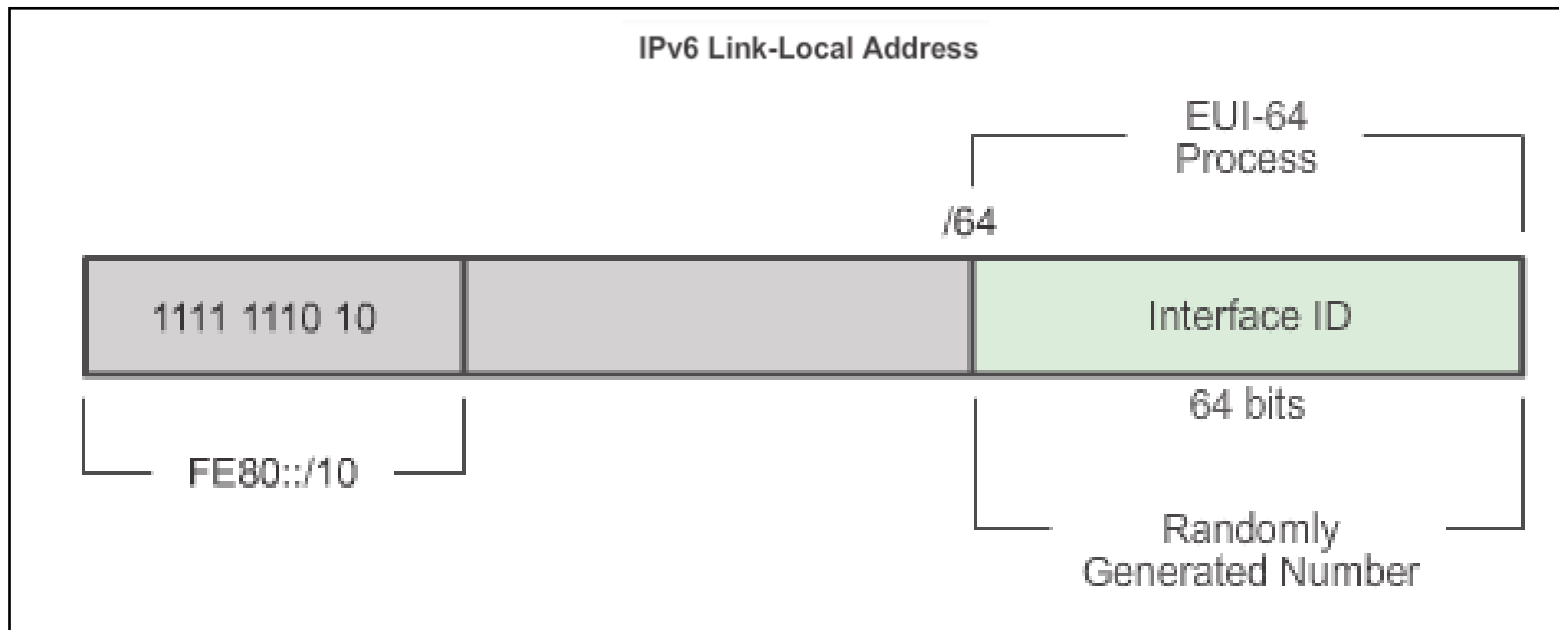
Dynamic Link-local Addresses (cont.)

Dynamically Assigned

The link-local address is dynamically created using the FE80::/10 prefix and the Interface ID.

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Static Link-local Addresses

Configuring Link-local

```
R1(config)#interface gigabitethernet 0/0
R1(config-if)#ipv6 address fe80::1 ?
   link-local  Use link-local address

R1(config-if)#ipv6 address fe80::1 link-local
R1(config-if)#exit
R1(config)#interface gigabitethernet 0/1
R1(config-if)#ipv6 address fe80::1 link-local
R1(config-if)#exit
R1(config)#interface serial 0/0/0
R1(config-if)#ipv6 address fe80::1 link-local
R1(config-if)#
```

Static Link-local Addresses (cont.)

Configuring Link-local


```
R1#show ipv6 interface brief
GigabitEthernet0/0      [up/up]
    FE80::1
    2001:DB8:ACAD:1::1
GigabitEthernet0/1      [up/up]
    FE80::1
    2001:DB8:ACAD:2::1
Serial0/0/0            [up/up]
    FE80::1
    2001:DB8:ACAD:3::1
Serial0/0/1            [administratively down/down]
    unassigned
R1#
```
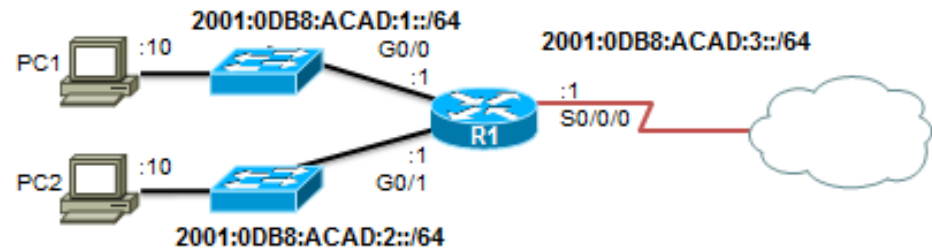
Statically configured link-local addresses

Verifying IPv6 Address Configuration

Each interface has two IPv6 addresses -

1. global unicast address that was configured
2. one that begins with FE80 is automatically added as a link-local unicast address


```
R1#show ipv6 interface brief
GigabitEthernet0/0        [up/up]
    FE80::FE99:47FF:FE75:C3E0
    2001:DB8:ACAD:1::1
GigabitEthernet0/1        [up/up]
    FE80::FE99:47FF:FE75:C3E1
    2001:DB8:ACAD:2::1
Serial0/0/0              [up/up]
    FE80::FE99:47FF:FE75:C3E0
    2001:DB8:ACAD:3::1
Serial0/0/1              [administratively down/down]
    unassigned
R1#
```

Verifying IPv6 Address Configuration (cont.)

```
R1#show ipv6 route
IPv6 Routing Table - default - 7 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user
Static

<output omitted>

C    2001:DB8:ACAD:1::/64 [0/0]
      via GigabitEthernet0/0, directly connected
L    2001:DB8:ACAD:1::1/128 [0/0]
      via GigabitEthernet0/0, receive
C    2001:DB8:ACAD:2::/64 [0/0]
      via GigabitEthernet0/1, directly connected
L    2001:DB8:ACAD:2::1/128 [0/0]
      via GigabitEthernet0/1, receive
C    2001:DB8:ACAD:3::/64 [0/0]
      via Serial0/0/0, directly connected
L    2001:DB8:ACAD:3::1/128 [0/0]
      via Serial0/0/0, receive
L    FF00::/8 [0/0]
      via Null0, receive
R1#
```

Assigned IPv6 Multicast Addresses

- IPv6 multicast addresses have the prefix FF00::/8

- There are two types of IPv6 multicast addresses:

  - Assigned multicast

  - Solicited node multicast

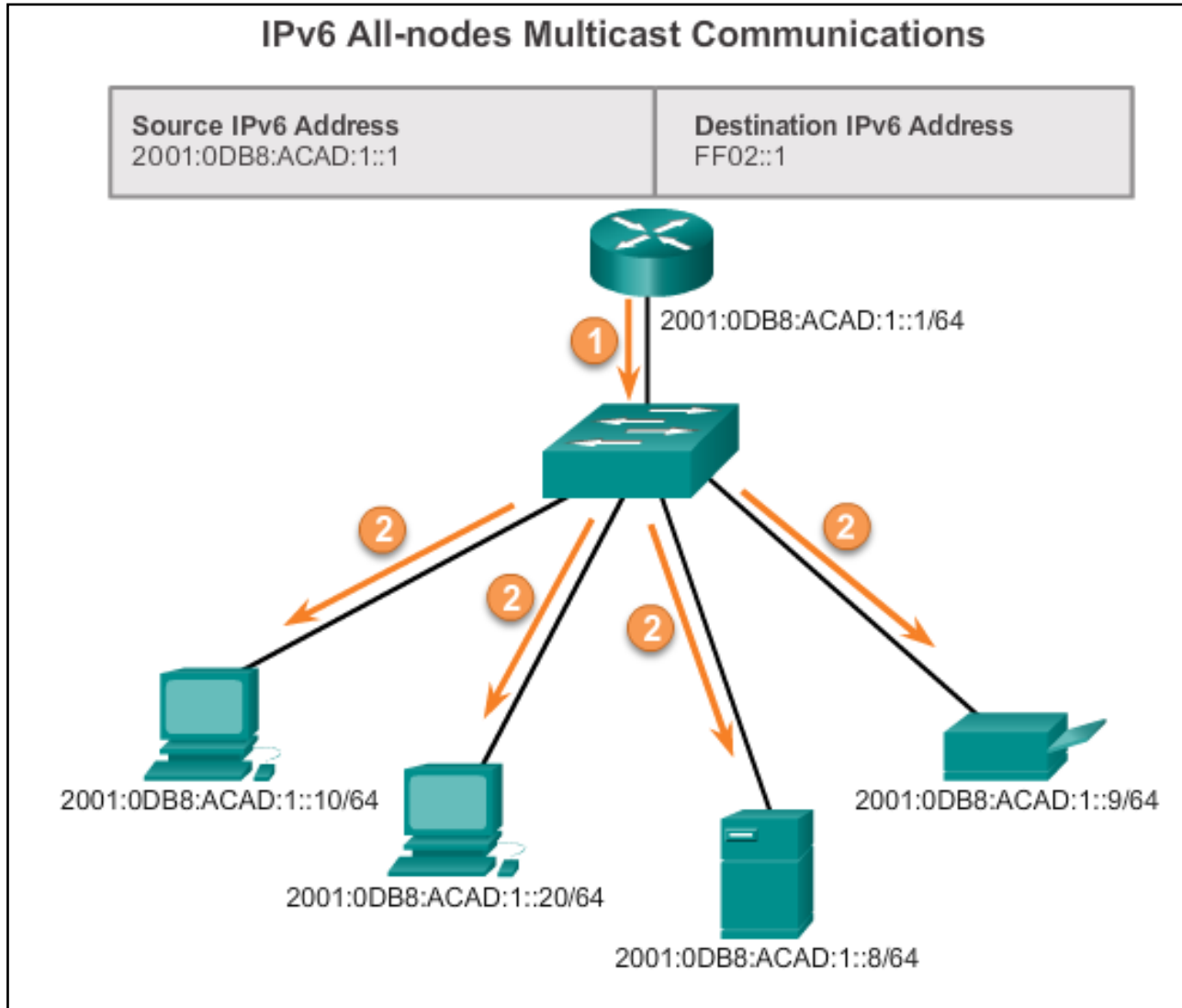# Assigned IPv6 Multicast Addresses (cont.)

Two common IPv6 assigned multicast groups include:

- **FF02::1 All-nodes multicast group** –

  - All IPv6-enabled devices join

  - Same effect as an IPv4 broadcast address

- **FF02::2 All-routers multicast group**

  - All IPv6 routers join

  - A router becomes a member of this group when it is enabled as an IPv6 router with the `ipv6 unicast-routing` global configuration mode command.

  - A packet sent to this group is received and processed by all IPv6 routers on the link or network.

Assigned IPv6 Multicast Addresses (cont.)

IPv6 All-nodes Multicast Communications

Source IPv6 Address	Destination IPv6 Address
2001:0DB8:ACAD:1::1	FF02::1

2001:0DB8:ACAD:1::1/64

2001:0DB8:ACAD:1::10/64

2001:0DB8:ACAD:1::20/64

2001:0DB8:ACAD:1::8/64

2001:0DB8:ACAD:1::9/64
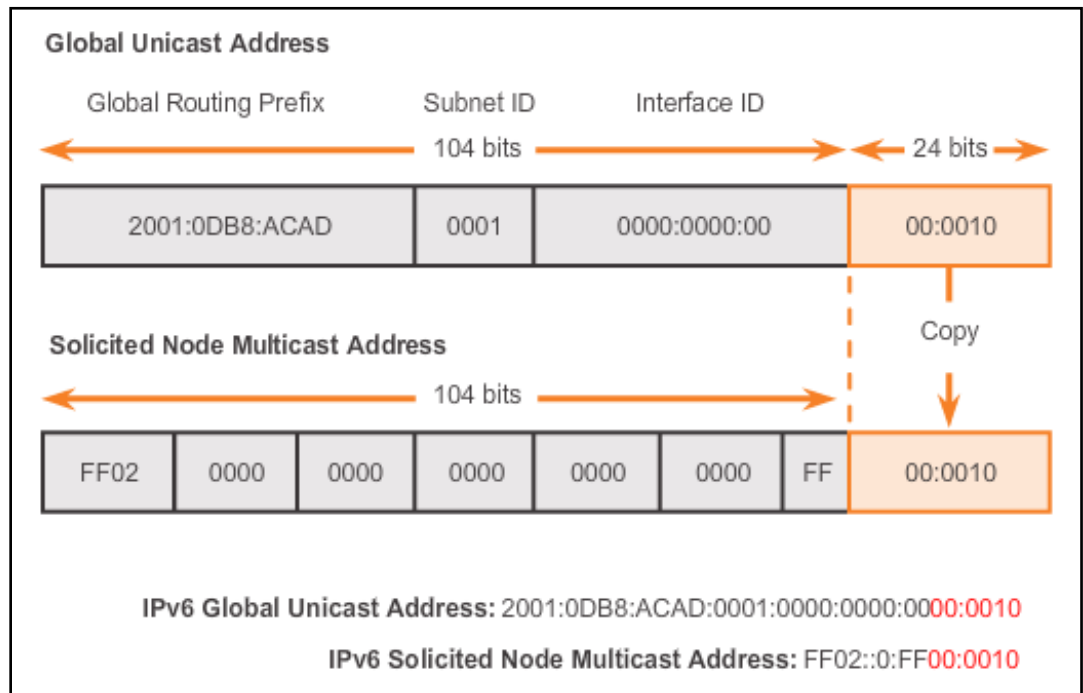
Solicited Node IPv6 Multicast Addresses

- Similar to the all-nodes multicast address, matches only the last 24 bits of the IPv6 global unicast address of a device

- Automatically created when the global unicast or link-local unicast addresses are assigned

- Created by combining a special FF02:0:0:0:0:0:FF00::/104 prefix with the right-most 24 bits of its unicast address
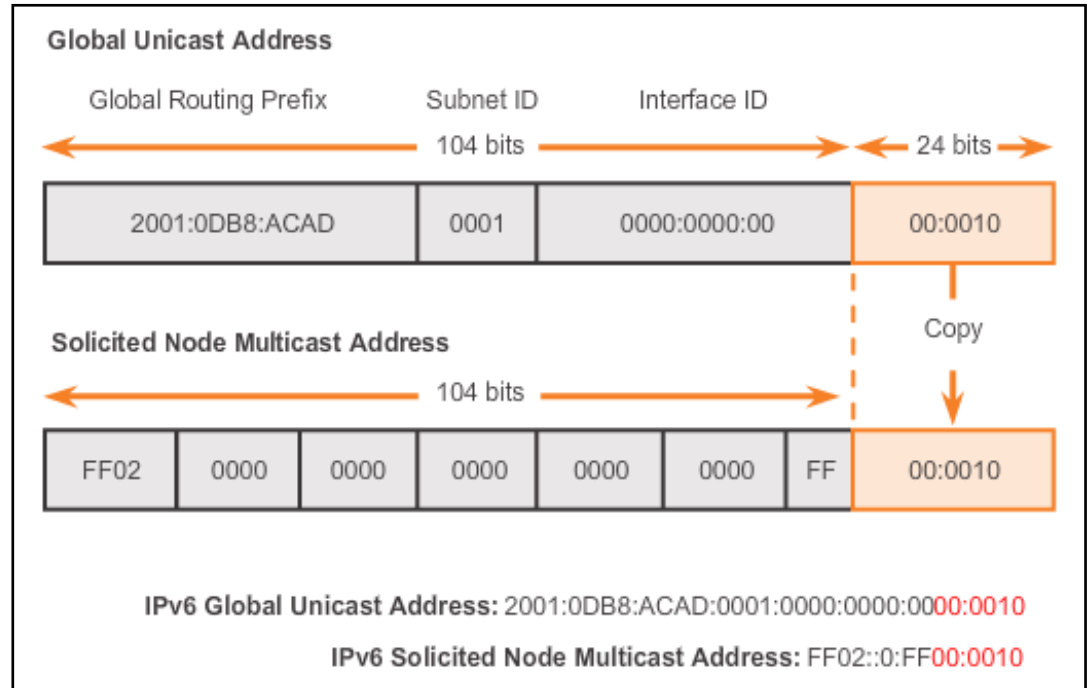

Global Unicast Address

Global Routing Prefix	Subnet ID	Interface ID

← 104 bits → ← 24 bits →

2001:0DB8:ACAD	0001	0000:0000:00	00:0010

Copy

Solicited Node Multicast Address

← 104 bits →

FF02	0000	0000	0000	0000	0000	FF	00:0010

IPv6 Global Unicast Address: 2001:0DB8:ACAD:0001:0000:0000:0000:0010

IPv6 Solicited Node Multicast Address: FF02::0:FF00:0010

Solicited Node IPv6 Multicast Addresses (cont.)

The solicited node multicast address consists of two parts:

- **FF02:0:0:0:0:0:FF00::/104 multicast prefix** – First 104 bits of the all solicited node multicast address

- **Least significant 24-bits** – Copied from the right-most 24 bits of the global unicast or link-local unicast address of the device

Global Unicast Address

Global Routing Prefix		Subnet ID	Interface ID	
104 bits				24 bits
2001:0DB8:ACAD		0001	0000:0000:00	00:0010

Copy

Solicited Node Multicast Address

104 bits

FF02	0000	0000	0000	0000	0000	FF	00:0010

IPv6 Global Unicast Address: 2001:0DB8:ACAD:0001:0000:0000:0000:0010

IPv6 Solicited Node Multicast Address: FF02::0:FF00:0010

8.3 Connectivity Verification

ICMPv4 and ICMPv6 Messages

- ICMP messages common to both ICMPv4 and ICMPv6 include:

    - Host confirmation

    - Destination or Service Unreachable

    - Time exceeded

    - Route redirection

- Although IP is not a reliable protocol, the TCP/IP suite does provide for messages to be sent in the event of certain errors, sent using the services of ICMP.

ICMPv6 Router Solicitation and Router Advertisement Messages

- ICMPv6 includes four new protocols as part of the Neighbor Discovery Protocol (ND or NDP):
    - Router Solicitation message
    - Router Advertisement message
    - Neighbor Solicitation message
    - Neighbor Advertisement message

- **Router Solicitation and Router Advertisement Message** – Sent between hosts and routers.

- **Router Solicitation (RS) message** – RS messages are sent as an IPv6 all-routers multicast message.

- **Router Advertisement (RA) message** – RA messages are sent by routers to provide addressing information.

ICMPv6 Router Solicitation and Router Advertisement Messages (cont.)

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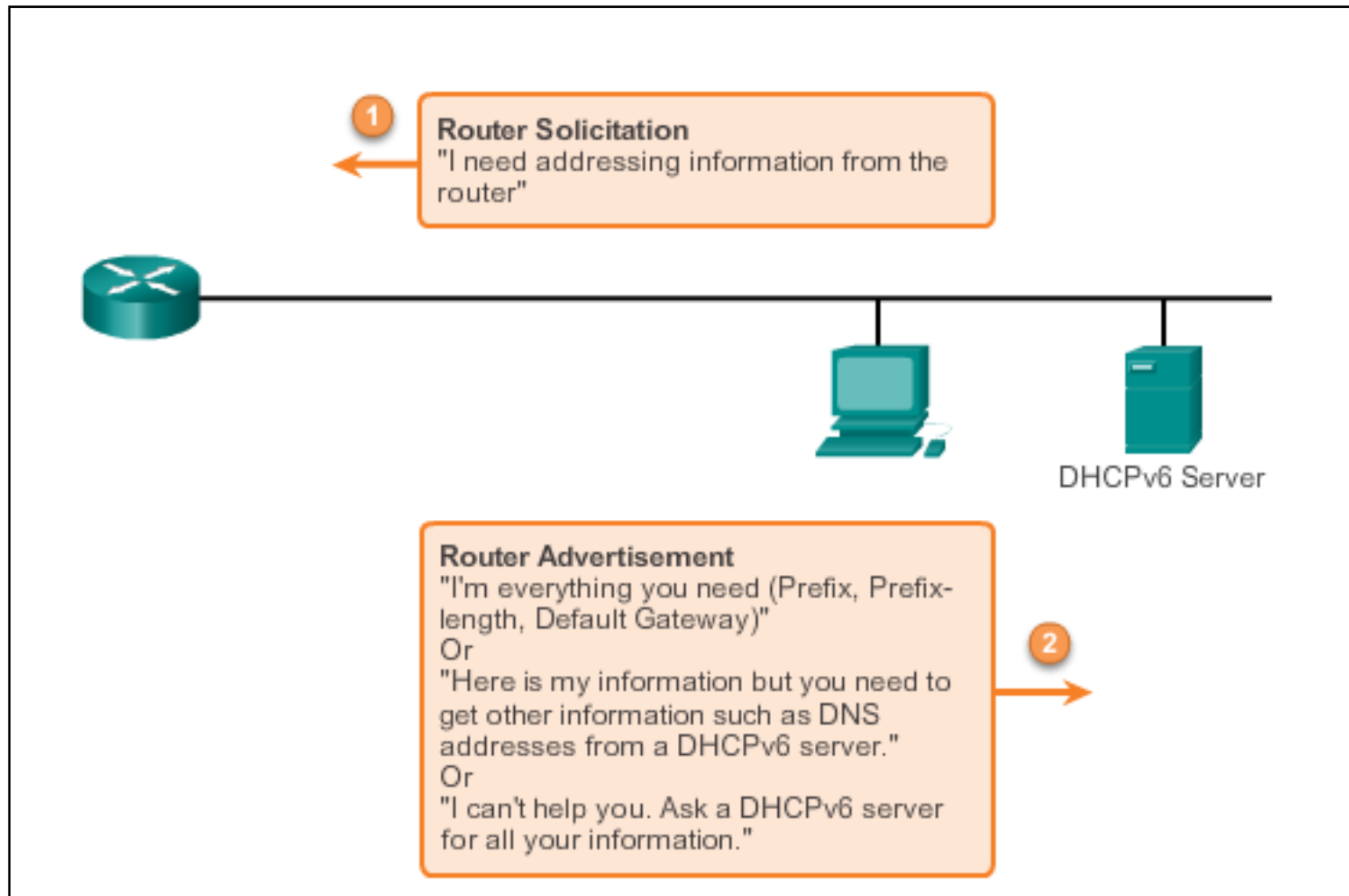
ICMPv6 Neighbor Solicitation and Neighbor Advertisement Messages

- Two additional message types:

    - Neighbor Solicitation (NS)

    - Neighbor Advertisement (NA) messages

- **Used for address resolution** is used when a device on the LAN knows the IPv6 unicast address of a destination, but does not know its Ethernet MAC address.

- **Also used for Duplicate Address Detection (DAD)**

    - Performed on the address to ensure that it is unique.

    - The device sends an NS message with its own IPv6 address as the targeted IPv6 address.

ICMPv6 Neighbor Solicitation and Neighbor Advertisement Messages (cont.)
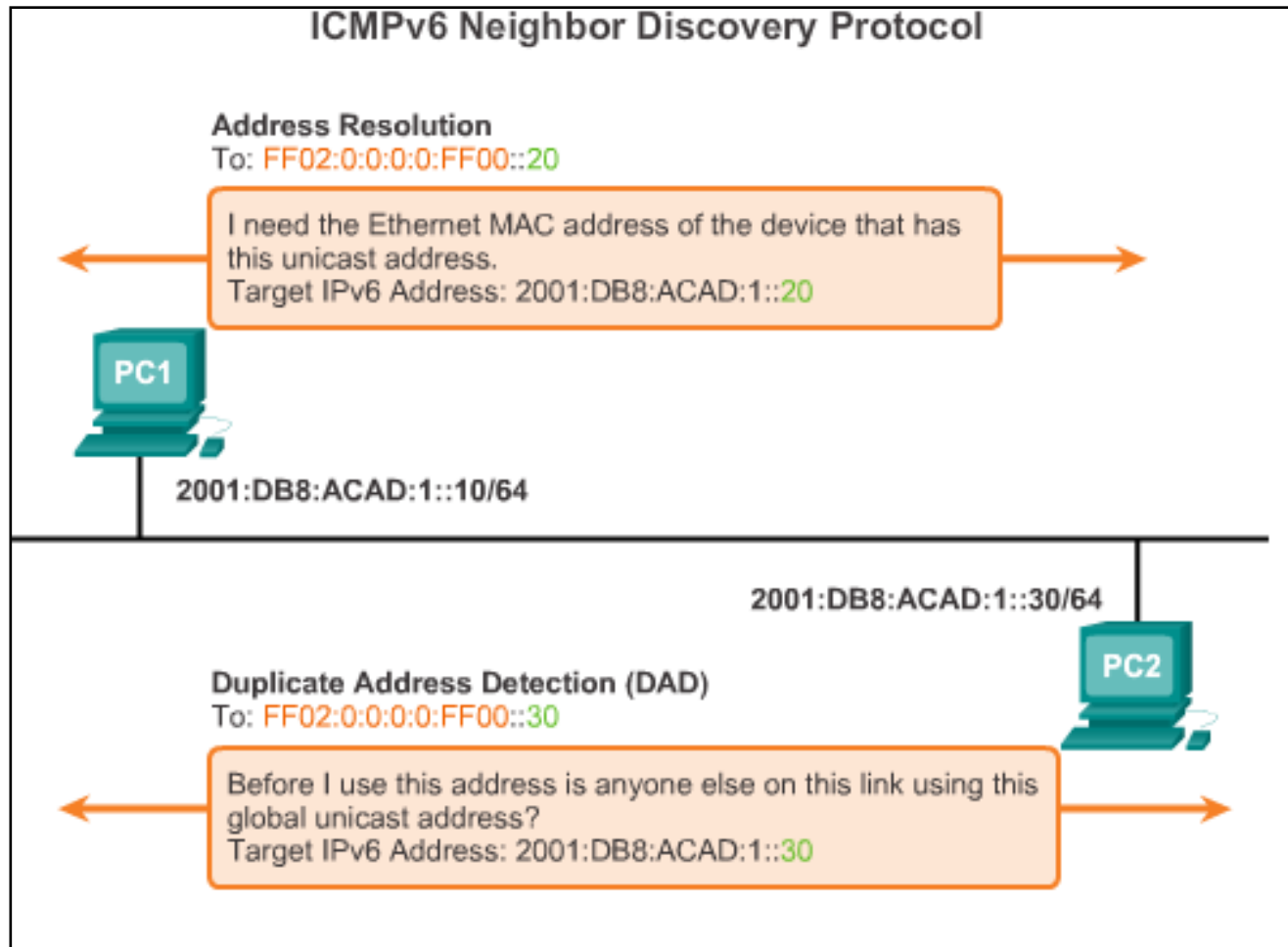
Routing and Switching Essentials
9.3 Design Considerations for IPv6

Subnetting Using the Subnet ID

An IPv6 Network Space is subnetted to support hierarchical, logical design of the network
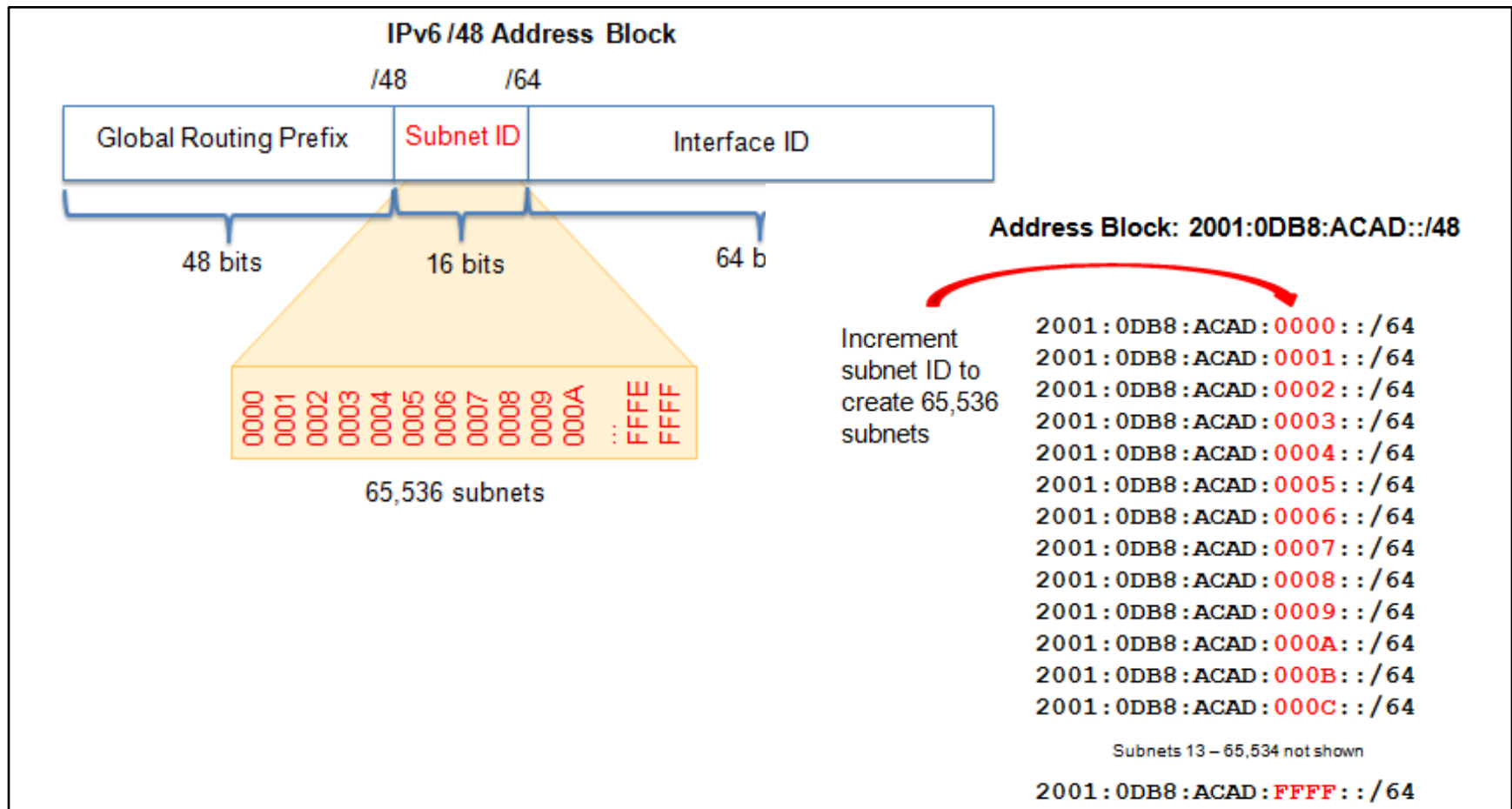
IPV6 Subnet Allocation

Subnetting into the Interface ID
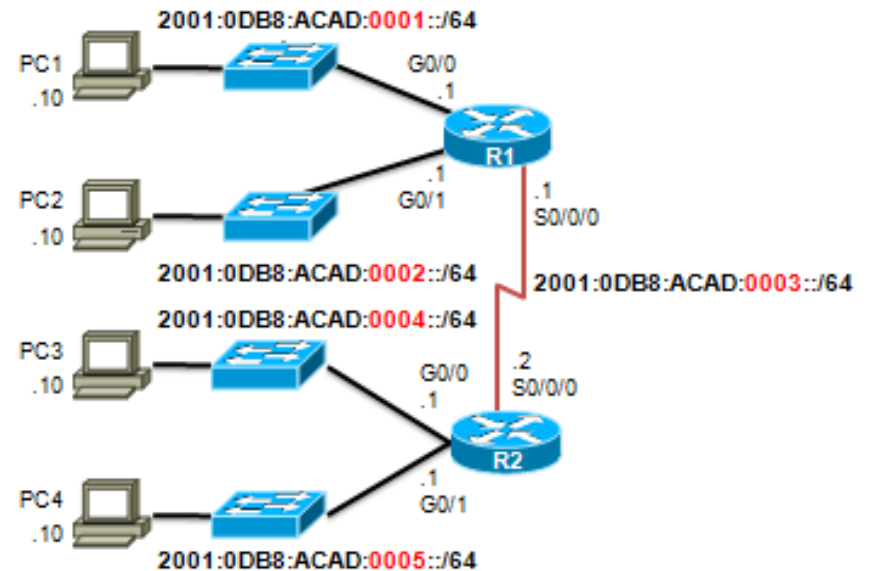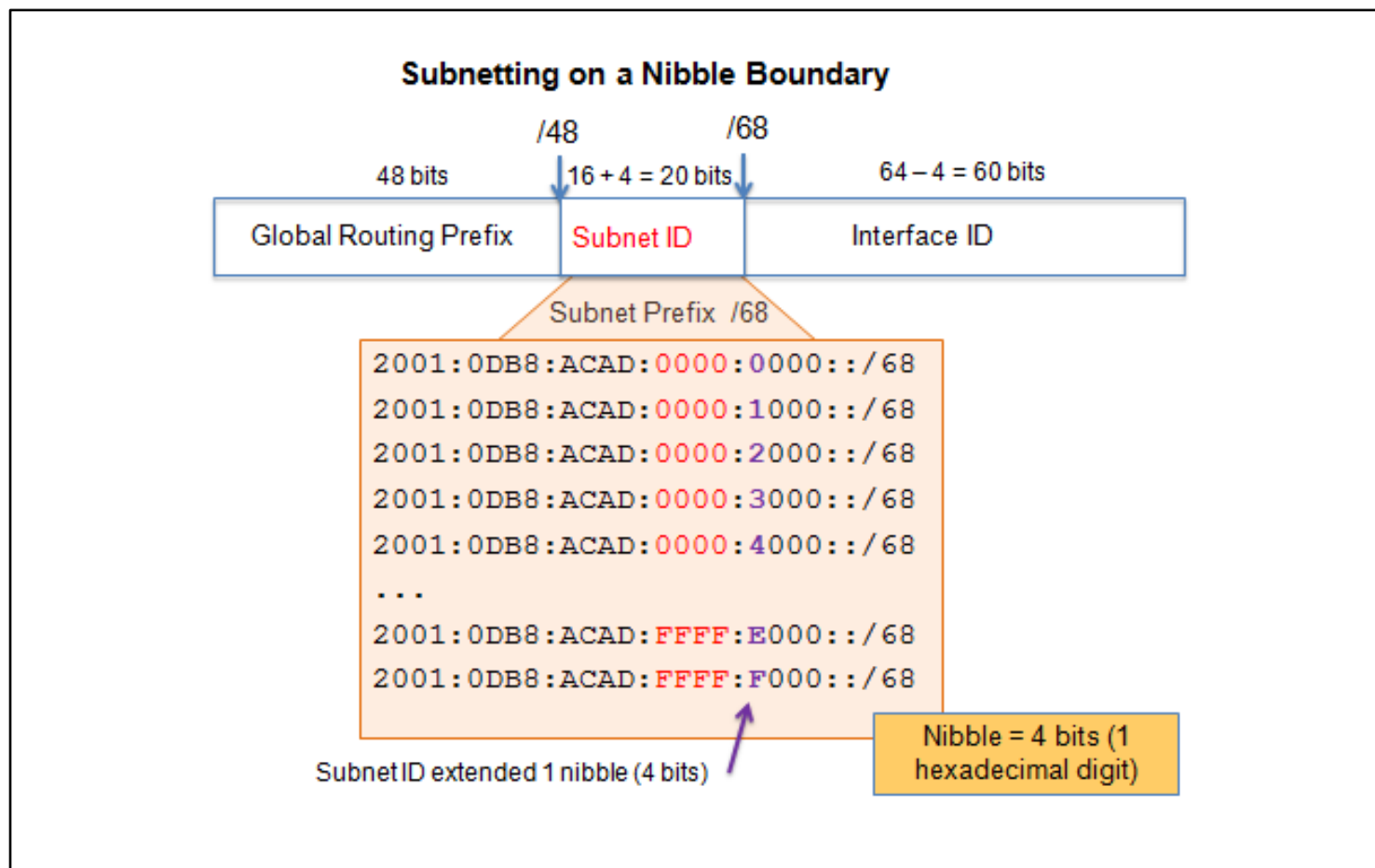
IPv6 bits can be borrowed from the interface ID to create additional IPv6 subnets.

Summary

- Each IPv6 address has 128 bits verses the 32 bits in an IPv4 address.

- The prefix length is used to indicate the network portion of an IPv6 address using the following format: IPv6 address/prefix length

- There are three types of IPv6 addresses: unicast, multicast, and anycast.

- An IPv6 link-local address enables a device to communicate with other IPv6-enabled devices on the same link and only on that link (subnet).

- Packets with a source or destination link-local address cannot be routed beyond the link from where the packet originated.

- IPv6 link-local addresses are in the FE80::/10 range.

- ICMP is available for both IPv4 and IPv6.