

Module 12: IPv6 Addressing

Introduction to Networks v7.0
(ITN)

IPv4 Issues Need for IPv6

IPv4 is running out of addresses. IPv6 is the successor to IPv4. IPv6 has a much larger 128-bit address space. The development of IPv6 also included fixes for IPv4 limitations and other enhancements.

With an increasing internet population, a limited IPv4 address space, issues with NAT and the IoT, the time has come to begin the transition to IPv6.



IPv4 Issues

IPv4 and IPv6 Coexistence

Both IPv4 and IPv6 will coexist in the near future and the transition will take several years.

The IETF has created various protocols and tools to help network administrators migrate their networks to IPv6. These migration techniques can be divided into three categories:

- **Dual stack** -The devices run both IPv4 and IPv6 protocol stacks simultaneously.
- **Tunneling** – A method of transporting an IPv6 packet over an IPv4 network. The IPv6 packet is encapsulated inside an IPv4 packet.
- **Translation** - Network Address Translation 64 (NAT64) allows IPv6-enabled devices to communicate with IPv4-enabled devices using a translation technique similar to NAT for IPv4.

Note: Tunneling and translation are for transitioning to native IPv6 and should only be used where needed. The goal should be native IPv6 communications from source to destination.



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IPv6 Address Representation

IPv6 Addressing Formats

IPv6 addresses are 128 bits in length and written in hexadecimal.

IPv6 addresses are not case-sensitive and can be written in either lowercase or uppercase.

The preferred format for writing an IPv6 address is x:x:x:x:x:x:x, with each "x" consisting of four hexadecimal values.

In IPv6, a hextet is the unofficial term used to refer to a segment of 16 bits, or four hexadecimal values.

Examples of IPv6 addresses in the preferred format:

```
2001:0db8:0000:1111:0000:0000:0000:0200
```

```
2001:0db8:0000:00a3:abcd:0000:0000:1234
```



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IPv6 Address Representation

Rule 1 – Omit Leading Zero

The first rule to help reduce the notation of IPv6 addresses is to omit any leading 0s (zeros).

Examples:

01ab can be represented as 1ab

09f0 can be represented as 9f0

0a00 can be represented as a00

00ab can be represented as ab

Note: This rule only applies to leading 0s, NOT to trailing 0s, otherwise the address would be ambiguous.

Type	Format
Preferred	2001 : 0db8 : 0000 : 1111 : 0000 : 0000 : 0000 : 0200
No leading zeros	2001 : db8 : 0 : 1111 : 0 : 0 : 0 : 200



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IPv6 Address Representation

Rule 2 – Double Colon

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

Example:

- 2001:db8:cafe:1:0:0:0:1 (leading 0s omitted) could be represented as 2001:db8:cafe:1::1

Note: The double colon (::) can only be used once within an address, otherwise there would be more than one possible resulting address.

Type	Format
Preferred	2001 : 0db8 : 0000 : 1111 : 0000 : 0000 : 0000 : 0200
Compressed	2001:db8:0:1111::200



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2001: 0DB8 : 0000 : 0000 : 1000 : 0000 : 0000 : 0000
2001: DB8 :: 1000 : 0 : 0 : 1F0
2001: DB8 :: 1000 ::

12.3 IPv6 Address Types



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IPv6 Address Types Unicast, Multicast, Anycast

There are three broad categories of IPv6 addresses:

Unicast – Unicast uniquely identifies an interface on an IPv6-enabled device.

Multicast – Multicast is used to send a single IPv6 packet to multiple destinations.

Anycast – This is any IPv6 unicast address that can be assigned to multiple devices. A packet sent to an anycast address is routed to the nearest device having that address.

Note: Unlike IPv4, IPv6 does not have a broadcast address. However, there is an IPv6 all-nodes multicast address that essentially gives the same result.



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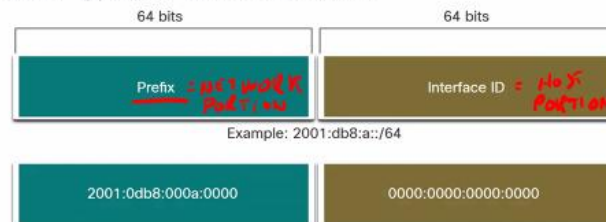
IPv6 Address Types

Address Type	Description	Topology
Unicast	<p>"One to One"</p> <ul style="list-style-type: none"> An address destined for a single interface. A packet sent to a unicast address is delivered to the interface identified by that address. 	
Multicast	<p>"One to Many"</p> <ul style="list-style-type: none"> An address for a set of interfaces (typically belonging to different nodes). A packet sent to a multicast address will be delivered to all interfaces identified by that address. 	
Anycast	<p>"One to Nearest" (Allocated from Unicast)</p> <ul style="list-style-type: none"> An address for a set of interfaces. In most cases these interfaces belong to different nodes. A packet sent to an anycast address is delivered to the closest interface as determined by the IGP. 	

IPv6 Address Types IPv6 Prefix Length

Prefix length is represented in slash notation and is used to indicate the network portion of an IPv6 address.

The IPv6 prefix length can range from 0 to 128. The recommended IPv6 prefix length for LANs and most other types of networks is /64.



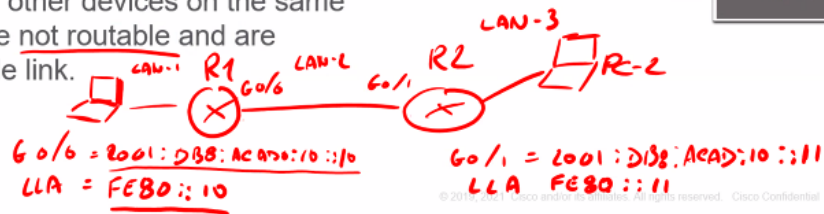
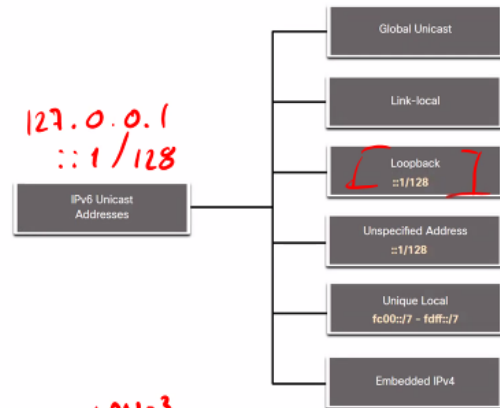
Note: It is strongly recommended to use a 64-bit Interface ID for most networks. This is because stateless address autoconfiguration (SLAAC) uses 64 bits for the Interface ID. It also makes subnetting easier to create and manage.

IPv6 Address Types

Types of IPv6 Unicast Addresses

Unlike IPv4 devices that have only a single address, IPv6 addresses typically have two unicast addresses:

- **[Global Unicast Address (GUA)]** – This is similar to a public IPv4 address. These are globally unique, internet-routable addresses.
- **[Link-local Address (LLA)]** – Required for every IPv6-enabled device and used to communicate with other devices on the same local link. LLAs are not routable and are confined to a single link.



Special IPv6 Addresses

IPv6 Address	Description
::/0	<ul style="list-style-type: none"> All routes and used when specifying a default static route. It is equivalent to the IPv4 quad-zero (0.0.0.0).
::/128	<ul style="list-style-type: none"> Unspecified address and is initially assigned to a host when it first resolves its local link address.
::1/128	<ul style="list-style-type: none"> Loopback address of local host. Equivalent to 127.0.0.1 in IPv4.
FE80::/10	<ul style="list-style-type: none"> Link-local unicast address. Similar to the Windows autoconfiguration IP address of 169.254.x.x.
FF00::/8	<ul style="list-style-type: none"> Multicast addresses.
All other addresses	<ul style="list-style-type: none"> Global unicast address.

Reserved IPv6 Multicast

Reserved Multicast Address	Description
FF02::1	<ul style="list-style-type: none"> All nodes on a link (link-local scope).
FF02::2	<ul style="list-style-type: none"> All routers on a link.
FF02::9	<ul style="list-style-type: none"> All routing information protocol (RIP) routers on a link.
FF02::1:FFxx:xxxx	<ul style="list-style-type: none"> All solicited-node multicast addresses used for host autoconfiguration and neighbor discovery (similar to ARP in IPv4). The xx:xxxx is the far right 24 bits of the corresponding unicast or anycast address of the node.
FF05::101	<ul style="list-style-type: none"> All Network Time Protocol (NTP) servers.

Neighbor Discovery ICMPv6 Packet Types

- Neighbor Discovery uses four ICMPv6 packet types:
 - Neighbor Solicitation and Neighbor Advertisement messages
 - Router Solicitation and Router Advertisement messages

ICMPv6 Message	Type	Description
Neighbor Solicitation (NS)	135	<ul style="list-style-type: none"> Sent by a host to determine the link-layer address of a neighbor. Used to verify that a neighbor is still reachable. An NS is also used for Duplicate Address Detection (DAD).
Neighbor Advertisement (NA)	136	<ul style="list-style-type: none"> A response to a NS message. A node may also send unsolicited NA to announce a link-layer address change.
Router Advertisement (RA)	134	<ul style="list-style-type: none"> RAs contain prefixes that are used for on-link determination or address configuration, a suggested hop limit value, MTU value, etc. RAs are sent either periodically, or in response to a RS message.
Router Solicitation (RS)	133	<ul style="list-style-type: none"> When a host is booting it sends out an RS requesting routers to immediately generate an RA rather than wait for their next scheduled time.

A Note About the Unique Local Address

The IPv6 unique local addresses (range fc00::/7 to fdff::/7) have some similarity to RFC 1918 private addresses for IPv4, but there are significant differences:

- Unique local addresses are used for local addressing within a site or between a limited number of sites.
- Unique local addresses can be used for devices that will never need to access another network.
- Unique local addresses are not globally routed or translated to a global IPv6 address.

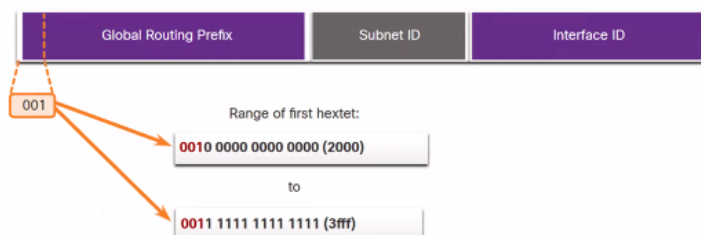
Note: Many sites use the private nature of RFC 1918 addresses to attempt to secure or hide their network from potential security risks. This was never the intended use of ULAs.



IPv6 GUA

IPv6 global unicast addresses (GUAs) are globally unique and routable on the IPv6 internet.

- Currently, only GUAs with the first three bits of 001 or 2000::/3 are being assigned.
- Currently available GUAs begins with a decimal 2 or a 3 (This is only 1/8th of the total available IPv6 address space).



IPv6 Address Types

IPv6 GUA Structure

Global Routing Prefix:

- The global routing prefix is the prefix, or network, portion of the address that is assigned by the provider, such as an ISP, to a customer or site. The global routing prefix will vary depending on ISP policies.

Subnet ID:

- The Subnet ID field is the area between the Global Routing Prefix and the Interface ID. The Subnet ID is used by an organization to identify subnets within its site.

Interface ID:

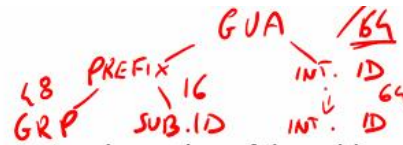
- The IPv6 interface ID is equivalent to the host portion of an IPv4 address. It is strongly recommended that in most cases /64 subnets should be used, which creates a 64-bit interface ID.

Note: IPv6 allows the all-0s and all-1s host addresses can be assigned to a device. The all-0s address is reserved as a Subnet-Router anycast address, and should be assigned only to routers.



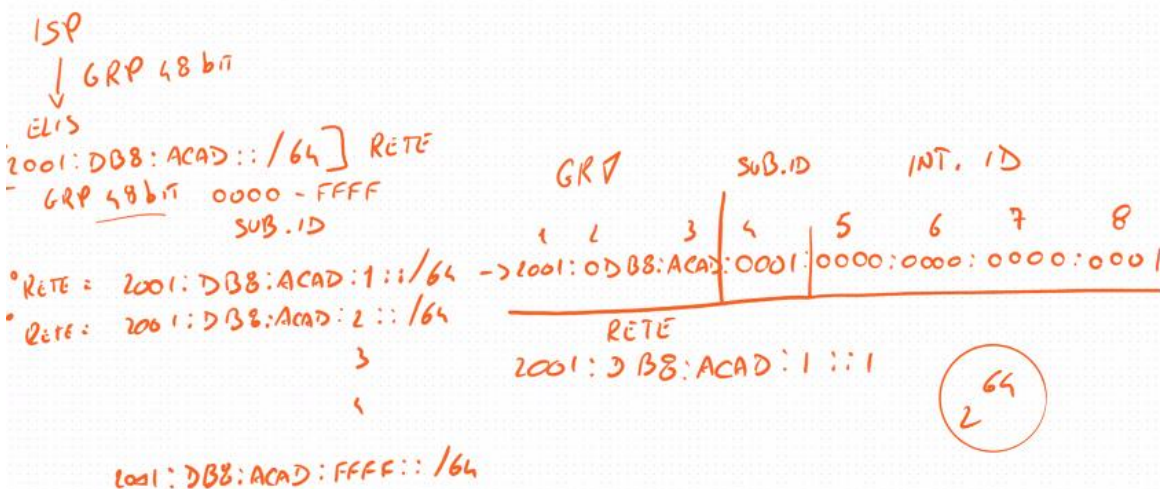
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29



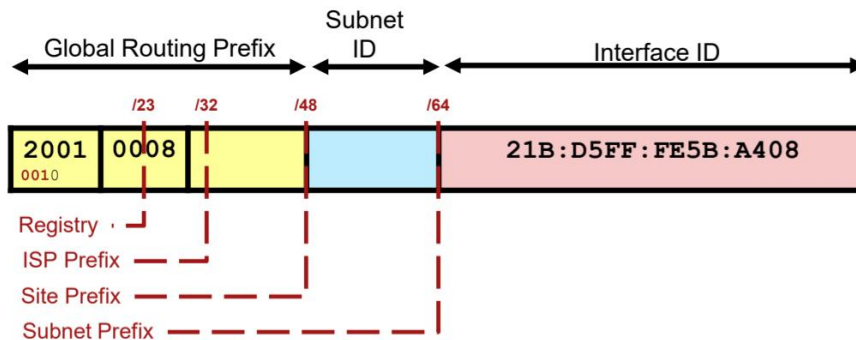
Whiteboard

Seguimi Condividi



IPv6 Global Unicast Address

- The global unicast address typically consists of:
 - A 48-bit global routing prefix
 - A 16-bit subnet ID
 - A 64-bit interface ID (typically in EUI-64 bit format discussed later).

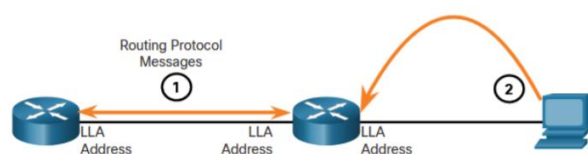


IPv6 Address Types

IPv6 LLA

An IPv6 link-local address (LLA) 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 LLA cannot be routed.
- Every IPv6-enabled network interface must have an LLA.
- If an LLA is not configured manually on an interface, the device will automatically create one.
- IPv6 LLAs are in the fe80::/10 range.



1. Routers use the LLA of neighbor routers to send routing updates.
2. Hosts use the LLA of a local router as the default-gateway.

Link local sarà sempre presente, una volta attivato IPv6 verrà automaticamente configurato sull'interfaccia (è prassi riconfigurarli).

12.4 GUA and LLA Static Configuration



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GUA and LLA Static Configuration Static GUA Configuration on a Router

Most IPv6 configuration and verification commands in the Cisco IOS are similar to their IPv4 counterparts. In many cases, the only difference is the use of **ipv6** in place of **ip** within the commands.

- The command to configure an IPv6 GUA on an interface is: **ipv6 address ipv6-address/prefix-length**.
- The example shows commands to configure a GUA on the G0/0/0 interface on R1:

```
R1(config)# interface gigabitethernet 0/0/0
R1(config-if)# ipv6 address 2001:db8:acad:1::1/64
R1(config-if)# no shutdown
R1(config-if)# exit
```



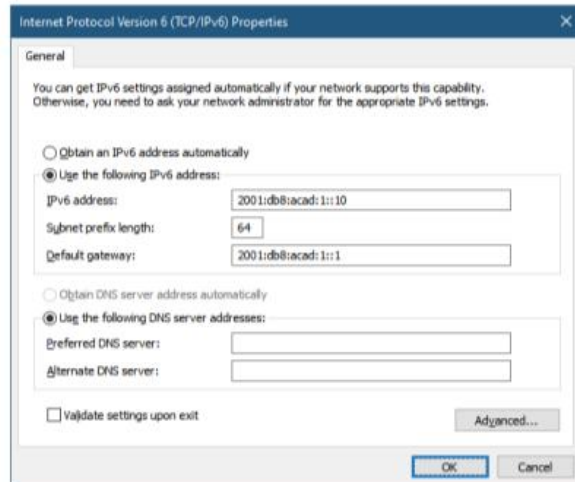
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GUA and LLA Static Configuration

Static GUA Configuration on a Windows Host

- Manually configuring the IPv6 address on a host is similar to configuring an IPv4 address.
- The GUA or LLA of the router interface can be used as the default gateway. Best practice is to use the LLA.

Note: When DHCPv6 or SLAAC is used, the LLA of the router will automatically be specified as the default gateway address.



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GUA and LLA Static Configuration

Static GUA Configuration of a Link-Local Unicast Address

Configuring the LLA manually lets you create an address that is recognizable and easier to remember.

- LLAs can be configured manually using the **ipv6 address ipv6-link-local-address link-local** command.
- The example shows commands to configure a LLA on the G0/0/0 interface on R1

```
R1(config)# interface gigabitethernet 0/0/0
R1(config-if)# ipv6 address fe80::1:1 link-local
R1(config-if)# no shutdown
R1(config-if)# exit
```

Note: The same LLA can be configured on each link as long as it is unique on that link. Common practice is to create a different LLA on each interface of the router to make it easy to identify the router and the specific interface.



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12.5 Dynamic Addressing for IPv6 GUAs



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Dynamic Addressing for IPv6 GUAs RS and RA Messages

Devices obtain GUA addresses dynamically through Internet Control Message Protocol version 6 (ICMPv6) messages.

- Router Solicitation (RS) messages are sent by host devices to discover IPv6 routers
- Router Advertisement (RA) messages are sent by routers to inform hosts on how to obtain an IPv6 GUA and provide useful network information such as:
 - Network prefix and prefix length
 - Default gateway address
 - DNS addresses and domain name
- The RA can provide three methods for configuring an IPv6 GUA :
 - SLAAC
 - SLAAC with stateless DHCPv6 server
 - Stateful DHCPv6 (no SLAAC)



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Dynamic Addressing for IPv6 GUAs

Method 1: SLAAC

- SLAAC allows a device to configure a GUA without the services of DHCPv6.
- Devices obtain the necessary information to configure a GUA from the ICMPv6 RA messages of the local router.
- The prefix is provided by the RA and the device uses either the EUI-64 or random generation method to create an interface ID.



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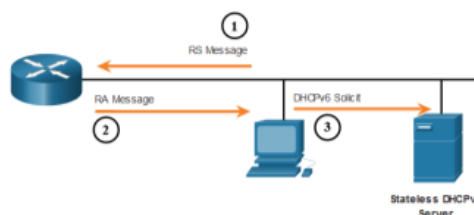
Dynamic Addressing for IPv6 GUAs

Method 2: SLAAC and Stateless DHCP

An RA can instruct a device to use both SLAAC and stateless DHCPv6.

The RA message suggests devices use the following:

- SLAAC to create its own IPv6 GUA
- The router LLA, which is the RA source IPv6 address, as the default gateway address
- A stateless DHCPv6 server to obtain other information such as a DNS server address and a domain name



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Dynamic Addressing for IPv6 GUAs

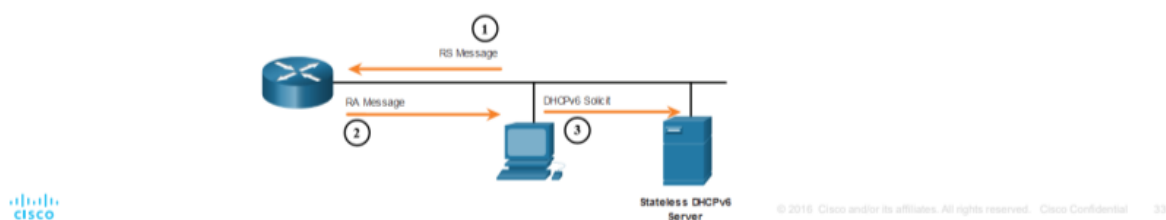
Method 3: Stateful DHCPv6

An RA can instruct a device to use stateful DHCPv6 only.

Stateful DHCPv6 is similar to DHCP for IPv4. A device can automatically receive a GUA, prefix length, and the addresses of DNS servers from a stateful DHCPv6 server.

The RA message suggests devices use the following:

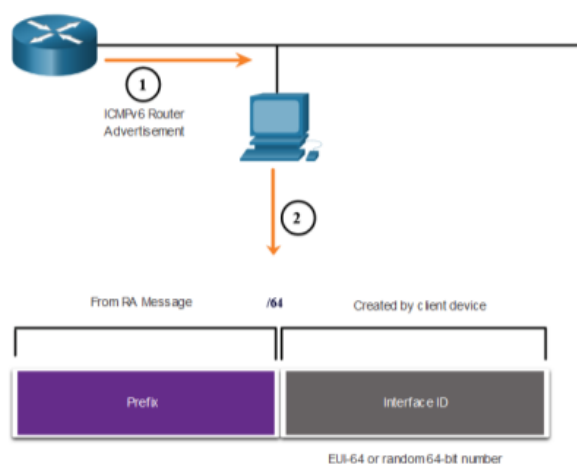
- The router LLA, which is the RA source IPv6 address, for the default gateway address.
- A stateful DHCPv6 server to obtain a GUA, DNS server address, domain name and other necessary information.



Dynamic Addressing for IPv6 GUAs

EUI-64 Process vs. Randomly Generated

- When the RA message is either SLAAC or SLAAC with stateless DHCPv6, the client must generate its own interface ID.
- The interface ID can be created using the EUI-64 process or a randomly generated 64-bit number.



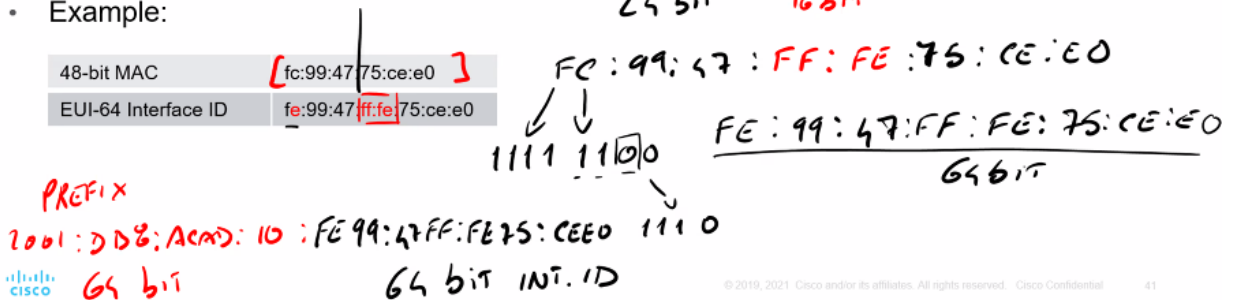
Dynamic Addressing for IPv6 GUAs EUI-64 Process

The IEEE defined the Extended Unique Identifier (EUI) or modified EUI-64 process which performs the following:

- A 16 bit value of fffe (in hexadecimal) is inserted into the middle of the 48-bit Ethernet MAC address of the client.

→ The 7th bit of the client MAC address is reversed from binary 0 to 1. $0 \rightarrow 1$
 $1 \rightarrow 0$

- Example:



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Dynamic Addressing for IPv6 GUAs Randomly Generated Interface IDs

Depending upon the operating system, a device may 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.

```
C:\> ipconfig
Windows IP Configuration
Ethernet adapter Local Area Connection:
Connection-specific DNS Suffix . : 
IPv6 Address. . . . . : 2001:db8:acad:1:50a5:8a35:a5bb:66e1
Link-local IPv6 Address . . . . . : fe80::50a5:8a35:a5bb:66e1
Default Gateway . . . . . : fe80::1
C:\>
```

Note: To ensure the uniqueness of any IPv6 unicast address, the client may use a process known as Duplicate Address Detection (DAD). This is similar to an ARP request for its own address. If there is no reply, then the address is unique.

ISP



GRP /64

48 bit + 16 (SUB.ID) + INT.ID

IPv6 128 bit

[2001:DB8:ACAD]:[0000]::/64
16 bit 16 16

[2001:DB8:ACAD:0001]:[::1] | EUI-64 | RANDOM



ISP



GRP /64


48 bit + 16 (SUB.ID) + INT.ID

IPv6 128 bit

1 -> 0
0 -> 1

[2001:DB8:ACAD]:[0000]::/64
16 bit 16 16

[2001:DB8:ACAD:0001]:[::1] | EUI-64 | RANDOM

 OUI
AA:10:30 | A1:23:10
24 24

[2001:DB8:ACAD:1:A910:30FF:FEA1:2310] | AA:10:30:FF:FE:A1:23:10

DAD NS ->

MAC
SOLICITED
NODE
MULTICAST

WELL-KNOWN

ALL-NODES -> FFB2::1

ALL-ROUTERS -> FFB2::2

FFB2::1:FF

ALL-SERVER

FF

