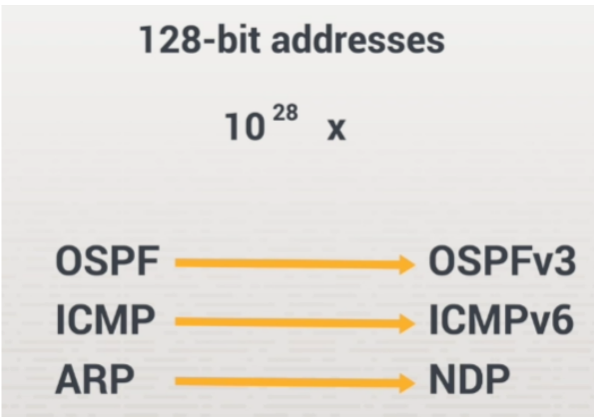
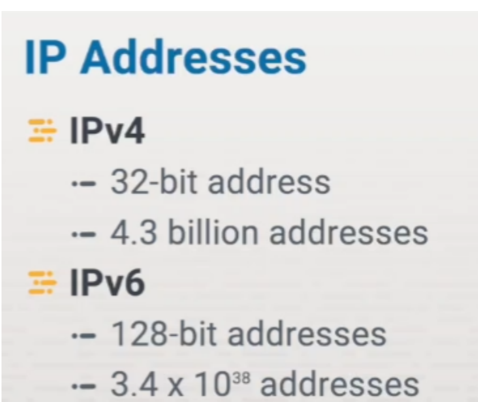
IPv6 Addressing

Dual-Homing: Running multiple protocols concurrently on the same network is called dual-homing. You'll likely see companies rolling out IPv6 alongside their current IPv4 networks.

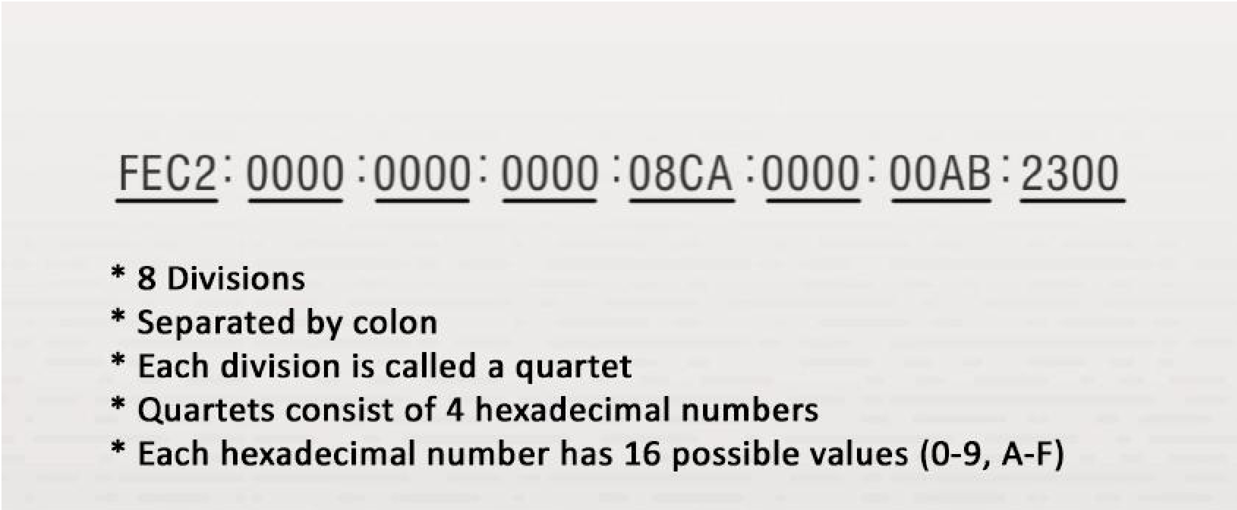


The primary reason IPv6 was developed was to provide a much larger address space. IPv6 is a 128-bit address, compared to IPv4's 32-bit addressing. That yields 10^28 times as many addresses as IPv4.

IPv6 Addressing Explained



IPv6 addresses have eight divisions, each separated by a colon. Each division is called a quartet. Each quartet consists of four hexadecimal numbers. Each hexadecimal number has 16 possible values, zero through nine and A to F.

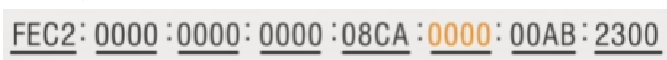


Ways to Simplify IPv6 Naming Formats

1) Omit leading zeros within a quartet

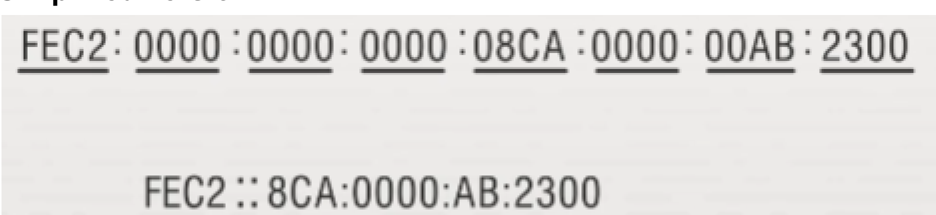
- You can't omit trailing zeros, only leading

2) Replace quartet blocks that contain only zeros with a double colon

- You can only omit one block of zeros in an address:
- This: 

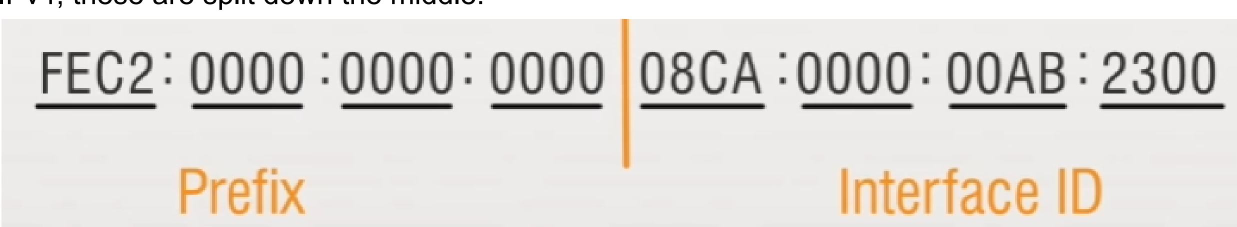
- OR this: 

Simplified version:



IPv6 Parts

Instead of network ID and hostname, IPv6 naming formats are Prefix and Interface ID. Unlike IPv4, these are split down the middle:

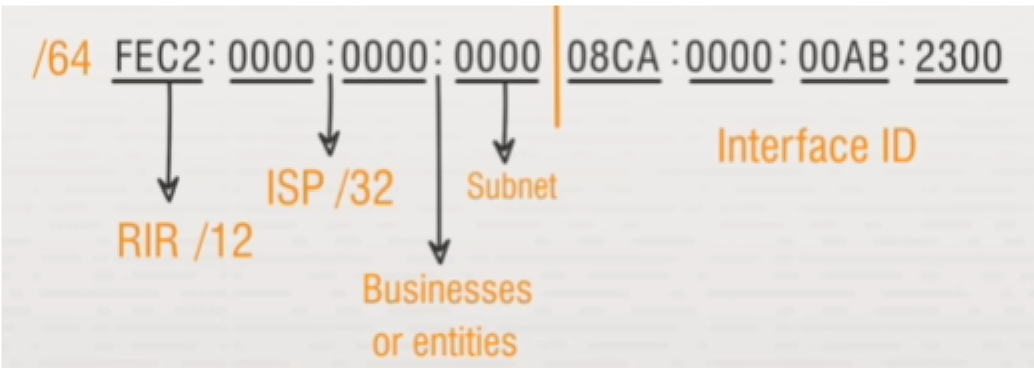


Segments

PREFIX PORTION

Within the prefix portion, the address is further divided into segments.

- **Regional Internet Registries (RIR)** - Different parts of the world are assigned different numbers to use for internet assignment. Because these are the first 12 bits of the address, often times a /12 is used to denote which part of the address you're referring to.
- **ISP:** The next segment of the prefix ends after 32 bits and is used to identify individual ISPs. It's designated using /32.
    - **Businesses or Entities:** The rest of the prefix is used by the ISP to assign to specific businesses or entities
        - **Subnets: T**hese entities use the last quartet to define various subnets within the organization.
- The entire IPv6 prefix is identified using /64, as it's the first 64 bits of the address.

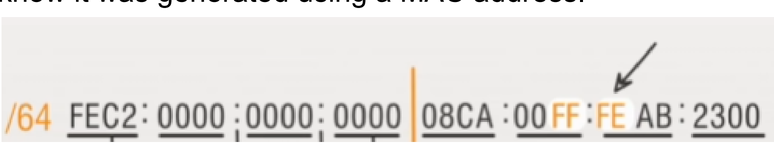


INTERFACE ID PORTION

The interface ID is used to uniquely identify a particular host. It is the last part of 64 bits of the address. The interface ID can either be dynamically generated by an individual host or regenerated using the MAC address of the NIC.

Generated using a MAC Address

Because MAC addresses are 48-bit numbers, the values FFFE are inserted in the middle. Whenever you see an IPv6 address with an FFFE quartet in the middle of the interface ID, you know it was generated using a MAC address.



Summary

In addition to providing more addresses, IPv6 was designed to include built-in security, quality of service, and auto-configuration features.

Even though IPv4 addresses have essentially run out, the transition to IPv6 will take time because a lot of IPv4 devices are unable to communicate with IPv6 devices. Many of these devices are embedded in the internet infrastructure. However, IPv6 addresses are used in a lot of situations. Therefore, it's important to understand the characteristics and features of IPv6 addresses.

IPv6 Address Facts

The explosive growth of the internet beginning in the 1990s and continuing through today, has depleted the number of available IPv4 32-bit addresses. To provide devices with globally unique addresses, IPv6 128-bit addresses were developed.

IPv6 Address Features

The IPv6 address is a 128-bit binary number. Below is an example IPv6 address:
35BC:FA77:4898:DAFC:200C:FBBC:A007:8973

The following list describes the features of an IPv6 address:

- The address is made up of 32 hexadecimal numbers, organized into 8 quartets.
- The quartets are separated by colons.
- Each quartet is represented as a hexadecimal number between 0 and FFFF. Each quartet represents 16 bits of data (FFFF = 1111 1111 1111 1111).
- Leading zeros can be omitted in each section. For example, the quartet 0284 could also be represented by 284.
- Addresses with consecutive zeros can be expressed more concisely by substituting two colons for the group of zeros. For example:
    - FEC0:0:0:0:78CD:1283:F398:23AB
    - FEC0::78CD:1283:F398:23AB (concise form)
- If an address has more than one consecutive location where one or more quartets are all zeros, only one location can be abbreviated. For example, FEC2:0:0:0:78CA:0:0:23AB could be abbreviated as:
    - FEC2::78CA:0:0:23AB or
    - FEC2:0:0:0:78CA::23AB
    - But not FEC2::78CA::23AB
- The 128-bit address contains two parts:
    - The prefix is the first 64 bits. The prefix includes the network and subnet address. Because addresses are allocated based on physical location, the prefix also includes global routing information. The 64-bit prefix is often referred to as the global routing prefix.
    - The interface ID is the last 64 bits. This is the unique address assigned to an interface.

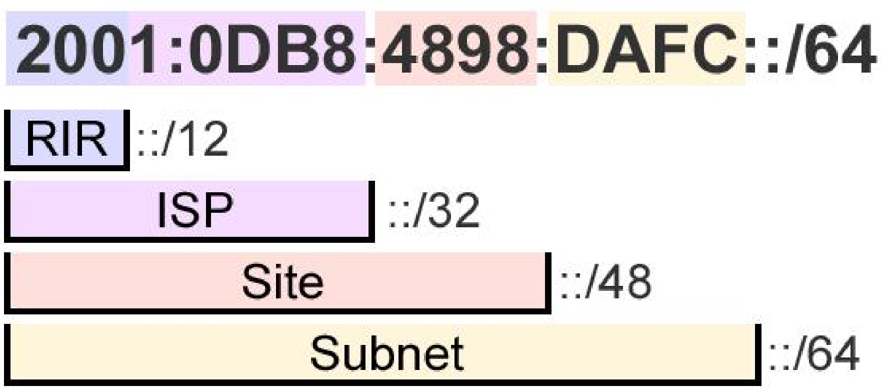
Addresses are assigned to interfaces (network connections), not to the host. Technically, the interface ID is not a host address.

The 64-bit prefix can be divided into various parts, with each part having a specific meaning as follows:

- The prefix length identifies the number of bits in the relevant portion of the prefix. To indicate the prefix length, add a slash (/) followed by the prefix length number.

- Bits past the end of the prefix length are all binary 0s. For example, the full 64-bit prefix for address 2001:7701:EC48:61B3:200C:FBBC:A007:8973 is 2001:7701:EC48:61B3:0000:0000:0000:0000/64.
- Full quartets with trailing 0s in the prefix address can be omitted (for example 2001:B1D1:523D:BF23::/64).
- If the prefix is not on a quartet boundary (this applies to any prefix that is not a multiple of 16), any hex values listed after the boundary should be written as 0s. For example, the prefix 2001:6B6F:8765:CA8E::/56 should be written as 2001:6B6F:8765:CA00::/56. Remember, only leading 0s within a quartet can be omitted.
- Be aware that the prefix length number is a decimal value, while the prefix itself is a hexadecimal value.

Global routing information is identified within the 64-bit prefix by subdividing the prefix using varying prefix lengths. The following graphic is an example of how the IPv6 prefix could be divided:



IPv6 Address Assignment

This assignment of IPv6 addresses is explained in the following table:

Prefix	Description
Regional Internet Registry (RIR)	**The Internet Corporation for Assigned Names and Numbers (ICANN) is responsible for the assignment of IPv6 addresses. ICANN assigns a range of IP addresses to Regional Internet Registry (RIR) organizations. Each current regional organization corresponds roughly to a continent.** **The exact size of the address range assigned to the RIR may vary, but current guidelines assign a minimum prefix of 12 bits. In the above example, the RIR has been assigned a 12-bit prefix and is responsible for addresses in the following range:** **2000::/12 to 200F:FFFF:FFFF:FFFF::/64**

Internet Service Provider (ISP)	**A regional organization subdivides its block of IP addresses into smaller blocks and assigns those blocks to National Internet Registries (NIRs), Local Internet Registries (LIRs), or Internet Service Providers (ISPs). Larger organizations can further subdivide the address space to allocate to smaller ISPs.** **The exact size of the address range assigned by the RIR may vary, but current guidelines assign a minimum prefix of 32 bits. In the above example, the ISP has been assigned a 32-bit prefix and is therefore responsible for addresses in the following range:** **2001:0DB8::/32 to 2001:0DB8:FFFF:FFFF::/64**
Site	**Individual companies and other organizations request blocks of IP addresses from an ISP for use in their private networks. Each network organized by a single entity is often called a *site*, although the exact definition of the term is under debate.** **Although the exact size of the address range assigned to a site may vary, by convention, each site is assigned a 48-bit site ID. In the above example, the site is responsible for managing the addresses in the following range:** **2001:0DB8:4898::/48 to 2001:0DB8:4898:FFFF::/64** **ISPs typically follow these guidelines for assigning address ranges to sites:** ● **By default, all sites that represent a network, including home networks, get an address with a 48-bit prefix.** ● **Sites that require an address space larger than this might be assigned two consecutive blocks or might be allocated an address with a 47-bit prefix.** ● **If the network is known to have only a single subnet, the ISP might assign a 64-bit prefix. This is typically used for mobile devices.** ● **If the network is known to have only a single device, such as a dialup connection, the ISP might assign a 128-bit prefix.**

Subnet ID	**Most networks receive an address range identified with a 48-bit prefix. The remaining 16 bits in the global routing prefix are then used by the local network administrator for creating subnets. In the example above, the site has received the prefix of 2001:0DB8:4898::/48. The following list shows some of the subnets (underlined) that could be created by the administrator using a 64-bit prefix:** **2001:0DB8:4898:<u>0001</u>::/64** **2001:0DB8:4898:<u>0002</u>::/64** **2001:0DB8:4898:<u>0003</u>::/64** **. . .** **2001:0DB8:4898:<u>FFFD</u>::/64** **2001:0DB8:4898:<u>FFFE</u>::/64** **2001:0DB8:4898:<u>FFFF</u>::/64**

IPv6 Address Type Facts

In IPv6, addresses are assigned to interfaces (network connections). All interfaces are required to have one address, and interfaces can have more than one address. IPv6 uses the following types of addresses:

Address Type	Description
Unicast	**Unicast addresses are assigned to a single interface for the purpose of allowing that one host to send and receive data. Packets sent to a unicast address are delivered to the interface identified by that address.**
Link-local	***Link-local* addresses (also known as *local link* addresses) are addresses that are valid on only the current subnet:** • **Link-local addresses have an FE80::/10 prefix. This includes any address beginning with FE8, FE9, FEA, or FEB.** • **All nodes must have at least one link-local address, although each interface can have multiple addresses.** • **Routers never forward packets destined for link-local addresses to other subnets.** • **Link-local addresses are used for automatic address configuration, neighbor discovery, or for subnets that have no routers.** **Do not use link-local IPv6 addressing on routed networks. Routers never forward packets destined for link-local addresses to other subnets.**

Unique local	*Unique local* addresses are private addresses used for communication within a site or between a limited number of sites. In other words, unique local addressing is commonly used for network communications that do not cross a public network. They are the equivalent of private addressing in IPv4. When using unique local addresses, remember that: • Unique local addresses have an FC00::/7 prefix. Currently, however, the 8th bit is always set to 1 to indicate that the address is local (and not global). Thus, addresses beginning with FC or FD are unique local addresses. • Following the prefix, the next 40 bits are used for the Global ID. The Global ID is generated randomly, creating a high probability of uniqueness on the entire internet. • Following the Global ID, the remaining 16 bits in the prefix are used for subnet information. • Unique local addresses are likely to be globally unique, but are not globally routable. Unique local addresses might be routed between sites by a local ISP. • Previous IPv6 specifications defined a site-local address that was not globally unique and had an FEC0::/10 prefix. The site-local address has been replaced with the unique local address. • Because unique local addresses are not registered with IANA, they cannot be used on a public network, such as the internet, without address translation. The process for designing a network addressing scheme when using unique local addresses is similar to that used for global unicast addresses. The key difference is how the prefix is defined. Because the address range is not registered, a global routing prefix does not have to be requested from an ISP. Instead, each organization defines the prefix to be used for their organization. However, there are several requirements that need to be observed when doing so. As with global unicast addressing, using this addressing scheme allows organizations to define a large number of IPv6 subnets (2^{16}). When using unique local addressing, separate IPv6 subnets should be identified for the following: • Network segments separated by routers • VLANs • Point-to-point WAN links, including both serial and Ethernet emulation links

Global unicast	*Global unicast* addresses are globally unique (unique throughout the entire internet) addresses that are assigned to individual interfaces. Global unicast addresses are any addresses that are not link-local, unique local, or multicast addresses. Originally, ISPs assigned global unicast addresses with a 2000::/3 prefix. This includes any address beginning with a 2 or a 3. However, this was later amended to require *all* IPv6 addresses that haven't been specifically reserved for other purposes to be defined as global unicast addresses. The global routing prefix assigned to an organization by an ISP is typically 48 bits long (/48). However, it could be as short as /32 or as long as /56, depending on the ISP. Using this addressing scheme allows organizations to define a large number (2^{16}) of IPv6 subnets. When designing an IPv6 network, separate IPv6 subnets should be defined for the following: ● Network segments separated by routers ● VLANs ● Point-to-point WAN links, including both serial and Ethernet emulation links All subnet IDs within the same organization must begin with the same global routing prefix and must also be uniquely identified using a different value in the subnet field.
Multicast	*Multicast* addresses represent a dynamic group of hosts. Packets sent to a multicast address are sent to all interfaces identified by that address. By using a different multicast address for different functions, only the devices that need to participate in the particular function will respond to the multicast; devices that have no need to participate in the function will ignore the multicast. Be familiar with the following facts about multicast addresses: ● All multicast addresses have an FF00::/8 prefix. ● Multicast addresses that are restricted to the local link have an FF02::/16 prefix. Packets starting with FF02 are not forwarded by routers. ● Multicast addresses with an FF01::/16 prefix are restricted to a single node. You should be familiar with the following well-known multicast addresses: ● FF02::1 is for all nodes on the local link. This is the equivalent of the IPv4 subnet broadcast address. FF01::1 is for all interfaces on a node.

	FF02::2 is for all routers on the local link. FF01::2 is for all routers on node-local. **FF02::1:2 is for all DHCP servers or DHCP relay agents on the local link. DHCP relay agents forward these packets to other subnets.**
Anycast	**The *anycast* address is a unicast address that is assigned to more than one interface, typically belonging to different hosts. An anycast packet is routed to the nearest interface having that address (based on routing protocol decisions). Remember the following facts about anycast addresses:** **An anycast address is the same as a unicast address. Assigning the same unicast address to more than one interface makes it an anycast address.** **You can have link-local, unique local, or global unicast anycast addresses.** **When you assign an anycast address to an interface, you must explicitly identify the address as an anycast address (to distinguish it from a unicast address).** **Anycast addresses can be used to locate the nearest server of a specific type, for example, the nearest DNS or network time server.**
Loopback	**The local loopback address for the local host is 0:0:0:0:0:0:0:1 (also identified as ::1 or ::1/128). The local loopback address is not assigned to an interface. It can be used to verify that the TCP/IP protocol stack has been properly installed on the host.**
Unspecified	**The unspecified address is 0:0:0:0:0:0:0:0 (also identifies as :: or ::/128). The unspecified address is used when there is no IPv6 address. It is typically used during system startup when the host has not yet configured its address. The unspecified address should not be assigned to an interface.**

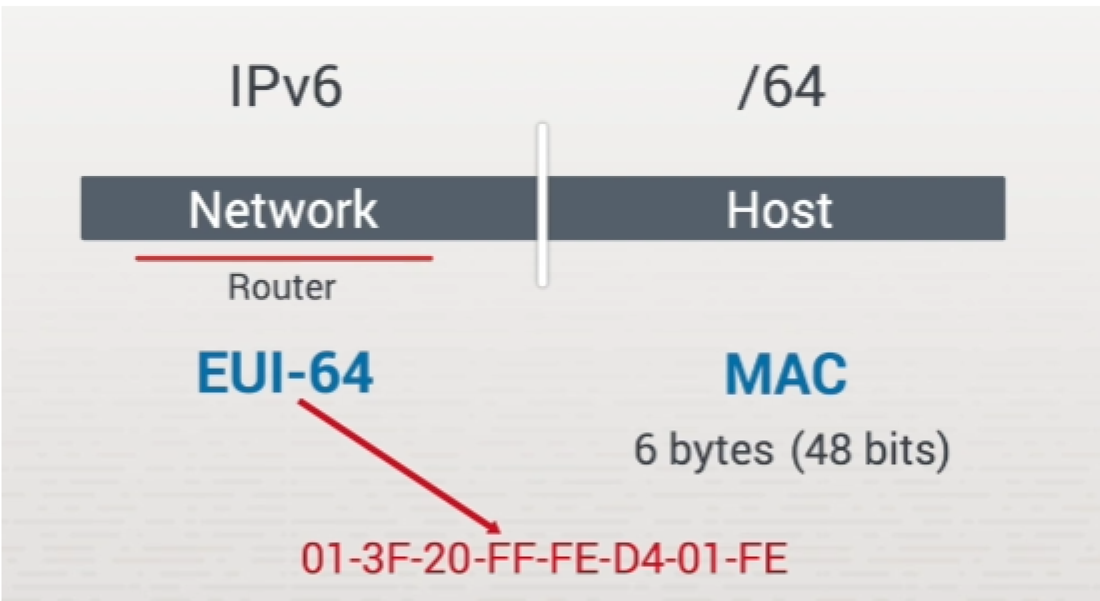
There are no broadcast addresses in IPv6. IPv6 multicast addresses are used instead of broadcast addresses.

EUI-64 and Auto-Configuration

- You can statically configure IP addresses.
- You can also use the Dynamic Host Configuration Protocol, or DHCP, to deliver IP address configs and additional options.
- Or use the EUI-64 mechanism which provides a way to give out unique addresses from your locally connected router.

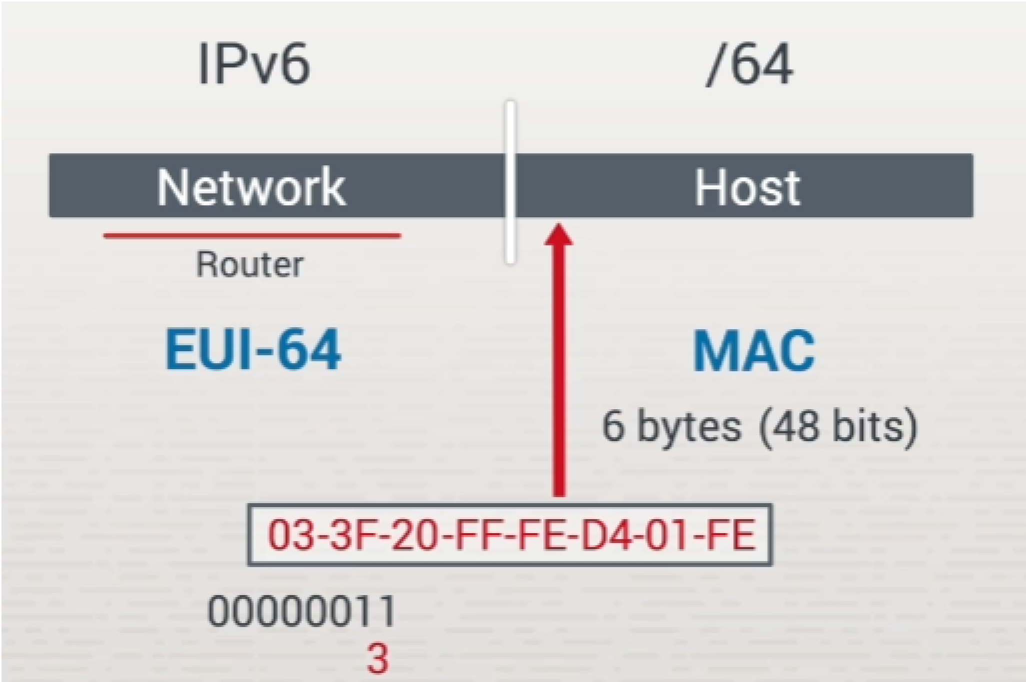
EUI-64 Mechanism

The 64-bit extended unique identifier, or 64-bit extended UID is used on IPv6 networks to auto-generate host addresses. IPv6 addresses are 16 bytes, or 128 bits, long. EUI-64 generates the host portion using the MAC address of the network node.



The last step in the EUI-64 process is it takes the seventh bit of the first byte—from left to right—and inverts it to 1. It's 01 in this case, which converts in binary to 00000001. The seventh bit flips to a 1, yielding 00000011. This equates to 3. The resulting EUI-64 address has a 03 in front.

The seventh bit for global unique addresses defaults to 0. So, for an address that we've generated locally, we have to flip that bit to a 1 to indicate so. This resulting 64-bit string becomes the host portion of the IP address. Now we have a unique 128-bit IPv6 address



EUI-64 Addressing Facts

In most cases, individual interface IDs are not assigned by ISPs; rather, they are generated automatically or managed by site administrators. Interface IDs must be unique within a subnet, but they can be the same if the interfaces are on different subnets. It is good practice to ensure that all IPv6 addresses are globally unique, even if the host resides on a private network. On Ethernet networks, this can be done using the EUI-64 format interface ID that can be automatically derived from each device's globally unique MAC address. This is done as follows:

- The MAC address is split into 24-bit halves.
- The hex constant FFFE is inserted between the two halves to complete the 64-bit address. For example, 20-0C-FB-BC-A0-07 becomes: 200C:FB**FF:FE**BC:A007.
- The seventh bit of the MAC address (reading from left to right) is set to binary 1. This bit is called the *universal/local (U/L)* bit:
    - Modifying the seventh binary bit modifies the second hex value in the address.
    - Using a MAC address of 20-0C-FB-BC-A0-07, the first two hex values translate to the following binary number:
      0010 0000
    - Setting the seventh bit to 1 yields 0010 0010, which translates into 22 hex.

In this example, the MAC address of 20-0C-FB-BC-A0-07 in modified EUI-64 format becomes:

2**2**0C:FB**FF:FE**BC:A007

(portions in red indicate modified values)

Configure IPv6 - Demo

To configure IPv6 addresses, go to interface mode g0/0 from global config.

```
Router>en
Router#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface g0/0
Router(config-if)#ipv6 address 2001::10/64
Router(config-if)#
```

using shorter version of IPv6 for demo purpose

IPv4 routing is on by default, IPv6 routing has to be turned on. This is done with the ipv6 unicast-routing command. This command, combined with either static or dynamic routing, allows the router to perform as expected.

```
Router>en
Router#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface g0/0
Router(config-if)#ipv6 address 2001::10/64
Router(config-if)#exit
Router(config)#ipv6 unicast-routing
Router(config)#
```

From global config, we'll type ‘ipv6 unicast-routing', and now our routing is turned on.

IPv6 Configuration Facts

IPv6 Configuration Methods

An IPv6 address can be configured using any of the following methods:

<table>
<tr><th>Method</th><th>Description</th></tr>
<tr><td>Static full assignment</td><td>The entire 128-bit IPv6 address and all other configuration information is statically assigned to the host.</td></tr>
<tr><td>Static partial assignment</td><td>The prefix is statically assigned and the interface ID uses the modified EUI-64 format derived from the MAC address.</td></tr>
<tr><td>Stateless autoconfiguration</td><td>Clients automatically generate the interface ID and learn the subnet prefix and default gateway through the Neighbor Discovery Protocol (NDP). NDP uses the following messages for autoconfiguration:
Router solicitation (RS) is a message sent by the client to request that routers respond.
Router advertisement (RA) is a message sent by the router periodically and in response to RS messages to inform clients of the IPv6 subnet prefix and the default gateway address.
NDP is also used by hosts to discover the address of other interfaces on the network, replacing the need for Address Resolution Protocol (ARP).

Even though NDP provides enough information for the addressing of the client and for clients to learn the addresses of other clients on the network, it does not provide the client with DNS server information or other IP configuration information. It provides only the IP address and the default gateway.</td></tr>
<tr><td>DHCPv6</td><td>IPv6 uses an updated version of DHCP (called DHCPv6) that operates in one of two different modes:
Stateful DHCPv6 uses the DHCP server to provide each client with the IP address, default gateway, and other IP configuration information, such as the DNS server IP address. The DHCP server tracks the status, or state, of the client.
Stateless DHCPv6 does not provide the client an IP address and does not track the status of each client but is instead used to supply the client with the DNS server IP</td></tr>
</table>

		address. Stateless DHCPv6 is most useful when used in conjunction with stateless autoconfiguration.

IPv6 Configuration Process

When a host starts up, it uses the following process to configure the IPv6 address for each interface:

1. The host generates an IPv6 address using the link-local prefix (FE80::/10) and modifies the MAC address to get the interface ID. For example, if the MAC address is 20-0C-FB-BC-A0-07, the link-local address for the interface would be: FE80::220C:FBFF:FEBC:A007.
2. The host then sends a neighbor solicitation (NS) message addressed to its own link-local address to see if the address it has chosen is already in use:
    - If the address is in use, the other network host responds with a neighbor advertisement (NA) message. The process stops and manual configuration of the host is required.
    - If the address is not in use (no NA message), the process continues.
3. The host waits for a router advertisement (RA) message from a router to learn the prefix:
    - If an RA message is not received, the host sends out a router solicitation (RS) message addressed to all routers on the subnet using the multicast address FF02::2.
    - The router sends out an RA message addressed to all interfaces on the subnet using the multicast address FF02::1.
    - If no routers respond, the host attempts to use stateful DHCPv6 to receive configuration information.
4. The RA message contains information that identifies how the IPv6 address and other information is to be configured. Possible combinations are:

Configuration Method	Description
Use stateful autoconfiguration	Obtain the interface ID, subnet prefix, default gateway, and other configuration information from a DHCPv6 server. The host sends out a REQUEST message addressed to the multicast address FF02::1:2 to request this information from the DHCPv6 server.
Use stateless autoconfiguration	Set the interface ID automatically. Get the subnet prefix and default gateway from the RA message. Get DNS and other configuration information from a DHCPv6 server. The host sends out an information-request message addressed to the multicast address

	FF02::1:2 to request this information from the DHCPv6 server.

5. If a manual address or stateful autoconfiguration is used, the host sends an NS message to make sure the address is not already in use. If stateless autoconfiguration is used, the NS message at this step is unnecessary because the interface ID has already been verified in step 2.

IPv6 Configuration Commands

The following table lists the commands used in configuring IPv6 addresses:

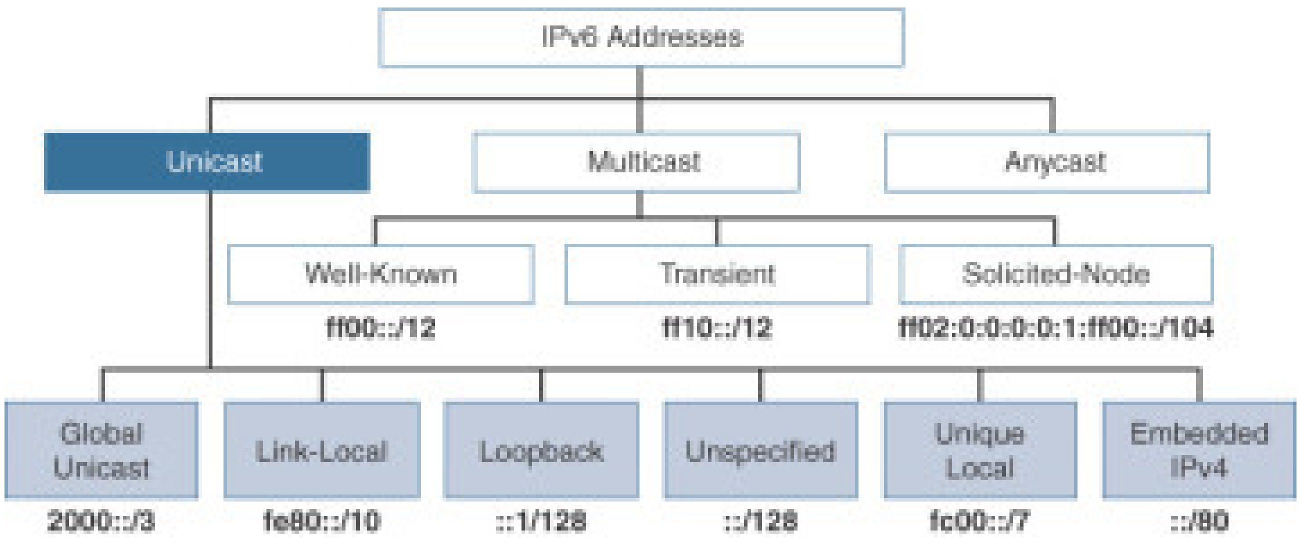
Command	Action
ipv6 address *[ipv6-prefix/prefix-length]* eui-64	Configures a global IPv6 address with an interface identifier (ID) in the low-order 64 bits of the IPv6 address: • Only the 64-bit network prefix for the address needs to be specified. • The last 64 bits are automatically computed from the interface ID. • This command automatically configures an IPv6 link-local address on the interface while also enabling the interface for IPv6 processing.
show ipv6 interface *[type] [number]*	Verifies that IPv6 addresses are configured correctly for the specified interface and validates the IPv6 status: • If the interface hardware is usable, the interface is marked up. • If the interface can provide two-way communication for IPv6, the line protocol is marked up.
show ipv6 interface brief	Displays a brief summary of IPv6 status and configuration for each interface.

The following example configures the Fa 0/0 interface for Global Unicast IPv6 processing and statically assigns an interface ID of ::20 on subnet 1:

Router(config)#**int fa 0/0**
Router(config-if)#**ipv6 address 2001:BEF:BAD:1::20/64**

The following example configures the Fa 0/0 interface for Unique Local Unicast IPv6 processing and statically assigns an interface ID of ::20 on subnet 1:

```
Router(config)#int fa 0/0
Router(config-if)#ipv6 address FD01:1:1:1::20/64
```



Based on previous standards, global unicast addresses start with 20, but can now include any prefix that is not reserved. Addresses beginning with FC or FD are unique local addresses. Addresses beginning with FE8, FE9, FEA, or FEB are link-local addresses. Addresses beginning with FF are multicast addresses. There are no broadcast addresses in IPv6.

Global Unicast IPv6 Address