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07/23/2025

IPv6 Notes

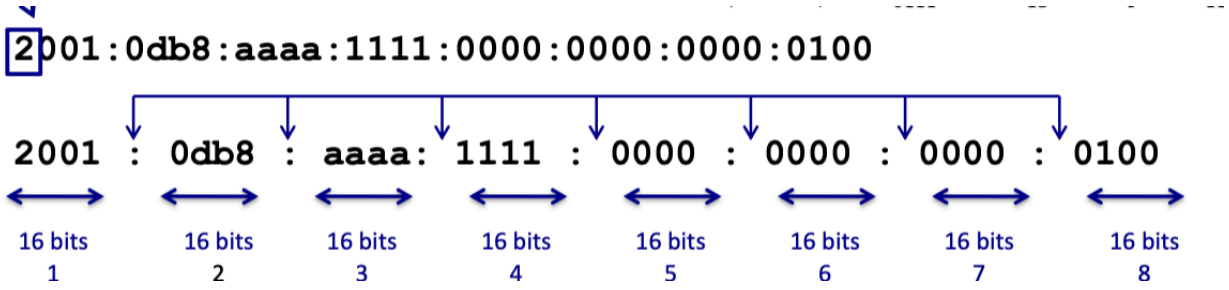
IPv6 Address Representation and Types (Lecture 2)

Decimal vs Hex:

- 4 bits = 1 hex digit

Dec:	Hex	Binary 8421	Dec	Hex	Binary 8421
0	0	0000	8	8	1000
1	1	0001	9	9	1001
2	2	0010	10	a	1010
3	3	0011	11	b	1011
4	4	0100	12	c	1100
5	5	0101	13	d	1101
6	6	0110	14	e	1110
7	7	0111	15	f	1111

IPv6 Address Notation



Ipv6 addresses are 128-hex bit addresses represented in:

- Hexadecimal: 1 hex digit = 4 bits
- Eight 16-bit segments or “hextets” (not a formal term) between 0000 & FFFF
- Separated by colons
- Every four hexadecimal digits are equivalent to 16 bits (4 bits for each hexadecimal)

128-bit address: How many is That

2^128 = 340,282,366,920,938,463,463,374,607,431,768,211,456 Ip addresses

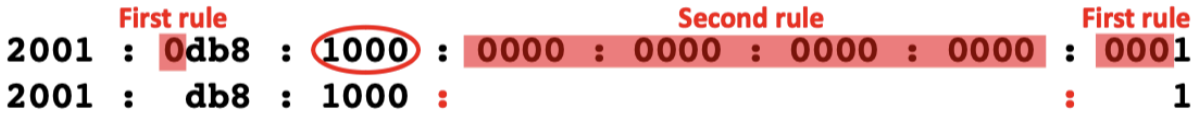
Two Rules for Compressing IPv6 Addresses

- Two rules for reducing the size of written IPv6 addresses
- **First rule**: Leading zeros in any 16-bit segment don't have to be written

```
2001 : 0db8 : 0001 : 1000 : 0000 : 0000 : 0ef0 : bc00
2001 :  db8 :    1 : 1000 :    0 :    0 :  ef0 : bc00

2001 : 0db8 : 010d : 000a : 00dd : c000 : e000 : 0001
2001 :  db8 :  10d :    a :   dd : c000 : e000 :    1

2001 : 0db8 : 0000 : 0000 : 0000 : 0000 : 0000 : 0500
2001 :  db8 :    0 :    0 :    0 :    0 :    0 :  500
```

Rule 2: Double Colon ::

- The second rule can reduce this address even further
- Second rule: Any single, contiguous string of one or more 16-bit segments consisting of all zeroes can be represented with a double colon (::)



2001:db8:1000::1

Can only do it once:

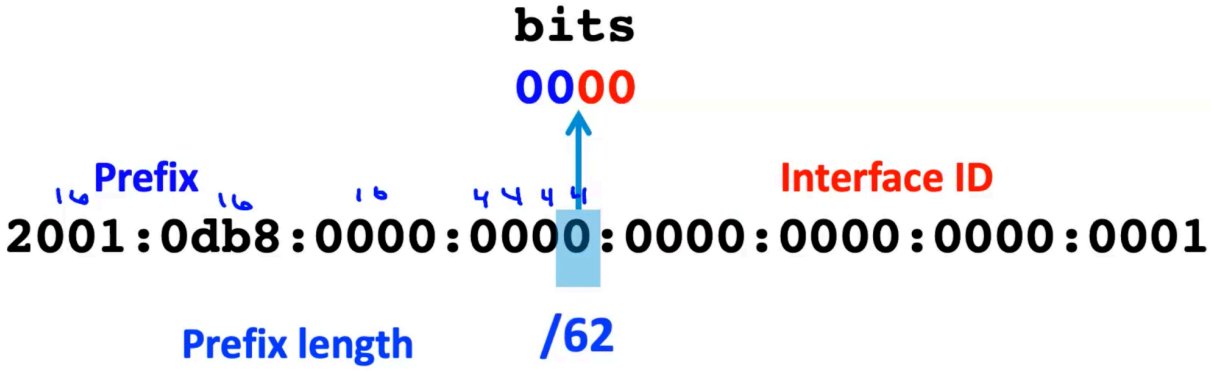
IPv4: Subnet MAsk and Prefix Length

- IPv4, the prefix, the network portion of the address, can be identified by:
- Dotted decimal subnet mask
- The number of bits in the prefix or network portion of the address

Terminalogy

- Prefix equivalent to the network address of an IPv4 address
- Prefix length equivalent to subnet mask in IPv4
- Interface ID equivalent to host portion of an IPv4

IPv6 Prefix Length



- IPv6 prefixes are always identified by prefix length
    - Written immediately following the IPv6 address, usually no space

- The prefix length doesn't have to fall on a nibble (4-bit) boundary
- What about a /62
- Prefix lengths can fall within a nibble - but with such a large address space this is usually not required or recommended

Prefixes (network/subnet address):

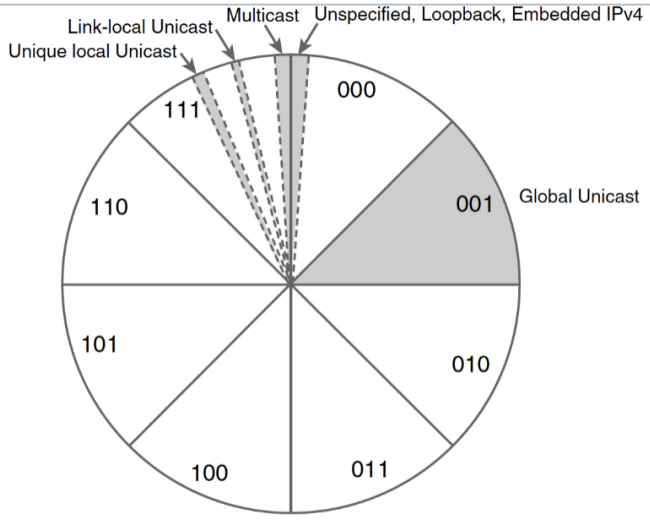
```
2001:db8::/32
2001:db8:1::/48
2001:db8:cafe::/48
2001:db8:cafe:1::/64
2001:db8:cafe:1234::/64
```

Just count hextets!

- /32 = 2 hextets
- /48 = 3 hextets
- **/64 = 4 hextets (most subnets including user subnets, LANs)**

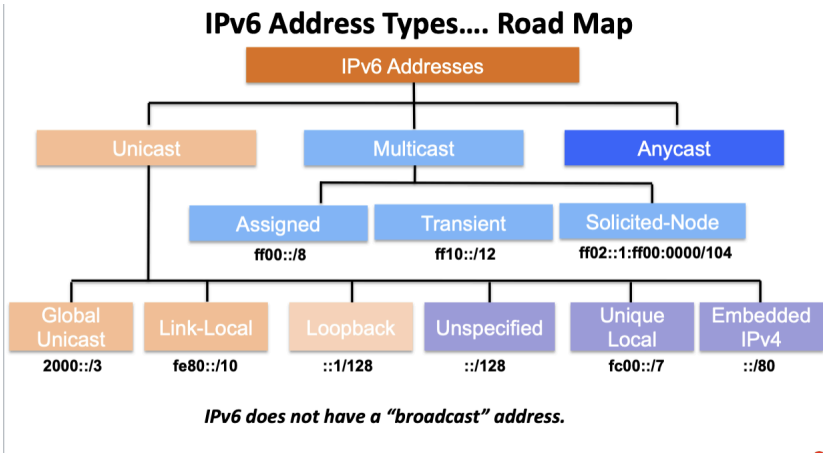
IPv6 devices (hosts, etc.):

```
2001:db8:cafe::1/48
2001:db8:cafe::99:2/48
2001:db8:cafe:1::100/64
2001:db8:cafe:1:aaaa:bbbb:cccc:dddd/64
```



The remaining portions of IPv6 address space are reserved by IETF for future use.

Figure 4-5 *IANA's Allocation of IPv6 Address Space in 1/8 Sections*



IPv6 does not have a "broadcast" address.

Unicast Address

```
Windows-OS> ipconfig

Ethernet adapter Local Area Connection:
   Connection-specific DNS Suffix  . :
   IPv6 Address. . . . . . . . . . . : 2001:db8:cafe:1:d0f8:9ff6:4201:7086
   Link-local IPv6 Address . . . . . : fe80::d0f8:9ff6:4201:7086%11
   IPv4 Address. . . . . . . . . . . : 192.168.1.100
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . : fe80::1%11
                                       192.168.1.1
-------------------------------------------------------------------------
Mac-OS$ ifconfig

en1: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
     ether 60:33:4b:15:24:6f
     inet6 fe80::6233:4bff:fe15:246f%en1 prefixlen 64 scopeid 0x5
     inet 192.168.1.111 netmask 0xffffff00 broadcast 192.168.1.255
     inet6 2001:db8:cafe:1:4bff:fe15:246f prefixlen 64 autoconf
```

Global Unicast Address (GUA) - More in Chapter 5

- 2000::/3 (range 2000::/64 thru 3fff:fff:fff:fff::/64
- Globally unique, globally routable, similar to public IPv4 addresses
- 2001:db8::/32 - RFC 2839 reserves this range of addresses of documents
- These are the addresses w e'll be referring to the most

Link-Local Address

- **fe80::/10** (First Hextet:fe80::/10 to febf::/10, but use fe80)
- Not routable off the link (Link = network or subnet)
- Unique only on the link
- **An IPv6 device must have at least a link-local address**
- Used by:
    - Hosts to communicate ot the IPv6 network before it has a GUA
    - Router's link-local address is used by hosts as the default gateway address
    - Adj routers to exchange routing updates
    - Next-hop addresses in IPv6 routing tables

Loopback Address

- ::1/128
- Same functionality as IPv4 loopback 127.0.0.1
- Not routable

Unspecified Address

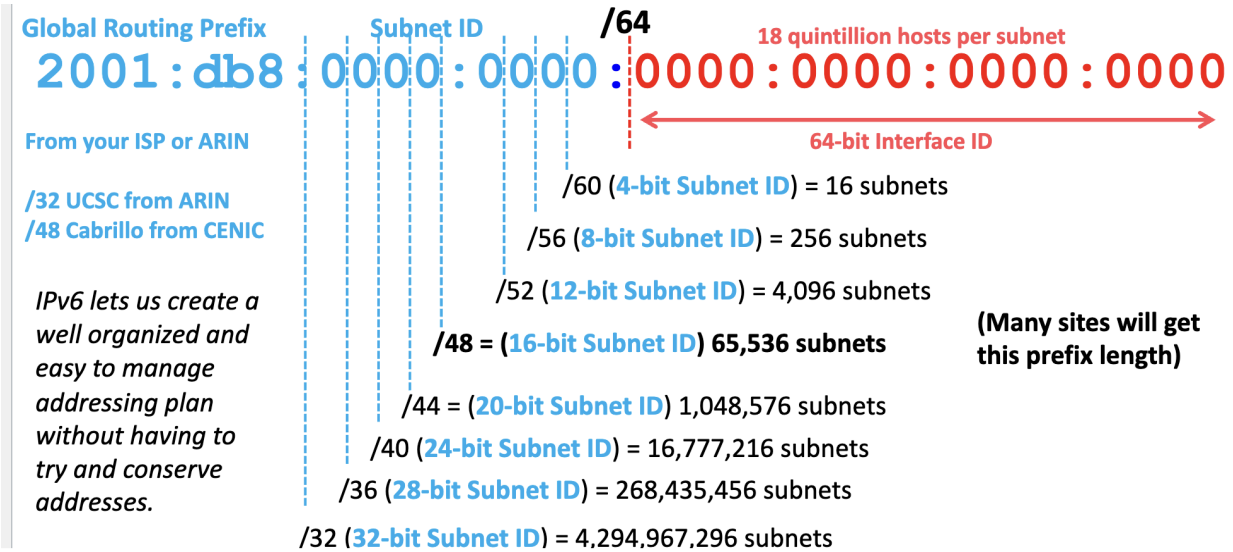
- ::(all-0s)
- Indicated the absence or anonymity of an IPv6 address (RS src address)
- Used a a src IPv6 address during duplicate address detection process

Unique Local Address

- fc00::/7 (First hextet:)
- Similar to RFC 1918 IPv4 addresses (which are the private IPv4 addresses ranges)

- Not meant to be translated to a global unicast (for security purposes)
- Shouldn't be routable in the global internet
- To be used in a more limited area such as within a site or devices inaccessible from the global internet

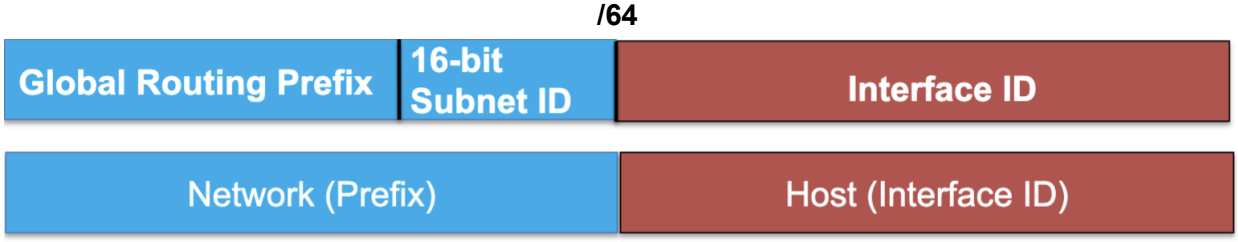
IPv6 Global Unicast Address (GUA) (Lecture 3)



Review

- Most content can be accessible natively using IPv6 without NAT to companies that have migrated to IPv6 already like facebook, Amazon Netflix
    - Others like Twitter still require you to use an IPv4 address since they have not gone to IPv6 yet

CABRILLO COLLEGE GOT A /48 (Global Routing Previx) from ISP CENIC



- The bold hexadecimals (a total of 48 bits) is how the internet sees Cabrillo (really Ceinic but Ceinic our isp sends it to cabrillo)

2607:f380:80f:0000:hhhh:hhhh:hhhh:hhhh

2607:f380:80f:0001:hhhh:hhhh:hhhh:hhhh
2607:f380:80f:0002:hhhh:hhhh:hhhh:hhhh
2607:f380:80f:0003:hhhh:hhhh:hhhh:hhhh
2607:f380:80f:0004:hhhh:hhhh:hhhh:hhhh
…
2607:f380:80f:fffe:hhhh:hhhh:hhhh:hhhh
2607:f380:80f:ffff:hhhh:hhhh:hhhh:hhhh

A Total of 65,536 subnets and 18 quintillion devices per subnet

Enterprises	Global Routing Prefix	Subnet ID	Interface ID (host portion)
Cabrillo College	2607:f380:80f	:f828	:hhhh:hhhh:hhhh:hhh
	/48	65,538 subnets	18 quintillion devices per subnet
UCSC	2607:f5f0	:ssss:ssss	:hhhh:hhhh:hhhh:hhh
	/32	4.29 billion subnets	18 quintillion devices per subnet
Google	2607:f8b0	:4005:801	::2004
	/32	4.29 billion subnets	18 quintillion devices per subnet
Facebook	2a03:2880:	f131:83	:face:b00c:0:25de
	/32	4.29 billion subnets	18 quintillion devices per subnet
Rick	2601:642:c300:6de0	N/A	:1417:983c:3b75:a4c7
	/64	1 network	18 quintillion devices per subnet

Subnet Masks do not always fall on a natural octet boundary

```
Network address:
10.1.192.0      00001010.00000001.11000000.00000000
255.255.240.0   11111111.11111111.11110000.00000000

Range of hosts:
10.1.192.1      00001010.00000001.11000000.00000001
10.1.207.254    00001010.00000001.11001111.11111110

Broadcast address
10.1.207.255    00001010.00000001.11001111.11111111
```

- Third octet contains both a network portion and a host portion

Subnetting IPv6

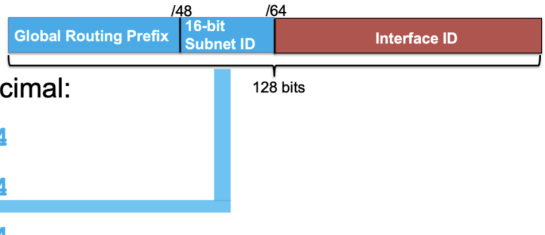
Subnetting IPv6 is much easier especially if you have a slash, 48, just do the 3, 1, 4 rule.

- The first 3 hextats is the global routing prefix
- The fourth is the subnet ID
- The last 4 is the interface ID

Can you count in hex?

Just increment by 1 in Hexadecimal:

```
2001:db8:cafe:0000::/64
2001:db8:cafe:0001::/64
2001:db8:cafe:0002::/64 ...
2001:db8:cafe:0009::/64
2001:db8 cafe:000a::/64
```



Valid abbreviation is to remove the leading 0s:

```
2001:db8:cafe:1::/64
```

Extending the Subnet ID

Note:

- It's highly recommended to NOT subnet into the /64 interface ID portion of the address to configure subnets
- The only exception would be for network infrastructure
- Networks with an end system attached should be a /64

2001 : db8 : cafe : ffff : 0000 : 0000 : 0000 : 0000
2001 : db8 : cafe : ffff : 0000 : 0000 : 0000 : 0000

Subnetting on a Nibble Boundary

- Subnetting on a nibble (4bit) boundary makes it easier to list the subnets

2001 : db8 : cafe : 0000 : 0000::/68
2001 : db8 : cafe : 0000 : 1000::/68
2001 : db8 : cafe : 0000 : 2000::/68
2001 : db8 : cafe : 0000 : 3000::/68
…. Through
2001 : db8 : cafe : ffff : f000::/68

	Binary	Four bits:
2001 : db8 : cafe : 0000 : 0000::/70	0000	*Two left most bits:
2001 : db8 : cafe : 0000 : 0400::/70	0100	Subnet-ID
2001 : db8 : cafe : 0000 : 0800::/70	1000	*Two right most bits:
2001 : db8 : cafe : 0000 : 0c00::/70	1100	Associated with the interface ID

Cool Pearl Script

ipv6gen.pl <base_prefix>/<base_length> <new_prefix_length>

- <base_prefix>/<base_length>: The starting IPv6 network (e.g., /48)
- <new_prefix_length>: The desired subnet size (e.g., /64)

Example:

```
ipv6gen.pl 2001:db8:cafe::/48 64
```

Output:

```
2001:0DB8:CAFE:0000::/64
2001:0DB8:CAFE:0001::/64
2001:0DB8:CAFE:0002::/64
```

...
2001:0DB8:CAFE:FFFC::/64
2001:0DB8:CAFE:FFFD::/64

More examples of valid IPv6 address

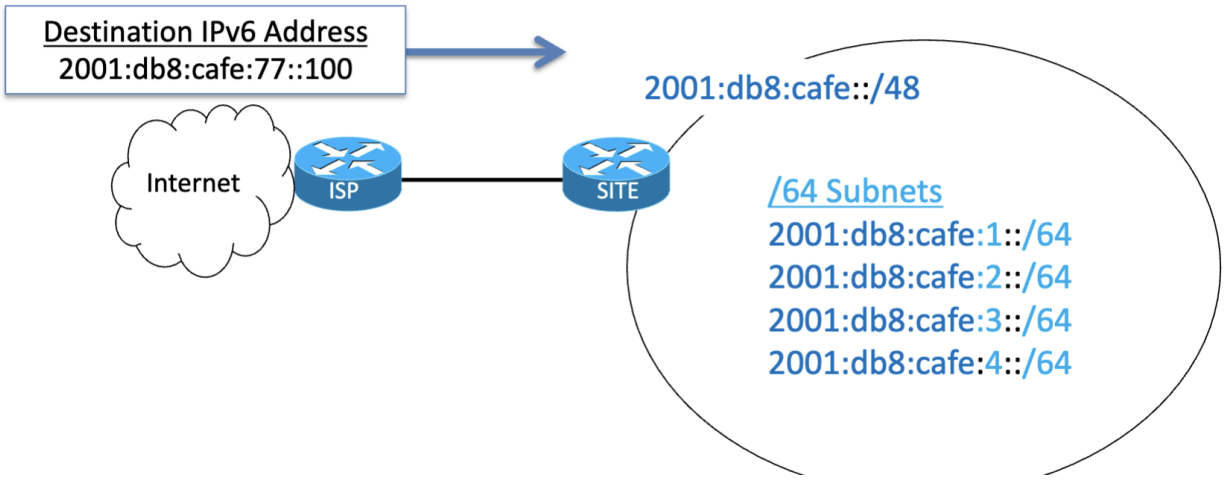
/48 Global Unicast Address	Global Routing Prefix	Subnet ID	Interface ID

\

2001:0db8:cafe:0001:0000:0000:0000:0001	2001:db8:cafe	0001	0000:0000:0000:0001
2001:0db8:cafe:0004:0000:0000:0000:0400	2001:db8:cafe	0004	0000:0000:0000:0400
2001:0db8:1234:0001:0000:0000:0000:0100	2001:db8:1234	0001	0000:0000:0000:0100
2001:db8:aaaa:9:0:0:0:a	2001:db8:aaaa	0009	0000:0000:0000:000a
2001:db8:aaaa:1::0200	2001:db8:aaaa	0001	0000:0000:0000:0200
2001:db8:aaaa::200	2001:db8:aaaa	0000	0000:0000:0000:0200
2001:db8::abc:0	2001:db8:0000	0000	0000:0000:0abc:0000
2001:db8:abc:1::	2001:db8:abc	0001	0000:0000:0000:0000
2001:db8:deed:450:0123:4567:89ab:cdef	2001:db8:deed	0450	0123:4567:89ab:cdef
2001:db8:deed:5:ffff:ffff:ffff:ffff	2001:db8:deed	0005	ffff:ffff:ffff:ffff

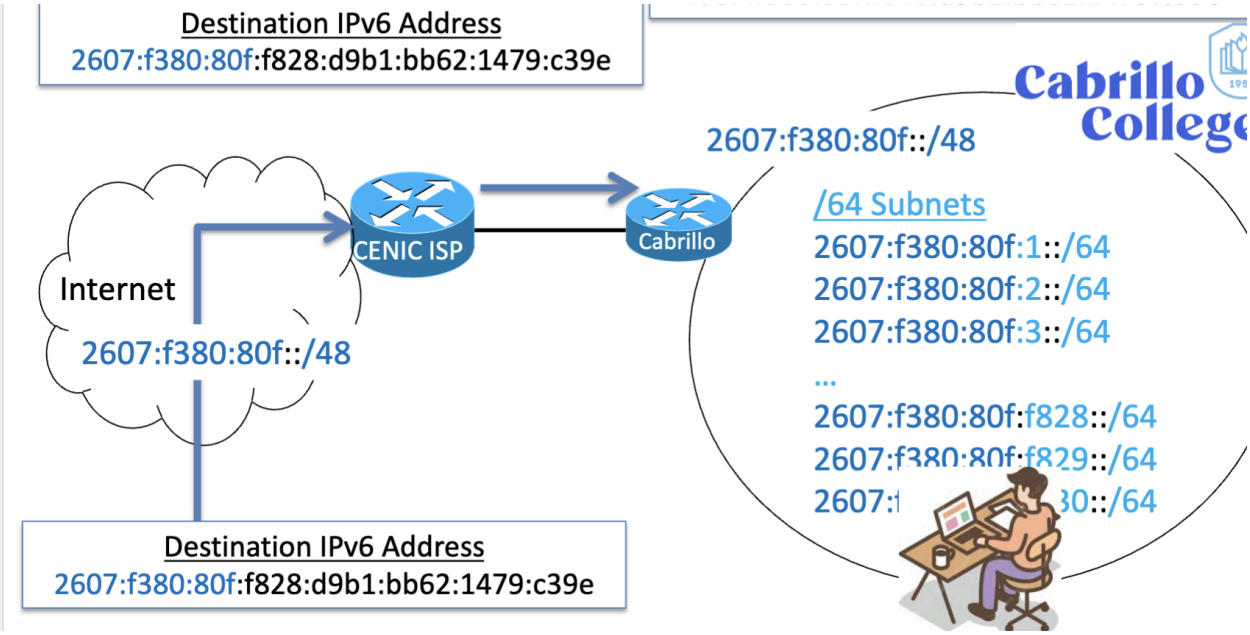
- Even subnet 0000 is correct as shown

General Example Image of how the Internet Sees us



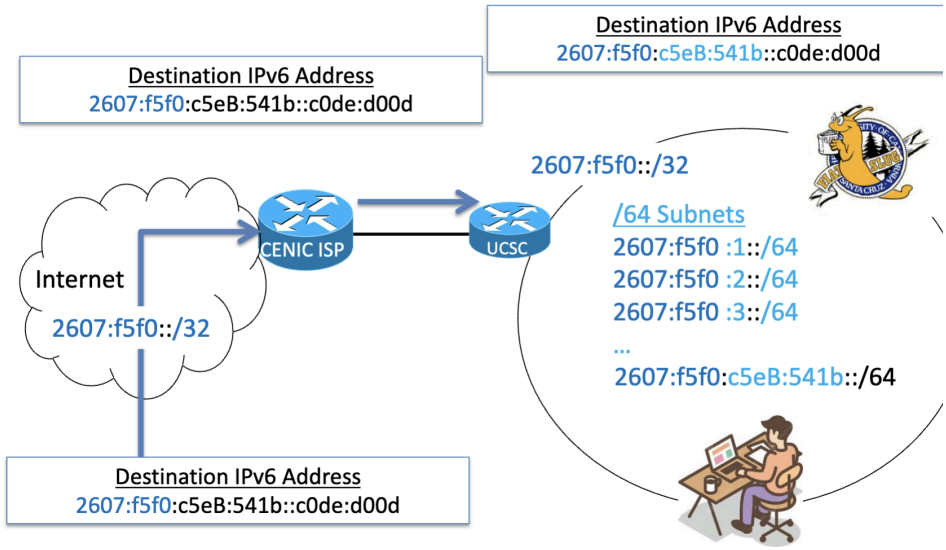
- The world sees us at this (or at least our ISP)
    - Anything belonging to goes here
- Once it reaches the site, there are subnets

Cabrillo Example Image

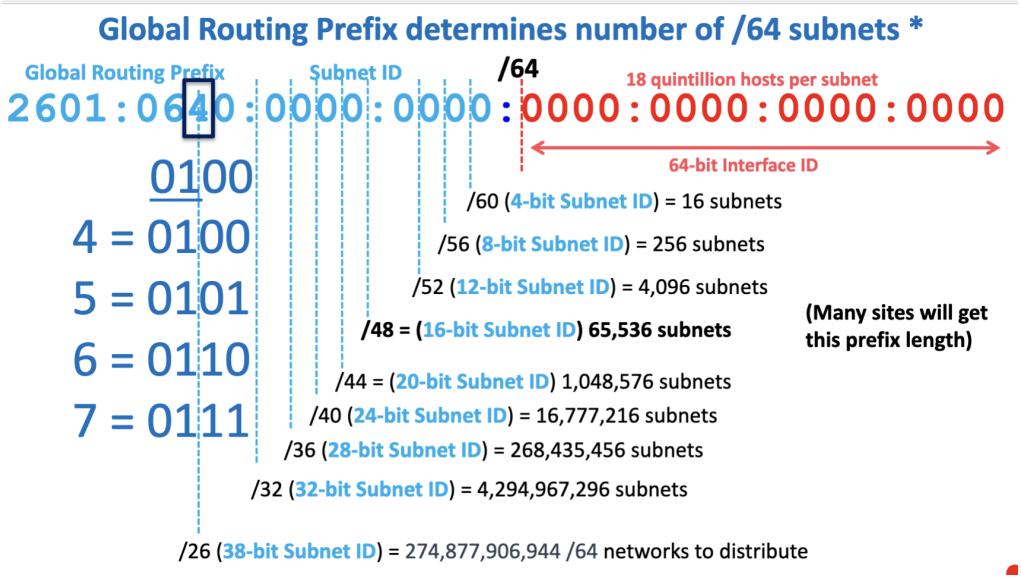


- Better Image using Cabrillo
- The internet sees us as 2607:f380:90f

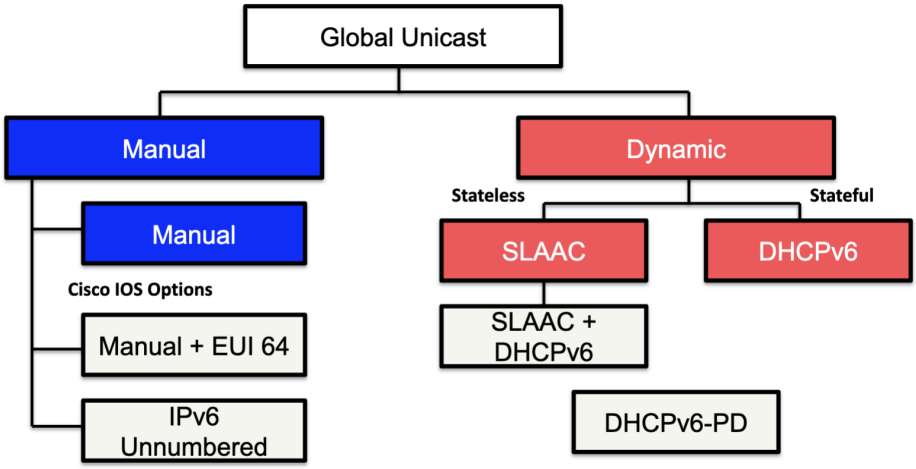
UCSC Example



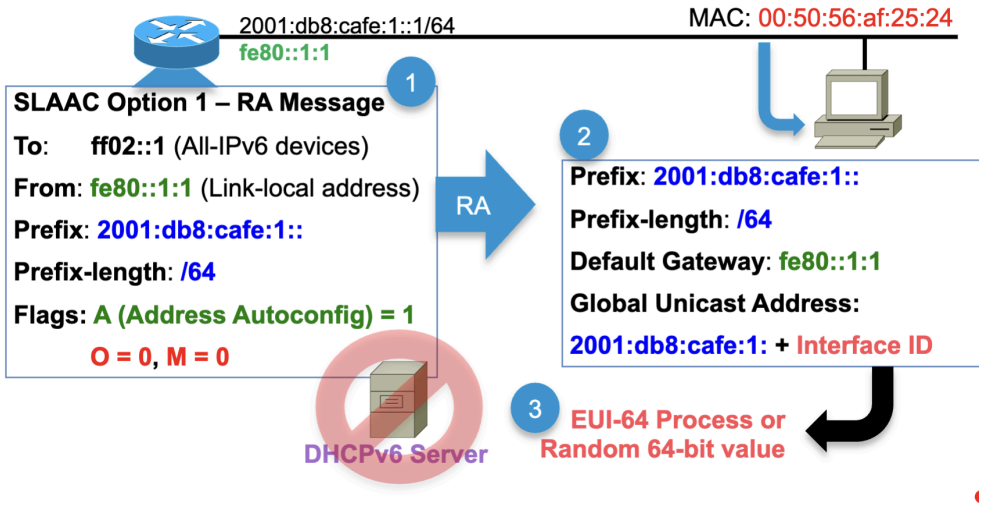
Comcast Example using a nibble on their IPv4 address



Options for configuration a GUA Address

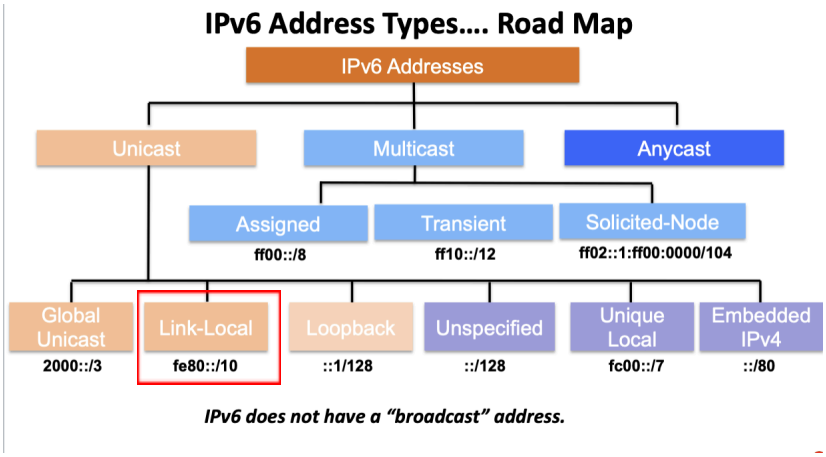


Quick Intro to SLAAC: Stateless Address Autoconfiguration



- In IPv6 networks, a device can connect to the internet by **automatically assigning itself an IP address** using **SLAAC (Stateless Address Autoconfiguration)**.
- This means that a **DHCP server is not required** to assign IP addresses, unlike in IPv4.
- As long as the device receives the **prefix** from the router (via Router Advertisement), it can generate a valid **globally routable address**.
- However, a **DHCPv6 server** may still be used in some networks to provide additional configuration (e.g., DNS).

Link-Local-Unicast (Lecture 4)



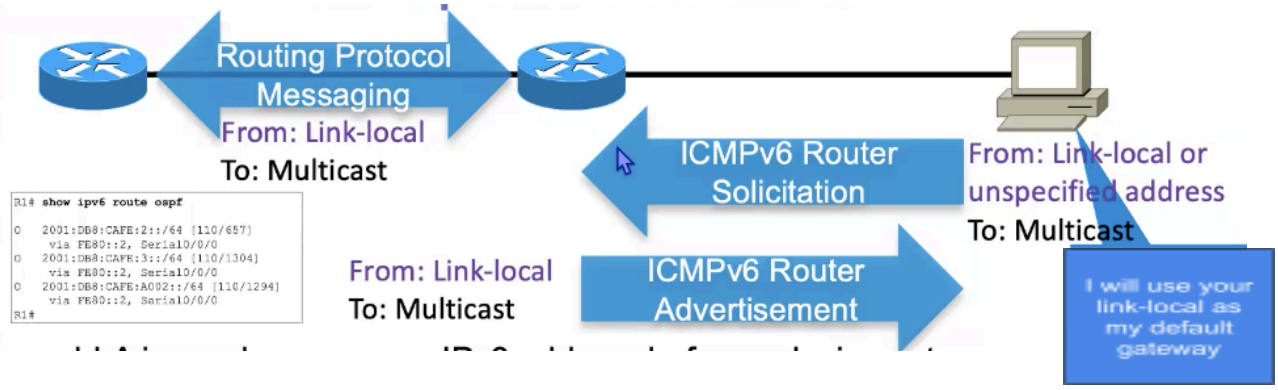
- Your device will always have a Link-Local Unicast Address

- **IPv6 Source** - Always a unicast
- **IPv6 Destination** - Unicast, multicast or anycast
- Unicast, including a **Link-local** address
- No such thing as broadcast in IPv6

Link-Local Unicast Address

- Used to communicate with other devices on the link
- Are **NOT** routable off the link (network)
    - The router should drop the packet, if the destination is for another network but the src address is a link local address
- **Only have to be unique on the link**
- Not included in the IPv6 routing table
- ONly one link-local address per interface
- RFC 4291 IPv6 Architecture: “Routers must not forward any packets with Link-Local source or destination address to other links”
- An “IPv6 device device” must have at least a link-local address
- Link local addresses are never in the routing table as they can be in any interface

An Important Role in IPv6



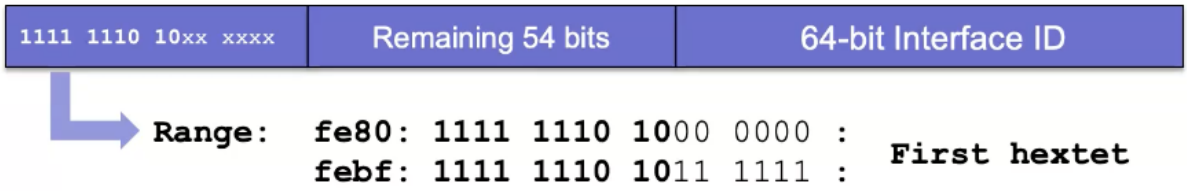
- LLA is used as a source IPv6 address before a device gets one dynamically (SLAAC and DHCPv6)
    - Router’s link-local address is used by devices as the default gateway
- Routers exchange routing messages

- Router use the link-local address as the next-hop address in the routing table: **via link-local address**

```
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        options=6460<TSO4,TSO6,CHANNEL_IO,PARTIAL_CSUM,ZEROINVERT_CSUM>
        ether 3c:06:30:44:56:fe
        inet6 fe80::1876:7c4e:ff9:7c6a%en0 prefixlen 64 secured scopeid 0xc
        inet6 2603:8001:c401:319f:18fd:3483:3aba:da90 prefixlen 64 autoconf secured
        inet6 2603:8001:c401:319f:9d21:897e:5d5d:a046 prefixlen 64 autoconf temporary
        inet6 fd00:a497:33a8:348e:885:c164:957f:94c6 prefixlen 64 autoconf secured
        inet6 2603:8001:c401:319f::1bc3 prefixlen 64 dynamic
        inet 192.168.1.25 netmask 0xffffff00 broadcast 192.168.1.255
        nd6 options=201<PERFORMNUD,DAD>
        media: autoselect
        status: active
```

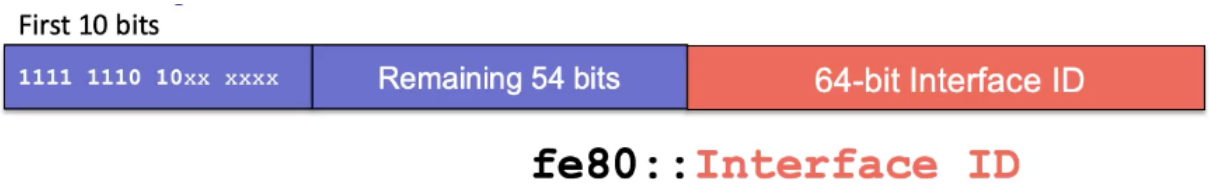
Looking the Bits

First 10 bits



- **Link** - Network segment (or subnet)
- **Link-Local** means, local to that **link** or network
- RFC 4291 doesn't give specific guidance on the remaining 54 bits,
- But **best practice** is to leave them all **0's**
- Also, **best practice** is to use **f80** (as OS's have had issues)
- Note febf is possible but highly unlikely

Dynamic Link-Local Unicast Address



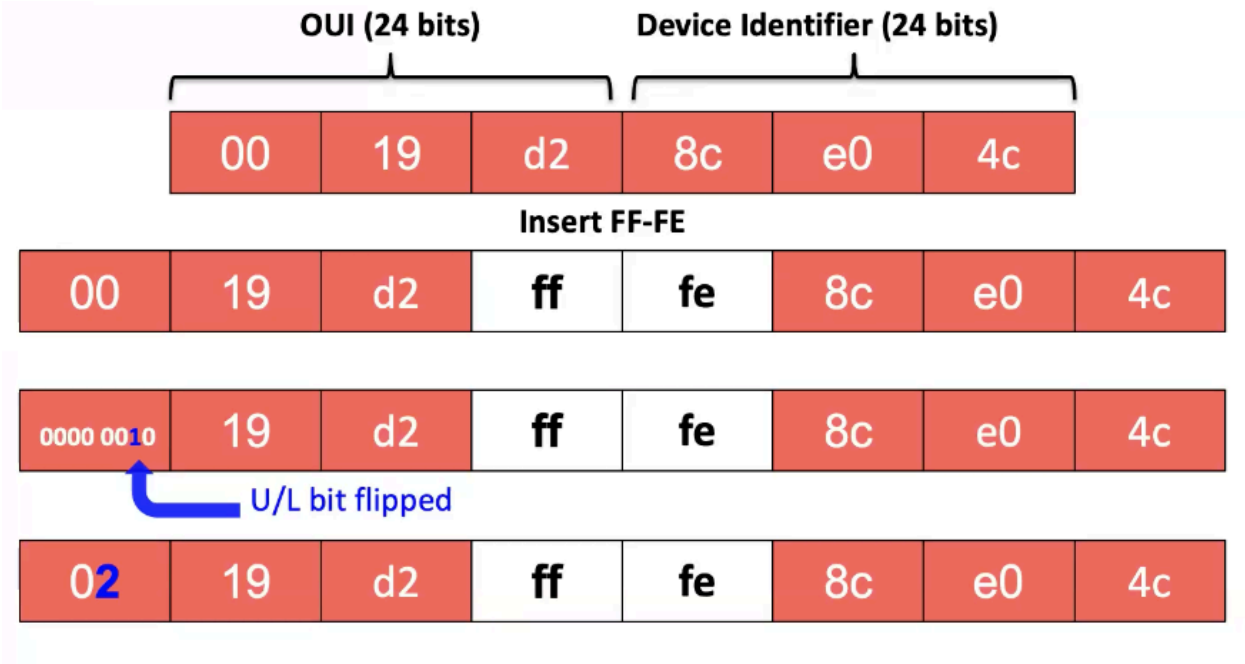
Link-local addresses are created

- **Automatically:**
  - **fe80** (usually) - First 10 bits
  - Interface ID
    - EUI-64
    - Random 64 bits (many host operating systems)
  - Static (manual) configuration - Common practice for Routers

```
WinPC> ipconfig /all
Windows IP Configuration
<output omitted for brevity>

Ethernet adapter Local Area Connection:
   Connection-specific DNS Suffix  . :
   Description: Intel<R> PRO/1000 MT Network Connection
   Physical Address: 00-50-56-AF-97-68
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled:. . . . : Yes
   IPv6 Address. . . . . . . . . . . : 2001:db8:cafe:1::100
   Link-local IPv6 Address . . . . . : fe80::d0f8:9ff6:4201:7086%11
```

- Many operating systems will use a random 64-bit interface IDs for GUA and Link-Local IPv6
- Why not use 48 bits?
    - Cpus with a (32 bit cpu or 64 cpu) can process 32 bits or 64 bits better when in that boundary

Modified EUI-64 format (Extended Unique Identifier-64)



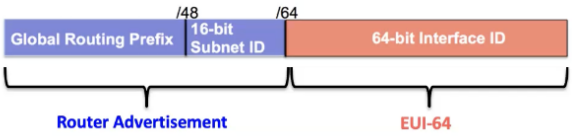
- When using EUI-64, that bit is flipped becoming the hex 02
    - The 7th bit of the first hextical is known as the U/L bit flipped
- With EUI-64 you can use your mac address to create a global unicast interface ID and a link-local interface ID

Verifying SLAAC on the PC using EUI-64

```
PC> ipconfig
Windows IP Configuration
Ethernet adapter Local Area Connection:
   IPv6 Address. . . . . . . . . . : 2001:db8:cafe:1:0219:d2ff:fe8c:e04c
   Link-local IPv6 Address . . . . : fe80::0219:d2ff:fe8c:e04c
   Default Gateway . . . . . . . . : fe80::1
```

A 64-bit interface ID and the EUI-64 process accommodates:

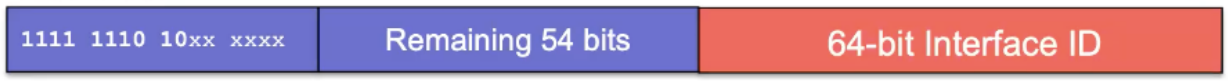
- The IEEE specification for a 64-bit MAC address
- 64-bit boundary processing



Concerns Using EUI-64 OPtion

- **Concerns** about using an i**nterface ID** that can be associated directly to a physical device (or Ethernet NIC) - an address that **never changes**
- Makes **tracking a single user easier** - Doesn't matter the prefix if the 64-bit Interface ID is unique and never changes

Static Link-Local Unicast Address



fe80:0000:0000:0000:iiii:iiii:iiii:iiii
fe80::Interface ID

Link-local addresses are created

- Automatically:
  - fe80 (usually) - First 10 bits
  - Interface ID
    - EUI-64 (cisco routers)
    - Random 64 bits (many host operating systems)
- Static (manual) Configuration

Zone ID

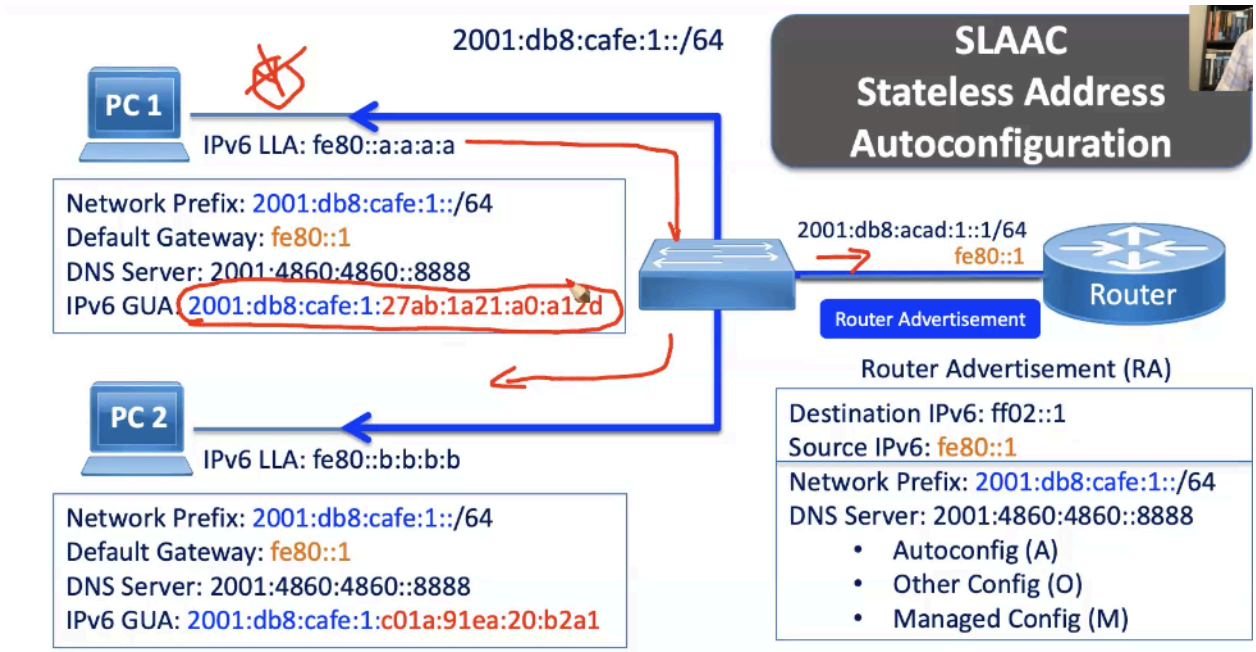
```
Windows-Host> ipconfig
<Selected output
Wireless LAN adapter Wireless Network Connection:
   IPv6 Address. . . . . . . . . . . : 2001:db8:face:1::aaaa
   Link-local IPv6 Address . . . . . : fe80::6c51:4f86:ff70:67f5%12
   Default Gateway . . . . . . . . . : fe80::481d:70ff:fe6f:9503%12

Ethernet adapter Local Area Connection:
   IPv6 Address. . . . . . . . . . . : 2001:db8:face:1::bbbb
   Link-local IPv6 Address . . . . . : fe80::9d23:50de:14ce:c8ab%11
   Default Gateway . . . . . . . . . : fe80::481d:70ff:fe6f:9503%11

Windows-Host> netsh interface ipv6 show interfaces
```

- Operating systems such as windows, Linux, and Mac OS use

the **Zone ID** to associate a link-local address with a specific interface

- The Zone ID helps determine which interface to use when sending packets destined for a link-local address

IPv6 SLAAC – Router Advertisement (RA) and Address Formation



This diagram shows SLAAC Option 1, where IPv6 devices autoconfigure their addresses using only the Router Advertisement (RA), with no DHCPv6 server involved.

1. **Router Advertisement (RA) Details**

- **To:** ff02::1 (all IPv6 nodes, multicast)
- **From:** fe80::1:1 (router's link-local address)
- **Prefix:** 2001:db8:cafe:1::
- **Prefix Length:** /64
- **Flags:**
  A = 1 (Address Autoconfiguration enabled)
  O = 0 (no other configuration)
  M = 0 (no managed DHCPv6)

2. **Host Behavior**

- The host receives the RA and configures itself using:
  - **Prefix:** 2001:db8:cafe:1::/64

- **Default Gateway:** fe80::1:1 (router's link-local address)
- **Global Unicast Address:** 2001:db8:cafe:1:: + Interface ID

3. **Interface ID Generation**

- The Interface ID can be created using either:
  - **EUI-64** format (based on MAC address)
    - Example MAC: 00:50:56:af:25:24 → becomes part of the IPv6 address
  - Random 64-bit value (used for privacy)

Why this matters:

- No DHCP server is required.
- Devices can configure themselves automatically when they connect
- Link-local addresses are still used for routing and gateway communication

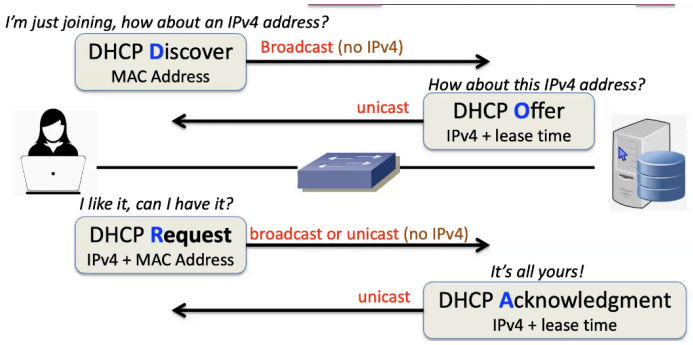
IPv6 Dynamic Address Allocation (Lecture 5)

Stateful vs Stateless

StateFul **Stateless Image**

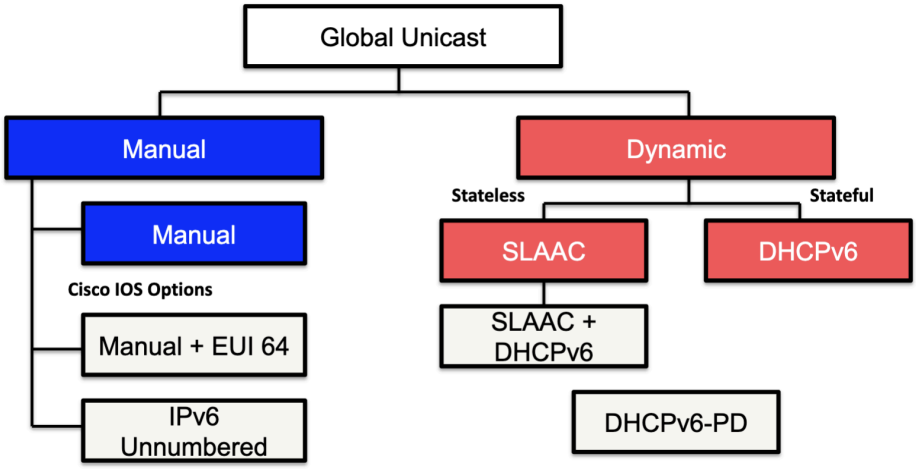
- **Stateful - Some** server is keeping track or a record of the interaction
- **Stateless -** No one is keeping track or a record

DHCPv4



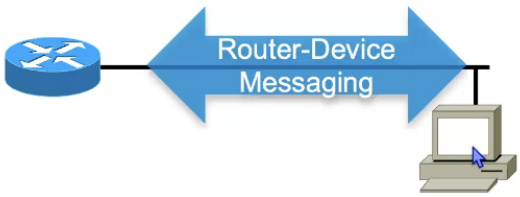
- Dora
  - Discovery
  - Offer
  - Request
  - Acknowledge
- DHCPv4 server is a STATEFUL server
- DHCPv6 - similar for IPv6

SLAACK for IPv6

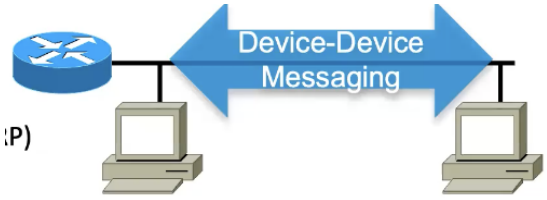


"Introducing" ICMPv6 Neighbor Discovery (RFC 4861)

- **Router-Solicitation Message**
- **Router Advertisement Message**
  - Used for dynamic address allocation

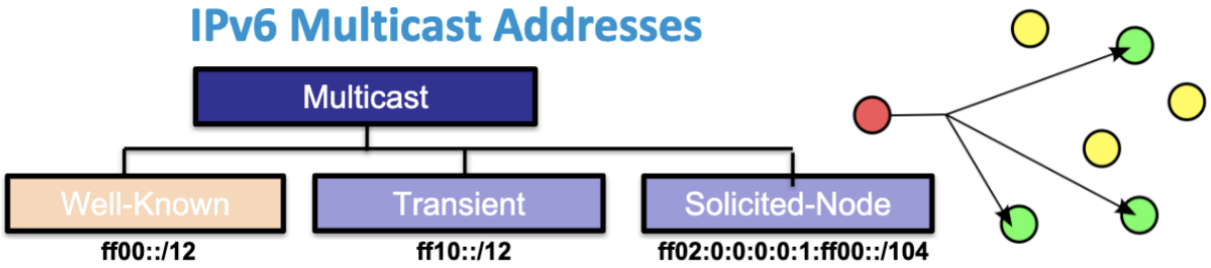


- Neighbor Solicitation Message
- Neighbor Advertisement Message
    - Used with address resolution (IPv4 ARP) with DAD



- Redirect Message (**Similar to ICMP4)**

IPv6 Multicast Addresses



- Used by a device to **send a single packet** to multiple destination simultaneously (one-to many)
- Equivalent to 224.0.0.0/4 in IPv4
- This address type is typically used for neighbor discovery and routing protocol message
- Three types of multicast addresses:
    1. Well-known or Assigned
    2. Transient
    3. Solicited-Node

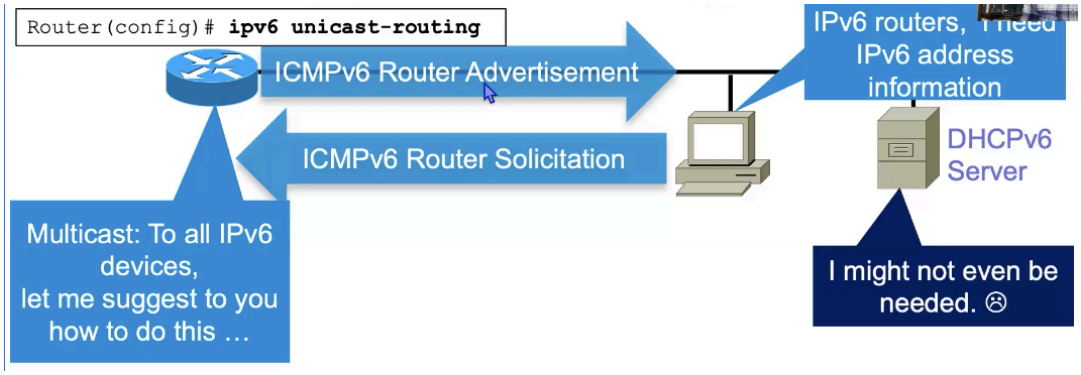
Assigned Multicast Addresses with Local-Link Scope

Flag = 0, Assigned multicast **8 bits** **4b** **4b** **112b**

Scope = 2, Link-local scope

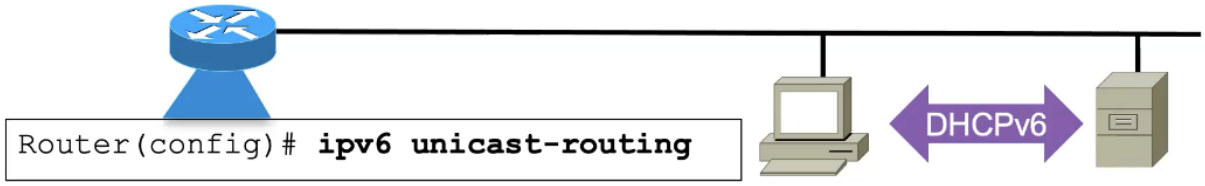
Prefix	Flag	Scope	Predefined Group ID	Compressed Format	Description (IPv6 assumed)
ff	0	2	0:0:0:0:0:0:1	ff02::1	All IPv6 devices
ff	0	2	0:0:0:0:0:0:2	ff02::2	All IPv6 routers
ff	0	2	0:0:0:0:0:0:5	ff02::5	OSPF routers
ff	0	2	0:0:0:0:0:0:6	ff02::6	OSPF DRs
ff	0	2	0:0:0:0:0:0:9	ff02::9	RIP routers
ff	0	2	0:0:0:0:0:0:A	ff02::a	EIGRP routers
ff	0	2	0:0:0:0:0:1:2	ff02::1:2	DHCP servers/relay agents

It begins with the RA message



- An ICMPv6 **Router Advertisement (RA)** suggest to all IPv6 devices on the link how it will receive IPv6 Address Information
- Sent periodically by an IPv6 Router
- … WHen the router receives a Router Solicitation message from a host
- Cisco IOS, IPv6 Unicast -routing - Enables IPv6 routing and forwarding

Router Advertisement: 3 Options



Option 1: SLAACK - No DHCPv6 (Default on Cisco routers) *"I'm everything you need (Prefix, Prefix-length, Default Gateway)"*
Option 2: SLAAC + stateless DHCPv6 for DNS address *"Here's my information but you need to get other information such as DNS address from a* ***DHCPv6 server****" (DNS can be in RA)*
Option 3: All addressing except default gateway us DHCPv6

“I can’t help you. Ask DHCPv6 server for all your information”

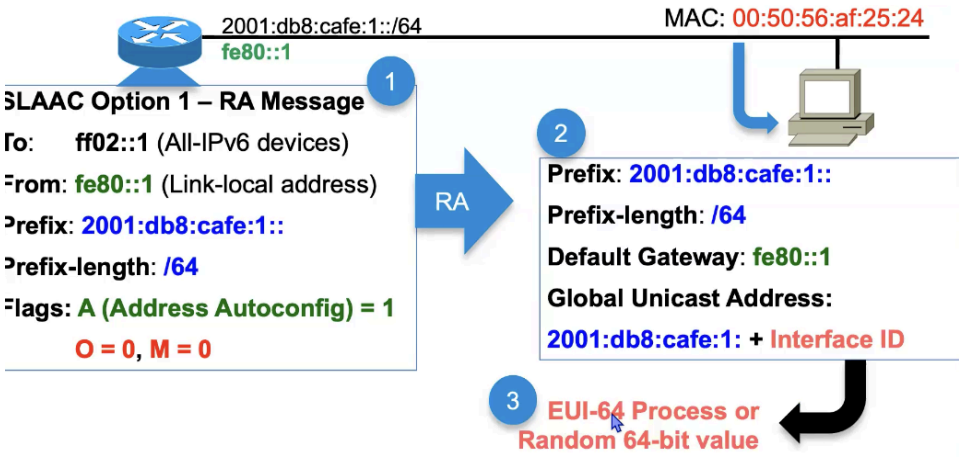
Router Advertisement Flag

Ra Address Allocation Method	A Flag (SLAAC) Default: on	O Flag (Stateless DHCPv6) Default: Off	M Flag (Stateful DHCPv6) Default: Off
Method 1: SLAAC (default)	**1(on)**	**0(Off)**	**0(Off)**
Method 2: SLAAC and Stateless DHCPv6	**1(on)**	**1(on)**	**0(Off)**
Method 3: Stateful DHCPv6	**0(Off)**	**N/A**	**1(on)**

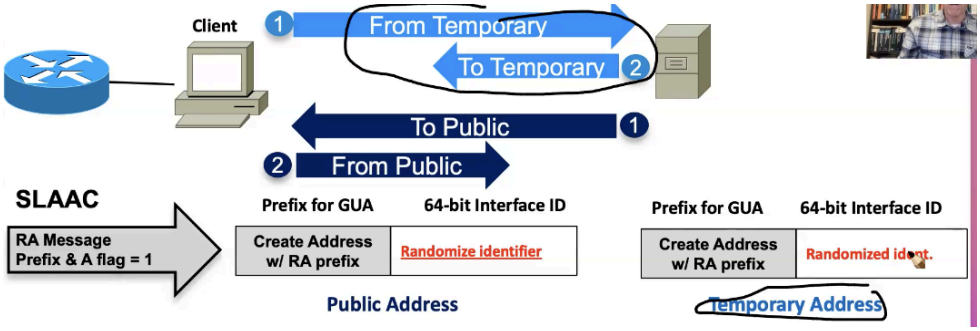
RA message contains three flags to tell a device how to obtain or create its global unicast address:

- **Address Autoconfiguration Flag (A Flag): When set to 1(on),** this flag tells the receiving host to use SLAAC to create its global unicast address
- **Other Configuration flag (O flag): When set to 1 (on),** this flag tells the host to get other addressing information, other than its global unicast address, from a stateless DHCPv6 Server
- **Managed Address Configuration flag (M flag): When set to 1 (on),** this flag tells the host to use a stateful DHCPv6 server for its global unicast address and other addressing information

SLAAC: Stateless Address Autoconfiguration (Option 1)



RFC 4941: Using Temporary and Randomized IPv6 Addresses for Enhanced Privacy in SLAAC



RFC 4941 **Privacy Extensions for Stateless Address Autoconfiguration in IPv6**, addresses these concerns:

- Generation of randomized interface IDs: This is a mechanism for:
  - Creating an interface ID that isn't traceable to a physical device
- **Generation of temporary addresses:** This provides
  - Additional addresses that have **relatively short lifetimes**
  - Used as the src address when originating connections

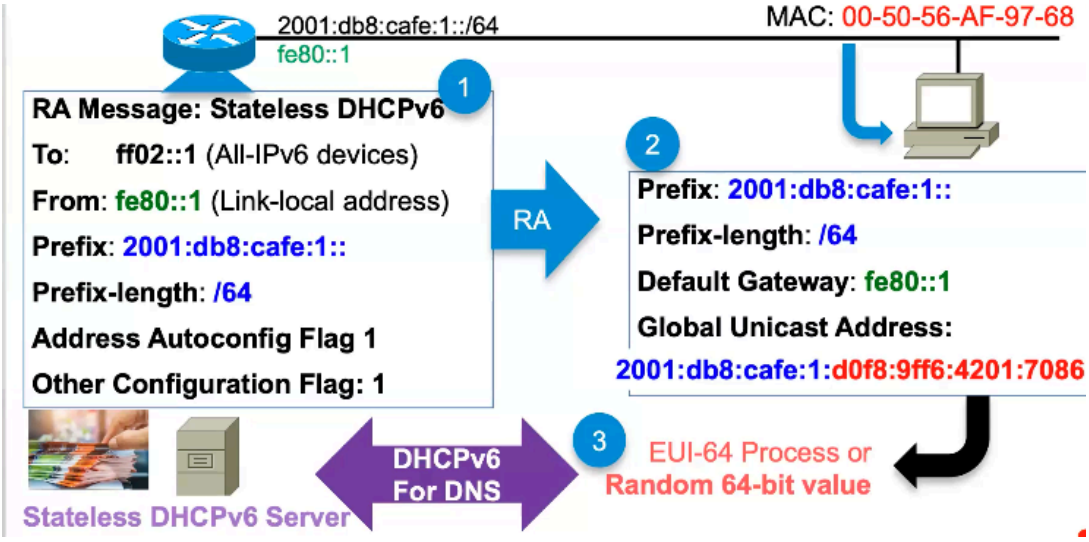
Verifying SLAAC on the WinPC using privacy extension

```
WinPC> ipconfig /all
<output omitted for brevity>

Ethernet adapter Local Area Connection:

   Connection-specific DNS Suffix  :
   Description . . . . . . . . . . . : Intel(R) PRO/1000 MT Network Connection
   Physical Address. . . . . . . . . : 00-50-56-AF-97-68
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes                    No ff-fe
   IPv6 Address. . . . . . . . . . . : 2001:db8:cafe:1:d0f8:9ff6:4201:7086(Preferred)
   Temporary IPv6 Address. . . . . . : 2001:db8:cafe:1:78bd:10b0:aa92:62c (Preferred)
   Link-local IPv6 Address . . . . . : fe80::d0f8:9ff6:4201:7086%11(Preferred)
   Default Gateway . . . . . . . . . : fe80::1%11
```

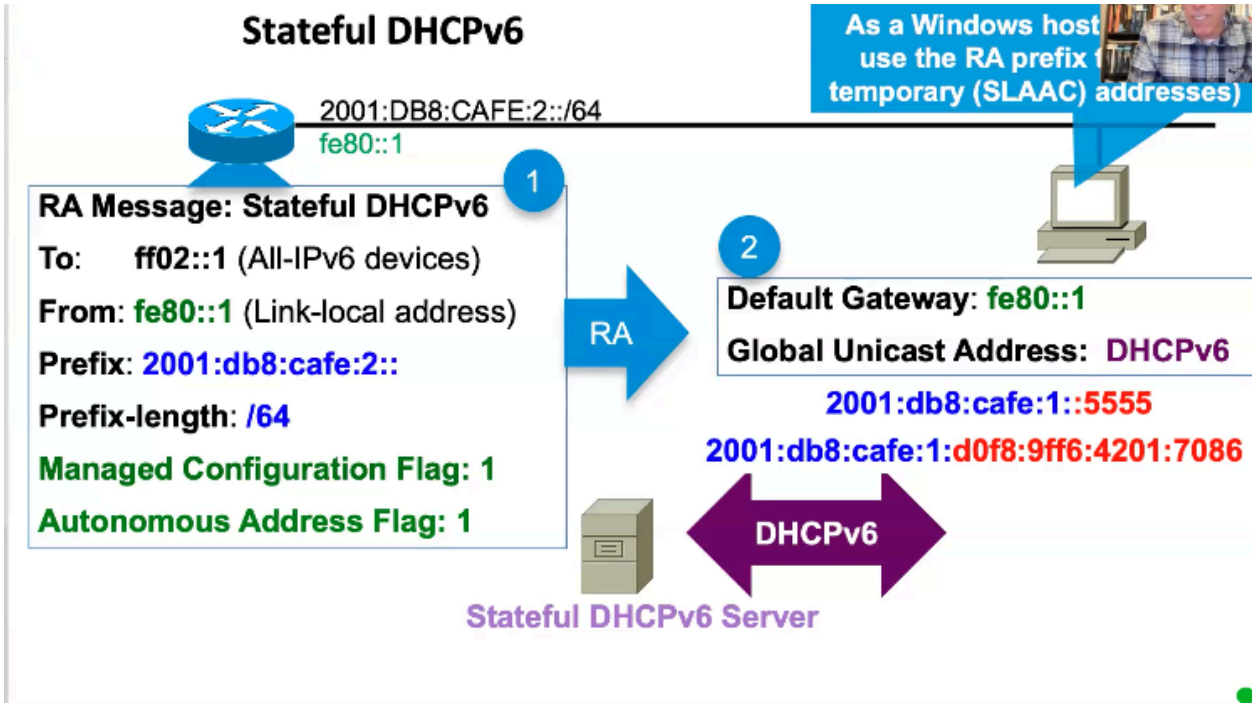
Rick's Map Example

```
MacOS$ ifconfig

en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu
1500
    ether 38:f9:d3:82:f5:ee
    inet6 fe80::1c5a:2eec:12b5:feba%en0 prefixlen 64 secured
scopeid 0xa
    inet 10.0.0.75 netmask 0xffffff00 broadcast 10.0.0.255
    inet6 2601:642:c300:6de0:1417:983c:3b75:a4c7 prefixlen 64
                    autoconf secured
    inet6 2601:642:c300:6de0:ec30:b3e3:d931:587a prefixlen 64
                    autoconf temporary
inet6 2601:642:c300:6de0::f86f prefixlen 64 dynamic
```

SLAAC for Addressing & DNS for other information (Option 2)



Stateful DHCPv6 (Option 3)



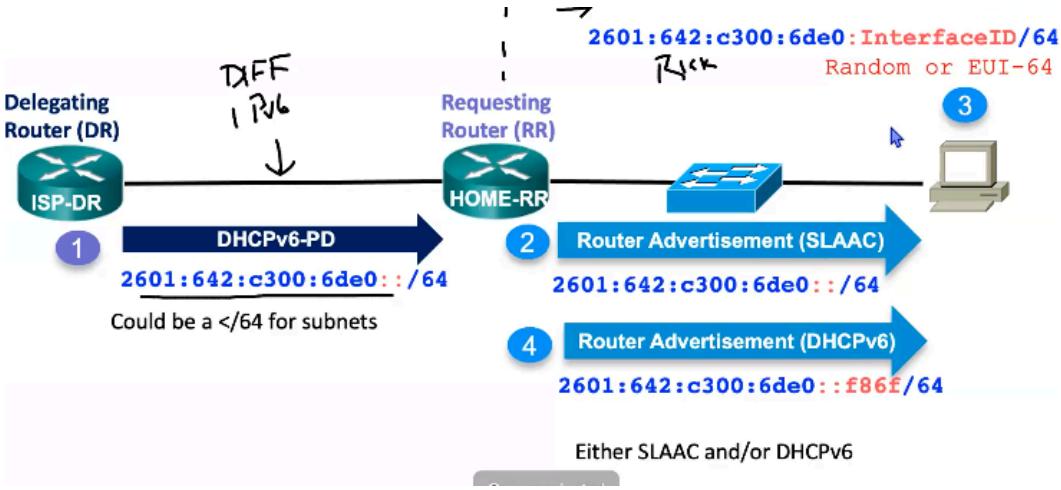
- In this example the Autonomous Address Flag is set to 1 with the Managed Configuration Flag

    - We don't want this to happen

```
WinPC> ipconfig
Ethernet adapter Local Area Connection:
   Connection-specific DNS Suffix  . :
   IPv6 Address. . . . . . . . . . . : 2001:db8:cafe:1:deed:3b2f:a6bc:ef77
   Temporary IPv6 Address. . . . . . : 2001:db8:cafe:1:f8b6:2536:ce2c:c53a
   Link-local IPv6 Address . . . . . : fe80::d0f8:9ff6:4201:7086%11
   Default Gateway . . . . . . . . . : fe80::1
<output omitted for brevity>
```

- The consequence of doing this is that you'll get 3 Global Link address instead of 1
    - 2 IPv6 addresses
    - 1 Temporary IPv6 address
- Comcast does it so there might be some benefits but Rick can't come up with on

DHCPv6 Prefix Delegation: IPv6 to the Home



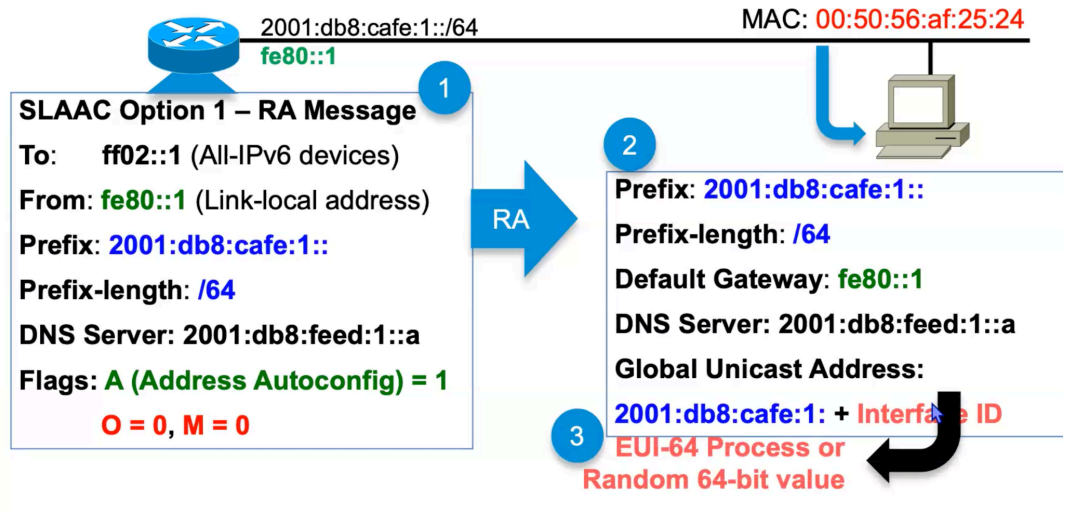

```
MacOS$ ifconfig

en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu
1500
    ether 38:f9:d3:82:f5:ee
    inet6 fe80::1c5a:2eec:12b5:feba%en0 prefixlen 64 secured
scopeid 0xa
    inet 10.0.0.75 netmask 0xffffff00 broadcast 10.0.0.255
    inet6 2601:642:c300:6de0:1417:983c:3b75:a4c7 prefixlen 64
                  autoconf secured
    i   6 2601:642:c300:6de0:ec30:b3e3:d931:587a prefixlen 64
                  autoconf temporary
    inet6 2601:642:c300:6de0::f86f prefixlen 64 dynamic
```

DHCPv6

- When you have all these addresses, there's a selection process

IPv6 SLAAC (Lecture 6)

SLAACC: Stateless Address Autoconfiguration



- **No DHCPv6 server is required** to assign addresses.
- The device **learns the network prefix** from Router Advertisements (RA).
- The **prefix length** tells the device where the network part ends and the host/interface part begins.
  It learns the link-local address of the **default gateway** from the RA.
- It may also get the **DNS server's** global unicast address from the RA (or optionally DHCPv6 for DNS).
  The device creates the rest of its IPv6 address by:
  EUI-64 (expands the MAC address), or
  - Generating a **random 64-bit interface ID** for privacy.
- NOTE: Before it gets a global IPv6 address, it assigns itself a **link-local address**, which is used to communicate on the local network segment.

From the Router's Perspective

```
R1(config)# ipv6 unicast-routing
R1(config)# exit
R1# debug ipv6 nd
  ICMP Neighbor Discovery events debugging is on
R1#
*Nov 27 18:34:52.494: ICMPv6-ND: (GigabitEthernet0/0,FE80::1) send RA to FF02::1
*Nov 27 18:34:52.494: ICMPv6-ND: (GigabitEthernet0/0,FE80::1) Sending RA (1800) to
FF02::1
*Nov 27 18:34:52.494: ICMPv6-ND:   MTU = 1500
*Nov 27 18:34:52.494: ICMPv6-ND:   prefix 2001:DB8:CAFE:1::/64 [LA] 2592000/604800
<output omitted for brevity>
R1# undebug all
```

What is the Privacy Extension for SLAAC?

In standard SLAAC, the **interface ID** is often generated from the device's **MAC address** using the **EUI-64 format**.

This creates a stable IPv6 address—but it also means your device can be **tracked across networks**, because the address doesn't change

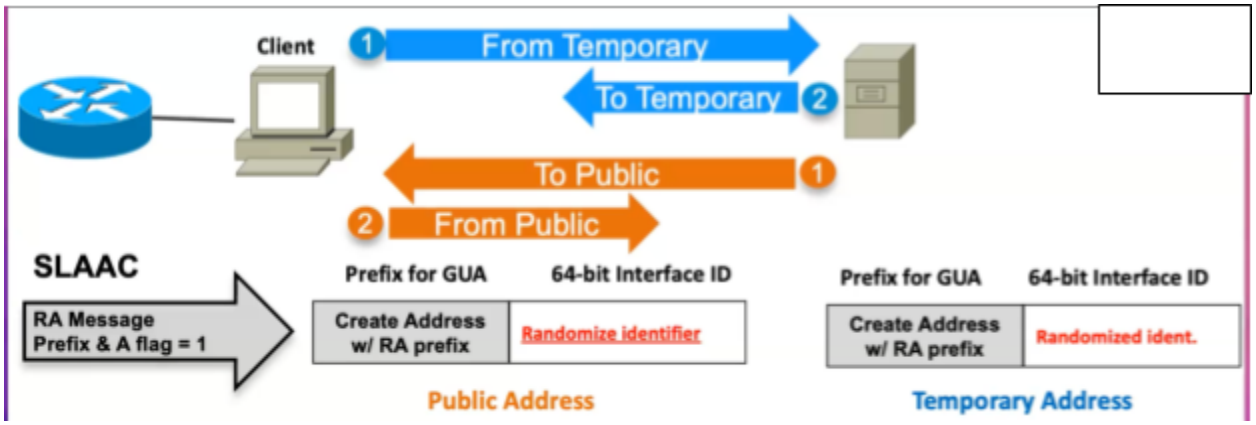
To improve privacy, **RFC 4941** introduced:

Privacy Extensions for SLAAC

- Instead of using the MAC address, the device **generates random interface IDs**
- These **temporary IPv6 addresses** change over time
- Used primarily for **outgoing connections** (like web browsing) to prevent tracking
- Your device can still keep a stable address (like for incoming connections), but **temporary ones are used for privacy**

Default Lifetime of Temporary Addresses

- **Windows:**
  - New temporary address generated every 24 hours
  - Existing temporary addresses expire after 7 days
- **Linux/macOS (typical defaults):**
  - Temporary address regenerated every few hours (often 1–24 hours)
  - Valid lifetime usually around 1 day (24 hours)
  - Preferred lifetime: ~1 hour (after which it's no longer used for new connections)



```
rigrazia@820bem002 ~ % ifconfig en7
en7: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        options=6467<RXCSUM,TXCSUM,VLAN_MTU,TSO4,TSO6,CHANNEL_IO,PARTIAL_CSUM,ZEROINVERT
        ether e8:9f:80:cd:61:77
        inet6 fe80::a9:2612:a5f6:768b%en7 prefixlen 64 secured scopeid 0x17
        inet6 2607:f380:80f:f828:407:ccbf:f9c8:26be prefixlen 64 autoconf secured
        inet6 2607:f380:80f:f828:c839:1548:3094:593a prefixlen 64 autoconf temporary
        inet 172.30.1.15 netmask 0xffffff00 broadcast 172.30.1.255
        nd6 options=201<PERFORMNUD,DAD>
        media: autoselect (1000baseT <full-duplex>)
```

PUB TEMP

- When **you initiate** a connection (e.g., visiting a website), your device uses the **temporary IPv6 address** for **privacy**
- When **others initiate** a connection **to you**, they use your **public/stable IPv6 address** (the one that may be based on EUI-64 or DHCPv6, depending on config)

Summary:

- **Without privacy extension**: IPv6 address is stable but trackable.
- **With privacy extension (RFC 4941)**: IPv6 address changes periodically to hide your identity across sessions.
    - They can still track you in other ways like Cookies
- If you want your friend to contact you using an IP then using your public Global-link address would be best

Router Solicitation again

- By default, sends it out every 200 seconds
- Dest: FF02:: is the multicast group for all IPv6 Routers
    - Within the link

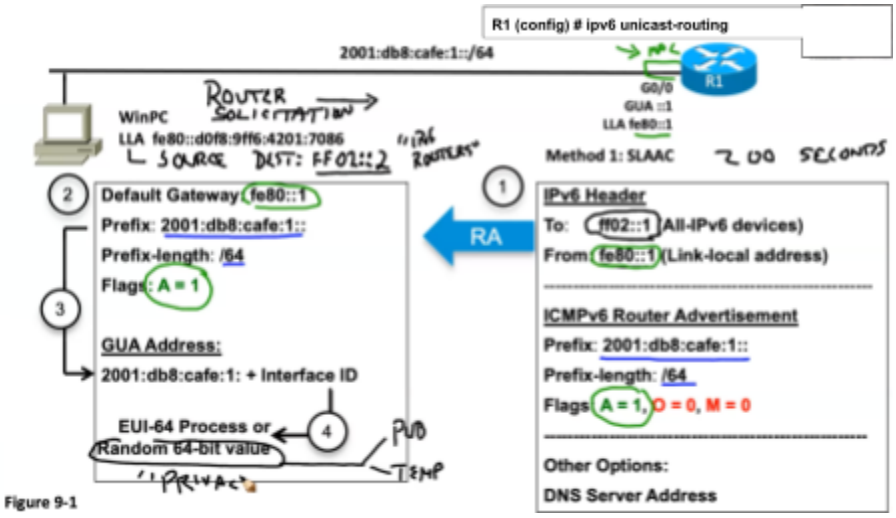
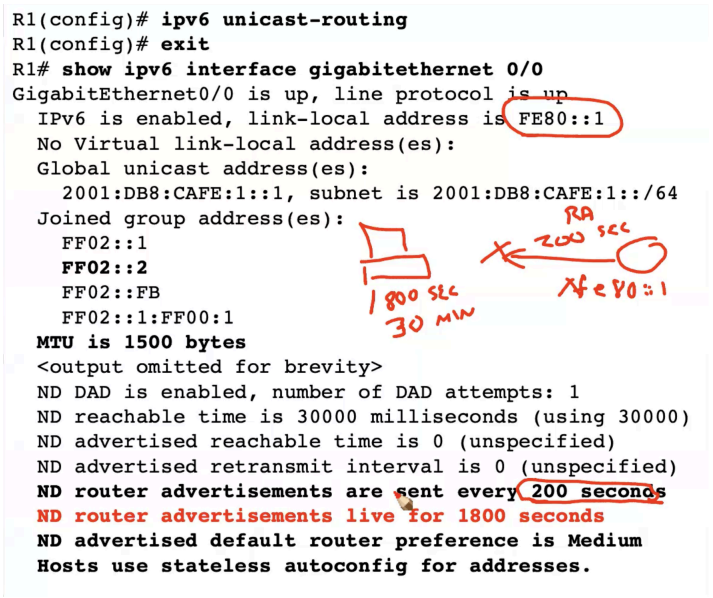


Figure 9-1

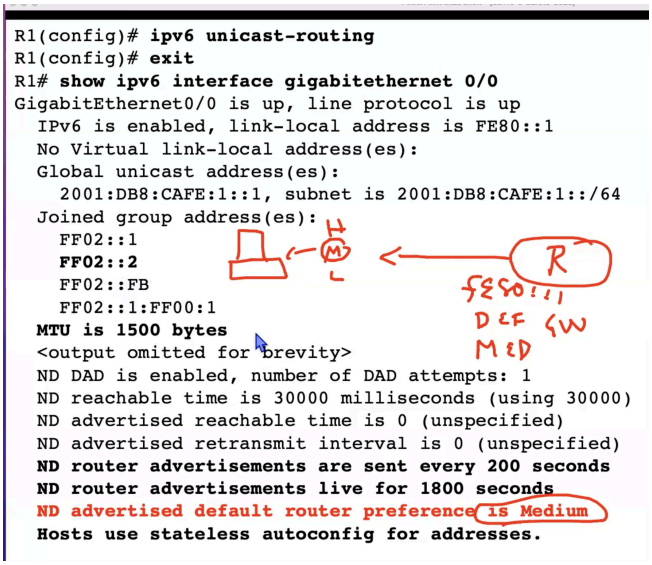
ND router advertisement 1800 seconds (30 mins)

- **Router Lifetime Information sent in RA messages**
- Informs a host of the duration, in seconds, that the router should be used as the default gateway
- **0** indicates that the router is not a default gateway
- Only applies to the router's function as a default gateway
- It does **not** apply to other information contained in the RA
- The **host refreshes its own timer** every time it receives a Router Advertisement

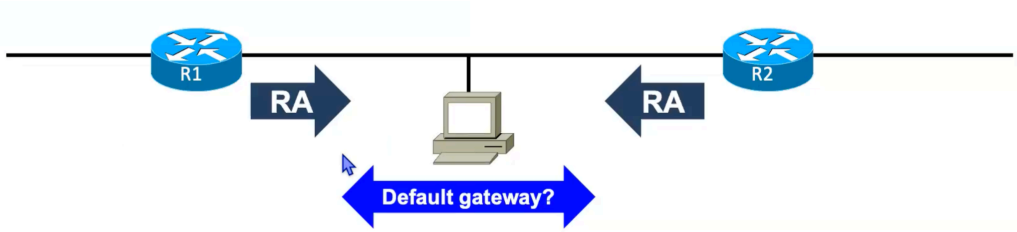


ND advertised fault preference is Medium

- The value of the **Default Router Preferences (DRP)**
- Hosts dynamically populate their **Default Router List** based on the source IPv6 addresses of the RA messages
- The DRP (default gateway) can be: high, medium (default), or low
- This helps the host determine which router to use as the default gateway when it receives **multiple RA messages**
- The **default is medium**



Default Router List



- A defice that is not a router maintains a Default Router List
- When a device receives a Router Advertisement, it adds the link-local source address of the packet as one of the routers it can use as a default gateway
- Each entry has an invalidation timer, the Router Lifetime, extracted from the Router Advertisement used to delete entries that are no longer being advertised

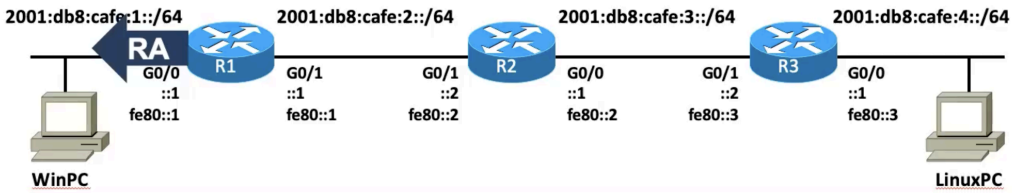
Hosts use stateless autoconfig for addresses:

- Indicates that the RA message sent on this interface is **suggesting that hosts obtain their dynamic IPv6 addressing using SLAAC**, as a result of the A flag being sent to 1
- Because the **0 and M flags are set to 0**, there's no mention of suggesting the use of a DHCPv6 server

```
R1(config)# ipv6 unicast-routing
R1(config)# exit
R1# show ipv6 interface gigabitethernet 0/0
GigabitEthernet0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::1
  No Virtual link-local address(es):
  Global unicast address(es):
    2001:DB8:CAFE:1::1, subnet is 2001:DB8:CAFE:1::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::FB
    FF02::1:FF00:1
  MTU is 1500 bytes
  <output omitted for brevity>
  ND DAD is enabled, number of DAD attempts: 1
  ND reachable time is 30000 milliseconds (using 30000)
  ND advertised reachable time is 0 (unspecified)
  ND advertised retransmit interval is 0 (unspecified)
  ND router advertisements are sent every 200 seconds
  ND router advertisements live for 1800 seconds
  ND advertised default router preference is Medium
  Hosts use stateless autoconfig for addresses.
```

A=1

Router Advertisement Message




```
R1(config)# ipv6 unicast-routing
R1(config)# exit
R1# debug ipv6 nd
  ICMP Neighbor Discovery events debugging is on
R1#
*Nov 27 18:34:52.494: ICMPv6-ND: (GigabitEthernet0/0,FE80::1) send RA to FF02::1
*Nov 27 18:34:52.494: ICMPv6-ND: (GigabitEthernet0/0,FE80::1) Sending RA (1800) to
FF02::1
*Nov 27 18:34:52.494: ICMPv6-ND:    MTU = 1500
*Nov 27 18:34:52.494: ICMPv6-ND:    prefix 2001:DB8:CAFE:1::/64 [LA] 2592000/604800
<output omitted for brevity>
R1# undebug all
```

DAD (Duplicate Address Detection (DAD)

- **ICMPv6 Duplicate Address Detection (DAD)** is used to guarantee that an IPv6 unicast address is unique on the link
    - Determines for global and Link -local address regardless if it was assigned manually, SLAAC, or dhcpv6
- A device will **send a Neighbor Solicitation** for its own unicast address (static or dynamic)
- **After a period of time,** if a **NA is NOT received**, then the address is deemed unique
- Once required, RFC was updated to where it's only recommended - /64 interface ID makes duplicates unlikely

Temporary IPv6 Address

- **Used as a source address** when initiating the connection
- Created using **SLAAC**
- **Host** is implementing privacy extension
- **Interface ID** is random only
- **Valid/Preferred timers** set by host OS (**not RA**)
- **Valid/Preferred:** Typically 7 days
- **Valid/Preferred timers** are NOT reset by RA
- **When deprecate state**, new temporary address is created
- Will **eventually become invalid** (not used)

Public IPv6 Address

- **Used by other devices** for reaching this device
- Created using **SLAAC**
- **Interface ID** is EUI-64 or random (host is implementing privacy extension)
- **Valid/Preferred** set by RA
- **Valid:** 2,592,000 seconds equals 30 days
- **Preferred:** 604,800 seconds equals 7 days

```
MacOS$ ifconfig
    inet6 fe80:: cf1:ba80:7ac5:8dd2%en0 prefixlen 64 secured scopeid 0x6
    inet6 2601:642:c300:6de0:1097:4d82:54cf:d257 prefixlen 64
    autoconf secured
    inet6 2601:642:c300:6de0:8464:39bc:a88:c865 prefixlen 64
    autoconf temporary
       inet6 2601:642:c300:6de0:1cbc:a61:9673:984d prefixlen 64
    deprecated autoconf temporary
```

- Deprecated means that it was being used and it's there only for existing connections but will go away real soon

Multicast Address Lecture 7

Unicast is the communication that there is only one receiver. This is one-to-one communication.
Multicast is the communication that there is one more receiver. Only the members of the multicast group receive the multicast traffic.

Broadcast is also the communication that there is one more receiver but this time, all the receivers receive broadcast traffic.

Anycast is the communication that is developed with **IPv6**. With anycast, the traffic is received by the nearest receiver in a group of the receivers that has the same IP.

Internet Engineering Task Force (IETF)
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BCP: 141
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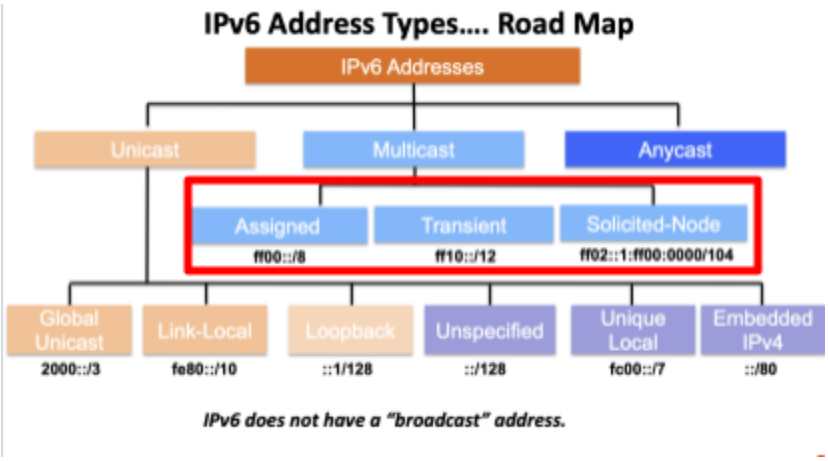
IANA Considerations and IETF Protocol and Documentation Usage for IEEE 802 Parameters

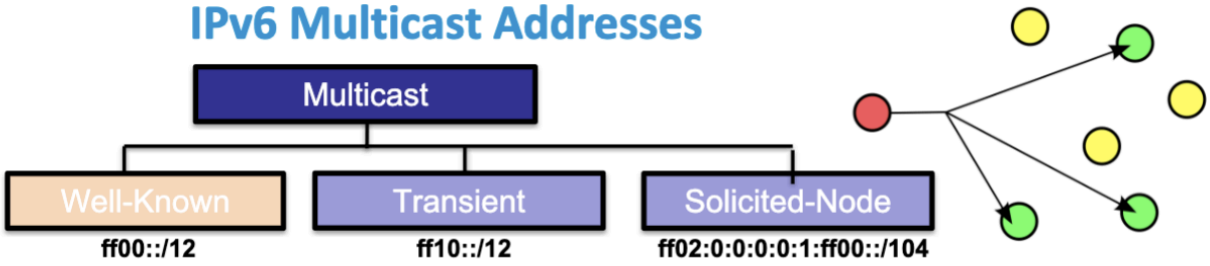
Abstract

Some IETF protocols make use of Ethernet frame formats and IEEE 802 parameters. This document discusses several uses of such parameters in IETF protocols, specifies IANA considerations for assignment of



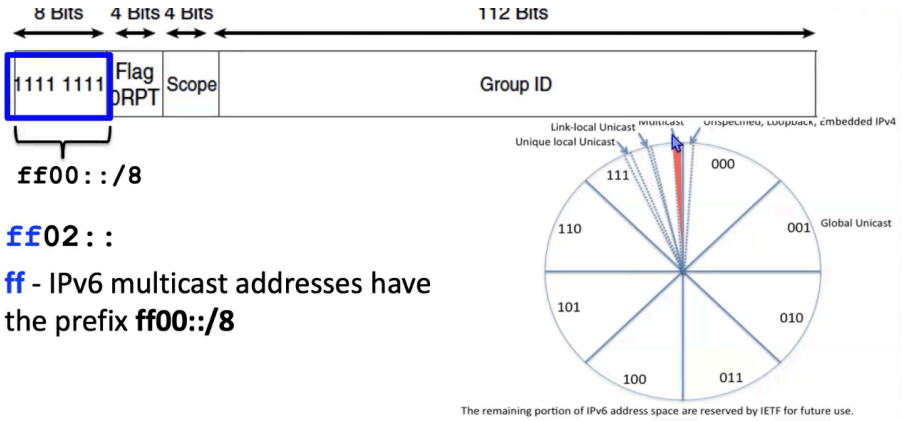
2224.0.0.5 and ff02::5 is a way for ipv4 and ipv6 respectively broadcast to the network routers running OPSF. In this case, for IPv6 its a multicast

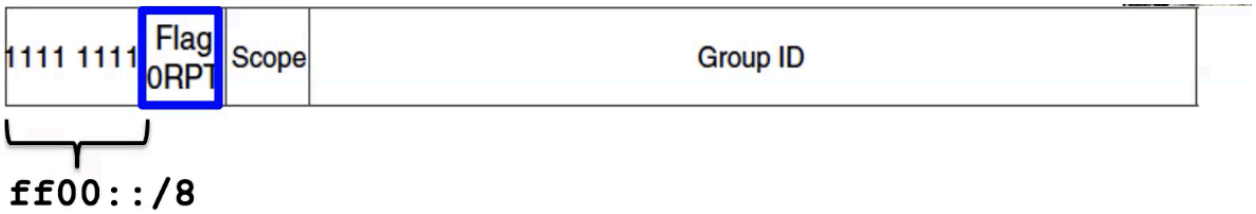
IPv6 Multicast Addresses



- Used by a device to **send a single packet** to multiple destination simultaneously (one-to many)
- Equivalent to 224.0.0.0/4 in IPv4
- This address type is typically used for neighbor discovery and routing protocol message
- Three types of multicast addresses:
    4. Well-known or Assigned
    5. Transient
    6. Solicited-Node

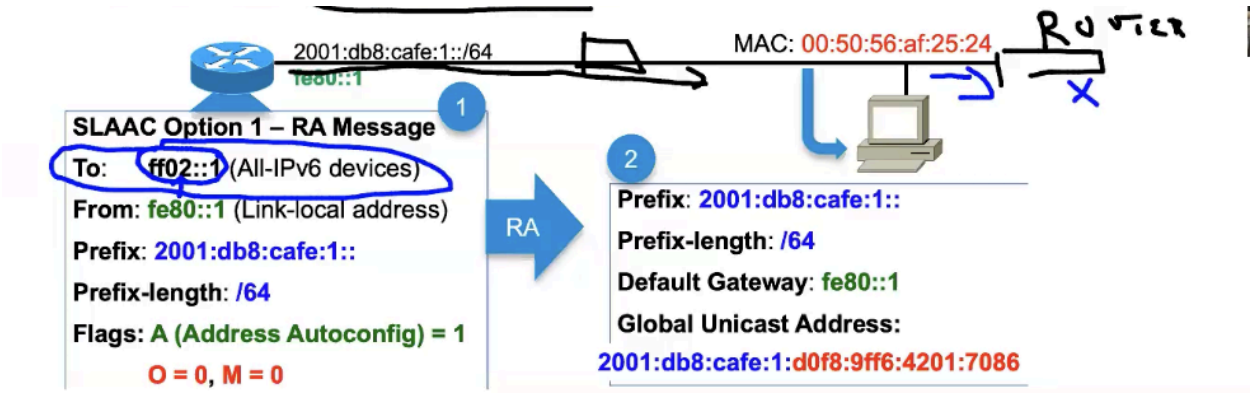
Multicast Range





- ff - IPv6 Multicast address have the prefix **ff00:/8**
- Transient flag (t flag) of 0 **(permanent)**: These addresses, known as **predefined multicast addresses**
    - Includes well-known (ff02:1 All IPv6 devices)
    - Solicited-node
- Scope (partial List):
    - 0 Reserved
    - 1 Interface-Local scope
    - 2 Link-Local scope
    - 5 Site-local- scope
    - 8 ORganization-Local scope
    - e Global scope

Multicast with Link-Local Scope vs Link-Local Unicast Addresses



	Link-Local Unicast	Multicast with Link-Local scope
Type	Unicast	Multicast
Use as a src address	Yes	No
Dest. address	One-to-One	One-to-Many
Routable off-link?	No (drop if src or dest address)	Yes, with multicast routing enabled
Common uses	Used as a default gateway, routing protocol messages • Ex: source address RS	All-IPv6 devices, All-IPv6 routers • Ex: Destination address RA

Well-known IPv6 Multicast Addresses

- RFC 2375, IPv6 Multicast Address Assignments, defines the initial assignments of IPv6 multicast addresses that have permanently assigned Global IDs
- Reference for assigned multicast addresses
    - (IANA) IPv6 multicast Address Space - Registry

Assigned Multicast Addresses with Local-Link Scope

Flag = 0, Assigned multicast **8 bits** **4b** **4b** **112b**

Scope = 2, Link-local scope

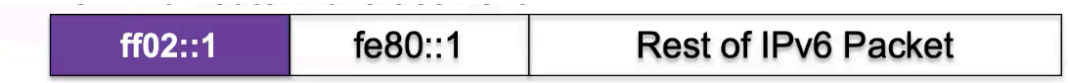
Prefix	Flag	Scope	Predefined Group ID	Compressed Format	Description (IPv6 assumed)
ff	0	2	0:0:0:0:0:0:1	ff02::1	All IPv6 devices
ff	0	2	0:0:0:0:0:0:2	ff02::2	All IPv6 routers
ff	0	2	0:0:0:0:0:0:5	ff02::5	OSPF routers
ff	0	2	0:0:0:0:0:0:6	ff02::6	OSPF DRs
ff	0	2	0:0:0:0:0:0:9	ff02::9	RIP routers
ff	0	2	0:0:0:0:0:0:A	ff02::a	EIGRP routers
ff	0	2	0:0:0:0:0:1:2	ff02::1:2	DHCP servers/relay agents

- When implementing site-local scope or any scope requiring multicast packets to
- Be routed, IPv6 multicast routing must be enabled using:
    - Router(config# ipv6 multicast-routing

Address	Meaning	Scope
FF02::1	All nodes	Link-local
FF02::2	All routers	Link-local
FF02::9	All RIP routers	Link-local
FF02::1:FFXX:XXXX	Solicited-node	Link-local
FF02::4	DVMRP routers	Link-local
FF02::5	All OSPF routers	Link-local
FF02::6	OSPF designated routers	Link-local
FF02::A	All EIGRP routers	Link-local
FF02::D	All PIM routers	Link-local
FF05::101	All NTP routers	Site-local
FF05::1:3	All DHCP routers	Site-local

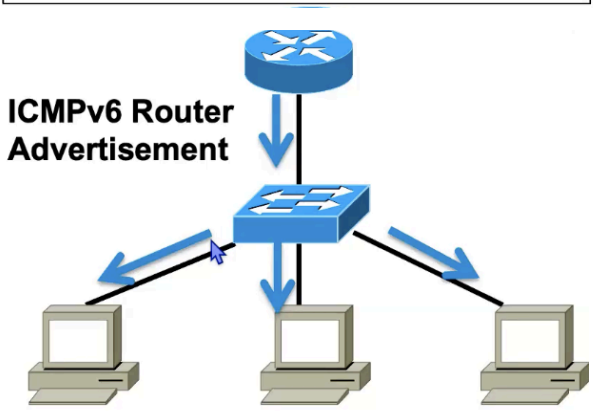
“All IPv6 Devices” Assigned Multicast Address

ICMPv6 Router advertisement




```
Router(config)# ipv6 unicast-routing
```

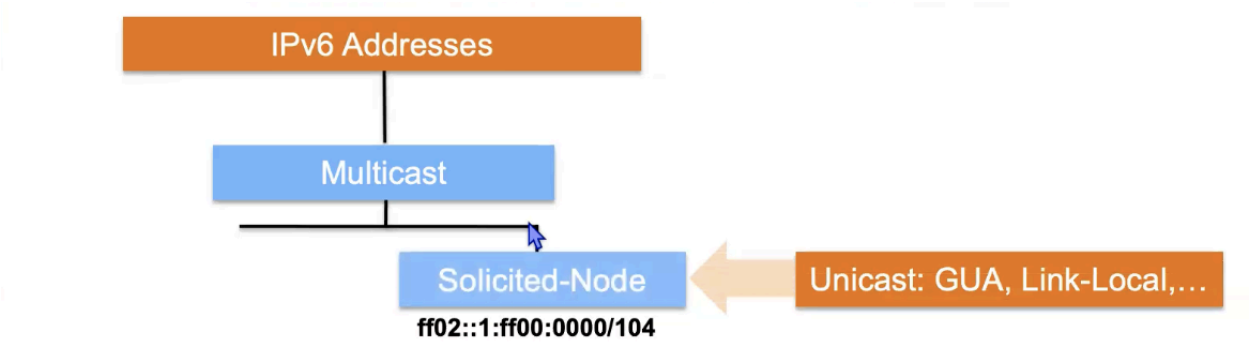
- **Ff02:1 - All IPv6 Devices**
- **Any Ipv6 device (LLA address)**
  - End Devices
  - Router
  - Switches (with an IPv6 address)
- Every IPv6 device will list and process packets to this address
- Isn’t this the same as a broadcast?
  - **Same effect but no**, because it maps to a L2 MAC address which is more efficient.. Coming soon!
  - This is true for all multicast



Verifying IPv6 Multicast Addressing on the Router

```
R1(config)# ipv6 unicast-routing
R1(config)# exit
R1# show ipv6 interface gigabitethernet 0/0
GigabitEthernet0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::5AAC:78FF:FE93:DA00
  No Virtual link-local address(es):
  Global unicast address(es):
    2001:DB8:CAFE:1::1, subnet is 2001:DB8:CAFE:1::/64
  Joined group address(es):
    FF02::1              ! All-IPv6 devices
    FF02::2              ! All-IPv6 routers
    FF02::FB             ! Multicast DNS (See book for additional info)
    FF02::1:FF00:1       ! Solicited-node multicast for GUA
    FF02::1:FF93:DA00    ! Solicited-node multicast for LLA
<output omitted for brevity>
```

Solicited-Node IPv6 Multicast Address (Lecture 8)



- In addition to every unicast address assigned to an interface, a device will also have a special multicast address known as a solicited-node multicast address
- **Every unicast address** (GUA, LLA,...) will have an associated Solicited-Node Multicast address

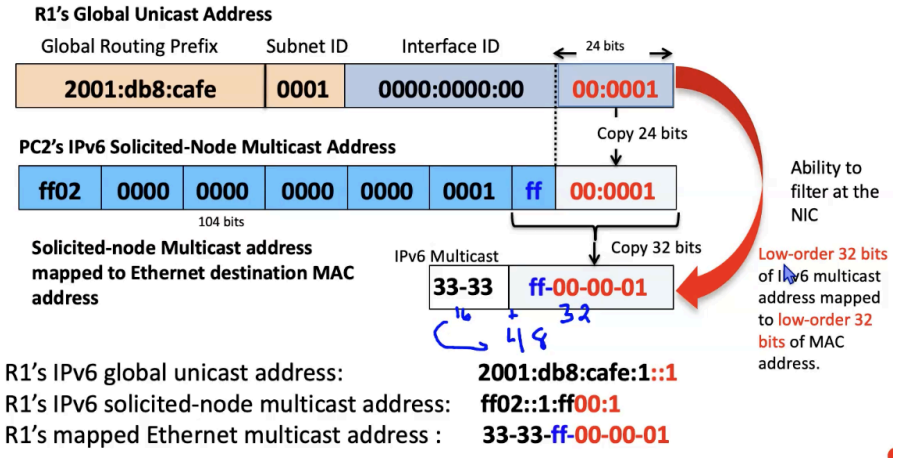
Solicited-Node Multicast Address

How is it created?

	Unicast Addresses	Solicited Node Multicast
Global Unicast	2001:db8:cafe:1::1	ff02::1:ff00:1
Link-local unicast	fe80::5aac:78ff:fe93:da00	ff02::1:ff93:da00

- There's a direct relationship between the unicast/anycast address and its solicited node multicast address
- The solicited node multicast address formed by:
  - Prefix ff02:0:0:0:0:1:ff00::/104 (ff02::1:ff:xx:xxxx)
  - Append the low-order 24 bits of the address (unicast or anycast)
  - Like other multicast addresses, solicited node multicast addresses are also mapped to an Ethernet MAC address (coming)

How Solicited-Node Multicast Addresses are Created



Solicited-Node IPv6 Multicast Address

- 33-33-xx-xx-xx-xx is the **reserved Ethernet Multicast MAC address** when carrying an IPv6 multicast packet, as described in RFC 7042, IANA Considerations and IETF Protocol and Documentation Usage for IEEE 802 Parameters
- Why 33-33?
  - Thats the address of Xerox PARC at Palto Alto, 3333 Coytote Hill RD

Linkedin Post:

Something that confused me at first—compared to IPv4—is how IPv6 subnetting works when it *doesn't* land on a clean nibble boundary.

Each hex digit in IPv6 represents 4 bits, so subnetting at something like /66 doesn't line up neatly. You're slicing a hex digit mid-way, and that limits the values it can take.

For example:
2001:db8:cafe:8000::/66
In this case, only addresses where that block starts with 8, 9, A, or B fall into your subnet. If you accidentally use C000 or F000, you're stepping into someone else's network space.

It's all just binary underneath, but seeing hex chopped up like that definitely threw me off at first.

IPv6 Global Unicast Address (Neil A.)

- **Global Unicast Addresses** are similar to IPv4 Public addresses
- They are assigned to an individual host and have global reachability (unless blocked by security policy such as on a firewall)
- They are assigned from the range 2000::/3
- Internet authorities assign blocks from the overall 2000::/3 range to organizations
- A common assignment for a company is a /48 block, eg 2001:10:10::/48
- A smaller or larger size block can be assigned depending on the size of the company
- IPv6 standards state that addresses assigned to individual hosts should use a /64 mask

- The IPv6 address is 128 bits so /64 splits it in half for the network and host portions of the address
- X:X:X:X:|X:X:X:X
  Network host
- If a company is assigned a /48 address by the Internet authorities can uses /64 host address, that leaves 16 bits the company can assign to its internal subnets
- For example, if the company was assigned 2001:10:10::/48 by the Internet Autohorites, it can assign subnets 2001:10:10:0::/64 to 2001:10:10:FFFF::/64 to its internal network segments
- 16 bits = 65,536 possible subnetes
- 64 bits left over = 81,446,774,073,709,551,616 hosts per subnet
- X:X:X:| X |:X:X:X:X
  Company Subnet Host

Example:

- In this example the company has been assigned 2001:DB8:0::/48 by the internet authorities

- Using a /64 for all network subnets including point-to-point links and loopback addresses can seem wasteful, but the official declaration is that the IPv6 address space is so large that it doesn't not create a problem
- Using /64 everywhere simplifies the addressing and enables the use of EUI-64 addresses

Global Unicast Address Configuration

- Enable IPv6 routing first

```
R1(config)#ipv6 unicast-routing
R1(config)# int f0/0
R1(config)# ipv6 add 2001:db8:0:1::1/64
R1(config)# int f2/0
R1(config)# ipv6 add 2001:db8:0:0::1/64
```

EUI-64 Addresses (Neil A.)

- A cisco router can generate full IPv6 addresses for itself when given the interface and /64 network to use
- The host portion of the address is derived from the interface's MAC address, which is guaranteed to be globally unique
- A MAC address is /48 address compared to the /64 host portion of the IPv6 address
- FF:FE is injected in the middle of the /48 address compared to the /64 MAC address to bring it up to 64 bits. ALSO, the 7th bit is inverted

```
R1(config)#int f0/0
R1(config-if)# ipv6 address 2001:db8:0::/64 eui-64
R(config)#int f2/0
R1(config-if)# ipv6 address 2001:db8:0::/64 eui-64
```

```
EUO-64 Address Verification
R1#sh int f0/0
Hardware is DEC21140, address is ca01.2f24.0000
R1#sh int f2/0
Hardware is DEC21140, address is ca01.2f24.0038

R1#sh ipv6 interface brief
FastEthernet 0/0        [up/up]
2001:DB8:0:1:c801:2FFF:FE24:0
FastEthernet2/0         [up/up]
2001:DB8::C801:2FFF:FE24:38
! truncated
```

EUI-64 Addresses

- The router borrow with the MAC address form the first Ethernet port for non-Ethernet interfaces such a Serial ports
- It's not recommended to use EUI-64 on the router interfaces. It's better to use a memorable address such as 2001:db8:0:1::1

Unique Local and Link Local addresses (Niel A.)

- Unique LOcal Addresses are similar to IPv4 RFC 1918 private addresses
- They are not publicly reachable
- They are assigned from the range FC00::/7
- Hosts should be assigned /64 addresses
- Link local addresses are valid for communications on that link only
- They're assigned from the range FF80::/10 - FEB0::/10
- Hosts should be assigned /64 addresses

Link Local Connectivity

- A, B and C have connectivity to each other via the FF80::1, FE880::2 and FE80::3 link local addresses on the same segment

- B and D have connectivity to each other via the FE80::4 and FE80::5 link local addresses on the same segment
- FF80::1, FE80::2 and FE80::3 don't have connectivity to FE80::4 or FE80:5
- Link local addresses can be used for communications wich shouldn't be forwarded beyond the local link, like routing protocol help packets and updates
- THey're mandatory on IPv6 enabled Cisco router interfaces
- Link local addresses are automatically generated with EUI-64 addresses on IPv6 enabled Cisco router interfaces
- The EUI-64 address can be overridden with manual configuration

Link Local Address AUto Generation

- New router with no IPv6 configuration
- Configure a global unicast address which enables IPv6 on the interface

```
R1(config)#ipv6 unicast-routing
R1(config)#int f0/0
R1(config-if # ipv6 add 2001:db8:0:1::1/64
R1(config-if)#int f2/0
Rq(config-if)#ipv6 add 2001:db8:0:0::1/64
```

- EUI-64 Link Local addresses are automatically generated

```
R1#sh ipv6 interface brief
FastEthernet0/0         [up/up]
      FE80::C801:2FFF:FE24:0
      2001:DB8:0:1::1
FastEthernet1/0         [administratively down/down]
FastEthernet2/0         [up/up]
      FE80::C801:2FFF:FE24:38
      2001:DB8::1
FastEthernet3/0         [administratively down/down]
      unassigned
```

Manual Link Local Address COnfiguration

- Link local addresses are valid on the local link only so you can use the same address on multiple interfaces

```
R1(config)#int f0/0
R1(config-if)# ipv6 address fe80::1 link-local
R1(config-if)#int f2/0
R1(config-if)# ipv6 address fe80::1 link-local
```

Multiple Addresses on Interfaces: IPv4 vs IPv6

IPv4

```
R1(config)#int f0/0
R1(config-if)#ip address 10.10.10.1 255.255.255.0
R1(config-if)#ip address 192.168.10.1 255.255.255.0
R1#sh run int f0/0
interface FastEthernet0/0
 ip address 192.168.10.1 255.255.255.0

R1(config)#int f0/0
R1(config-if)#ip address 172.16.0.1 255.255.255.0 secondary
R1#sh run int f0/0
interface FastEthernet0/0
 ip address 172.16.0.1 255.255.255.0 secondary
 ip address 192.168.10.1 255.255.255.0
```

- In IPv4, if you configure multiple IP addresses on an interface, the last one entered overwrites the previous one. To have multiple IPv4 addresses on an interface, you must use the `secondary` keyword. For example:
    - Primary IP: 192.168.10.1/24
    - Secondary IP: 172.16.0.1/24
- Traffic originating from the router uses the primary IP address as the source. Configuring secondary IPv4 addresses is rare

IPv6

```
R1(config)#int f0/0
R1(config-if)#ipv6 address FE80::1 link-local
R1(config-if)#ipv6 add 2001:db8:0:0::1/64
R1(config-if)#ipv6 add 2001:db8:0:1::1/64

R1#sh run int f0/0
interface FastEthernet0/0
 ip address 172.16.0.1 255.255.255.0 secondary
 ip address 192.168.10.1 255.255.255.0
 ipv6 address FE80::1 link-local
 ipv6 address 2001:DB8::1/64
 ipv6 address 2001:DB8:0:1::1/64
```

- In contrast, IPv6 allows multiple addresses on the same interface without overwriting. For example, an interface can have:
    - Link Local address: FE80::1
    - Global Unicast address: 2001:DB8:0:0::1
    - Another Global Unicast address: 2001:DB8:0:1::1
- All these addresses coexist on the interface.
- IPv6 and IPv4 can coexist on the same interface in a dual-stack configuration. The router uses IPv4 routing for packets with IPv4 destination addresses and IPv6 routing for packets with IPv6 destination addresses. The choice depends on the application on the end host sending the traffic.

Summary of Multiple IPv6 Addresses

- Link Local addresses are mandatory on IPv6-enabled interfaces.
- Global Unicast and Unique Local addresses are optional.
- Multiple IPv6 addresses can be assigned to the same interface.
- Typically, one Link Local address is used for routing protocol traffic, and one Global Unicast address is used for normal routing on routers.

Static Routing (Neil Anderson)

IPv6 Routing

- IPv6 routing works the same way as IPv4 routing, but the processes are separate, and there are separate IPv4 and IPv6 routing tables
- If a router receives an IPv4 packet, it will route it according to its IPv4 routing table
- If a router receives an IPv6 packet, it will route it according to its IPv6 routing table
- The routing tables are built in the same way, through static routes or dynamic routing protocols

IPv6 Routing Protocol Support

- Updated versions of the existing IPv4 routing protocols were released to support IPv6
- The configuration and operation is very similar for IPv6 as for IPv4
    - RIPng (RIP next generation)
    - EIGRP for IPv6
    - OPSFv3
    - IS-IS
    - MP-BGP4 (MultiProtocol BGP-4)

Routing

- IPv4 routing is enabled by default on a Cisco IOS router
- IPv6 routing is disabled by default
- Enter the command '*IPv6 unicast-routing*' to enable it
- You can still configure IPv6 addresses on a router without ipv6 unicast-routing enabled and send and receive IPv6 traffic, but the router will not forward IPv6 traffic to other networks

Connected and Local Routes

- The administrator configures IP addresses on the router's interfaces

```
Router# show run
Interface FastEthernet0/0
  Ip address 10.10.1.1 255.255.255.0
  Duplex full
  Ipv6 address 2001:DB8:0:1::1/64
!
Interface FastEthernet2/0
  Ip address 10.10.0.1 255.255.255.0
  Duplex full
  Ipv6 address 2001:DB8::1/64
```

Show ip route - IPv4 Routes

- This will automatically enter connected and local routes in the routing table
- Local IPv5 routes always have a /32 mask and show the IP address configured on the interface

```
Router# show ip route
Codes: I - IGRP derived, R - RIP derived, O - OSPF derived
       C - connected, S - static, E - EGP derived, B - BGP derived
       * - candidate default route, IA - OSPF inter area route
       E1 - OSPF external type 1 route, E2 - OSPF external type 2 route
Gateway of last resort is 131.119.254.240 to network 129.140.0.0
O E2 150.150.0.0 [160/5] via 131.119.254.6, 0:01:00, Ethernet2
E    192.67.131.0 [200/128] via 131.119.254.244, 0:02:22, Ethernet2
O E2 192.68.132.0 [160/5] via 131.119.254.6, 0:00:59, Ethernet2
O E2 130.130.0.0 [160/5] via 131.119.254.6, 0:00:59, Ethernet2
```

```
E    128.128.0.0 [200/128] via 131.119.254.244, 0:02:22, Ethernet2
E    129.129.0.0 [200/129] via 131.119.254.240, 0:02:22, Ethernet2
E    192.65.129.0 [200/128] via 131.119.254.244, 0:02:22, Ethernet2
E    131.131.0.0 [200/128] via 131.119.254.244, 0:02:22, Ethernet2
E    192.75.139.0 [200/129] via 131.119.254.240, 0:02:23, Ethernet2
E    192.16.208.0 [200/128] via 131.119.254.244, 0:02:22, Ethernet2
E    192.84.148.0 [200/129] via 131.119.254.240, 0:02:23, Ethernet2
E    192.31.223.0 [200/128] via 131.119.254.244, 0:02:22, Ethernet2
E    192.44.236.0 [200/129] via 131.119.254.240, 0:02:23, Ethernet2
E    140.141.0.0 [200/129] via 131.119.254.240, 0:02:22, Ethernet2
E    141.140.0.0 [200/129] via 131.119.254.240, 0:02:23, Ethernet2
```

Show ipv6 route - Connected Routes

- Local routes always have a /128 mask and show the IP address configured on the interface

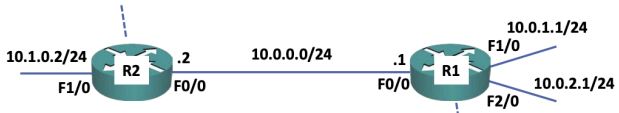
```
Router# show ipv6 route
IPv6 Routing Table - default - 3 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP
external
       ND - Neighbor Discovery
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C 2001:DB8::/64 [0/0] via Ethernet0/0, directly connected
L 2001:DB8::1/128 [0/0] via Ethernet0/0, receive
L FF00::/8 [0/0] via Null0, receive
```

- If a router receives traffic for a network which it's not directly attached to, it needs to know how to get there in order to forward the traffic
- An administrator can manually add a static route to the destination, or the router can learn it via a routing protocol

IPv4/6 Static Routes Configuration

IPv4

```
ip route 10.0.1.0 255.255.255.0 10.0.0.1
ip route 10.0.2.0 255.255.255.0 10.0.0.1
```




```
ip route 10.1.0.0 255.255.255.0 10.0.0.2
```

IPv6

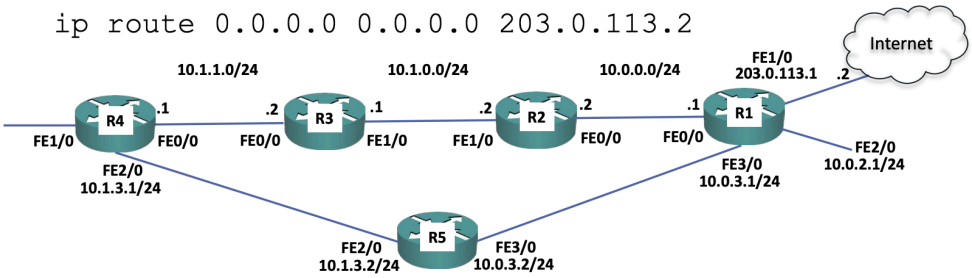
```
ipv6 route 2001:DB8:0:2::/64 2001:DB8:0:1::1
ipv6 route 2001:DB8:0:3::/64 2001:DB8:0:1::1
```


```
ipv6 route 2001:DB8::/64 2001:DB8:0:1::2
```

IPv4/6 Summary and Default Route

IPv4

```
ip route 10.1.0.0 255.255.0.0 10.0.0.2
ip route 10.1.3.0 255.255.255.0 10.0.3.2
ip route 0.0.0.0 0.0.0.0 203.0.113.2
```



IPv6

```
ipv6 route 2001:DB8:0::/48 2001:DB8:0::2
ipv6 route 2001:DB8:1:1::/64 2001:DB8:1::2
ipv6 route ::/0 2001:DB8:3::2
```