HO CHI MINH CITY UNIVERSITY OF SCIENCE
FACULTY OF ELECTRONICS AND TELECOMMUNICATIONS
DEPARTMENT OF TELECOMMUNICATIONS AND NETWORKS

COURSE

COMPUTER NETWORKS

Chapter 05

IP VERSION 6

Reference: Peter L Dordal, "An Introduction to Computer Networks," Feb 05, 2022

Lecturer: Nguyen Viet Ha, Ph.D. Email: nvha@fetel.hcmus.edu.vn

IPv6 – Why We Need More Address Space

IPv4 Address Allocation

1993

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
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240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255

Allocated

Unavailable

Available

16,777,216 addresses

IPv6 – Why We Need More Address Space

IPv4 Address Allocation

2000

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IPv6 – Why We Need More Address Space

IPv4 Address Allocation

2007

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IPv6 – Why We Need More Address Space

IPv4 Address Allocation

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16,777,216 addresses

IPv6 – Why We Need More Address Space

IPv4 Address Allocation

February 2011

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Allocated

Unavailable

Available

16,777,216 addresses

IPv6 – Why We Need More Address Space

❖ **Address Availability:**

➢ **IPv4:** 4 octets - 32 bits

- 2^32 *or* 4,294,467,295 IP Addresses.

➢ **IPv6:** 16 octets - 128 bits

- 2^128 ≈ 3.4 x 10^38 *or*

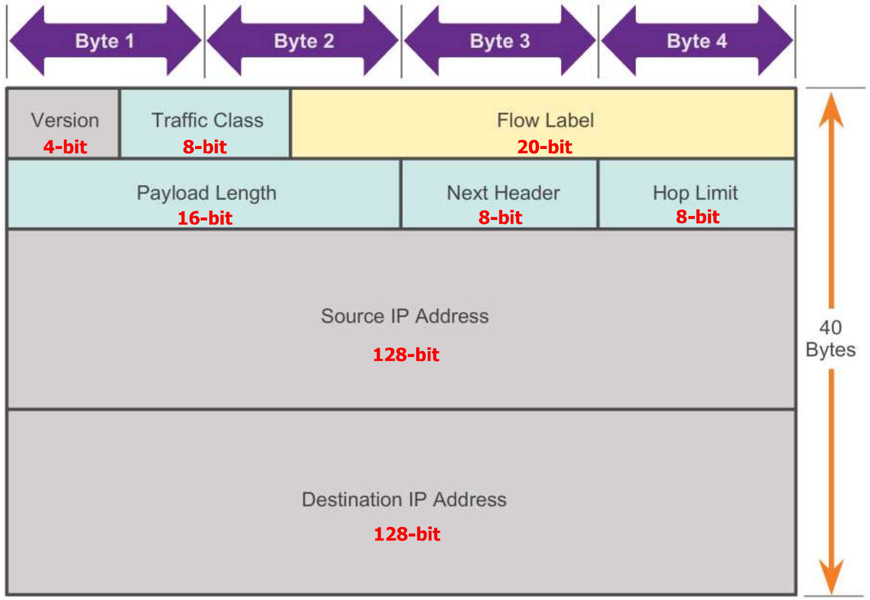
340,282,366,920,938,463,463,374,607,431,768,211,456

(340 undecillion) IP Addresses.

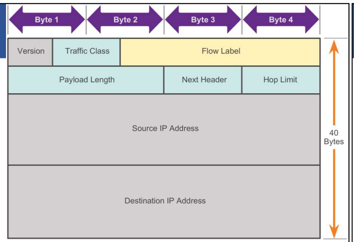
Number Name	Scientific Notation	Number of Zeros
1 Thousand	10^3	1,000
1 Million	10^6	1,000,000
1 Billion	10^9	1,000,000,000
1 Trillion	10^12	1,000,000,000,000
1 Quadrillion	10^15	1,000,000,000,000,000
1 Quintillion	10^18	1,000,000,000,000,000,000
1 Sextillion	10^21	1,000,000,000,000,000,000,000
1 Septillion	10^24	1,000,000,000,000,000,000,000,000
1 Octillion	10^27	1,000,000,000,000,000,000,000,000,000
1 Nonillion	10^30	1,000,000,000,000,000,000,000,000,000,000
1 Decillion	10^33	1,000,000,000,000,000,000,000,000,000,000,000
1 Undecillion	10^36	1,000,000,000,000,000,000,000,000,000,000,000,000

1 The IPv6 Header

1. The IPv6 Header



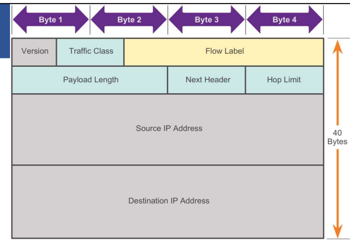
1. The IPv6 Header



- ❖ Fixed header (40 bytes)
  - ➢ No support for fragmentation
  - ➢ No header checksum
  - ➢ No option fields.

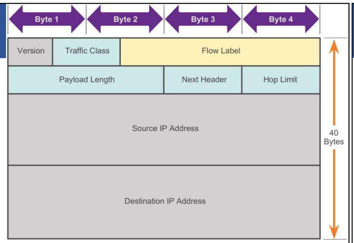
    - ○ **Extension headers** has been introduced to support some of these as options. (latter in Section 5)

1. The IPv6 Header



- ❖ **Version:** 4-bit, identifying the IP packet version (0110).
- ❖ **Traffic Class:** 8-bit, is equivalent to the IPv4 'Differentiated Services' field
- ❖ **Payload Length:** 16-bit, is equivalent to the IPv4 'Total Length' field.
- ❖ **Next Header:** 8-bit, is equivalent to the IPv4 'Protocol' field.
- ❖ **Hop Limit**: 8-bit, replaces the IPv4 'TTL' field.
- ❖ **Source Address:** 128-bit, identifies the IPv6 address of the sending host.
- ❖ **Destination Address:** 128-bit, identifies the IPv6 address of the receiving host.

1. The IPv6 Header



❖ **Flow Label:** 20-bit, be used by a source to label sequences of packets for which it requests **special handling** by the IPv6 routers, such as:

- Non-default quality of service
- "real-time" service.

➢ A flow, as the term is used here, is one-way; the return traffic belongs to a different flow.

➢ All packets belonging to the same flow should have the same Routing Extension header.

2 IPv6 Addresses

2. IPv6 Addresses

❖ **Hexadecimal** is a base sixteen system

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

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

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

2. IPv6 Addresses

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

❖ 32 hexadecimal values = IPv6 address

2001:0DB8:0000:1111:0000:0000:0000:0200
FE80:0000:0000:0000:0123:4567:89AB:CDEF

❖ **Hextet** used to refer to a segment of 16 bits or four hexadecimals

❖ Can be written in either lowercase or UPPERCASE

2. IPv6 Addresses

❖Rule 1- Omitting Leading 0s

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

- 01AB can be represented as 1AB
- 09F0 can be represented as 9F0
- 0A00 can be represented as A00
- 00AB can be represented as AB

Preferred	2001:0DB8:0000:1111:0000:0000:0000:0200
No leading 0s	2001: DB8: 0:1111: 0: 0: 0: 200

Preferred	0000:0000:0000:0000:0000:0000:0000:0001
No leading 0s	0: 0: 0: 0: 0: 0: 0: 1

2. IPv6 Addresses

❖Rule 2- Omitting All 0 Segments

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

➢Known as the *compressed format*

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

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

```
1843:0f01:0000:0000:0022:0000:0000:00fa    ?
1843:0f01:0000:0000:0000:0022:0000:00fa    ?
1843:0f01:0000:0022:0000:0000:0000:00fa    ?
```


2. IPv6 Addresses

❖Interface identifiers

➢IPv6 addresses can be divided into a 64-bit network prefix and a 64-bit "host" portion.

- ○ host-portion bits are known officially as the interface identifier.

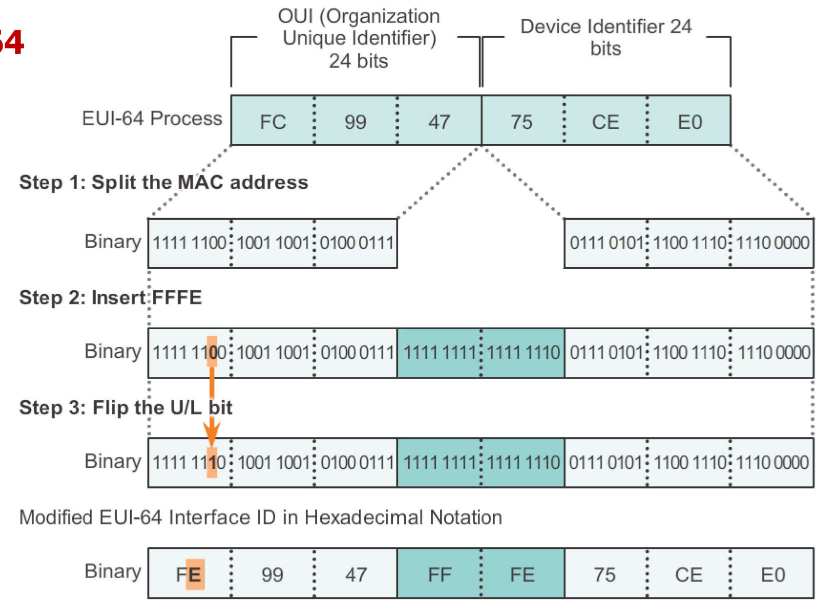
❖Original plan for the interface identifier was to derive it in most cases from the LAN address.

➢48 bits → 64 bits ???

- ○ **EUI-64**

2. IPv6 Addresses

❖EUI-64



2. IPv6 Addresses

❖**EUI-64**

➢Review MAC Address:

```
0         8         16        24        32        40        48  (bit)
+---------+---------+---------+---------+---------+---------+
|ccccccUG:cccccccc:cccccccc:mmmmmmmm:mmmmmmmm:mmmmmmmm|
+---------+---------+---------+---------+---------+---------+
```

- **"c"** is the bits of the assigned company_id,
- **"m"** is the bits of the manufacturer selected extension identifier.
- **"U"** is the value of the Universal/Local bit.
  - 0: Universal, i.e., MAC address is the burned-in-address (BIA)
  - 1: Local, i.e., MAC address that has been changed locally
- **"G"** is individual/group bit
  - 0: individual (i.e., unicast)
  - 1: group (i.e., multicast/broadcast)

2. IPv6 Addresses

❖**EUI-64**

➢A **major privacy concern**:

- No matter where a host connects to the Internet – home or work or airport or Internet cafe
  - Such an interface identifier always remains the same, and thus serves as a permanent host fingerprint.

➢Now **discouraged for personal** workstations and mobile devices. (Only for some fixed-location hosts)

2. IPv6 Addresses

❖**An alternative (RFC 7217):**

➢The interface identifier is a **secure hash** of:

- A "Net_Iface" parameter.
  - The interface's MAC address,
  - Or the interface's "name", e.g., eth0.
- 64-bit IPv6 address prefix.
- A host-specific secret key.

➢Interface identifiers created this way change from connection point to connection point (because the prefix changes).

2. IPv6 Addresses

❖**Link-local addresses:**

➢Used only on a single LAN and **never routed**.

➢ **FE80::/64**

- The remaining 64 bits are the interface identifier (EUI-64 or "Hashing" methods).

➢**Applications:**

- A "bootstrap" address for global-address auto-configuration
- An optional permanent address for routers.
  - IPv6 routers often communicate with neighboring routers via their link-local addresses.

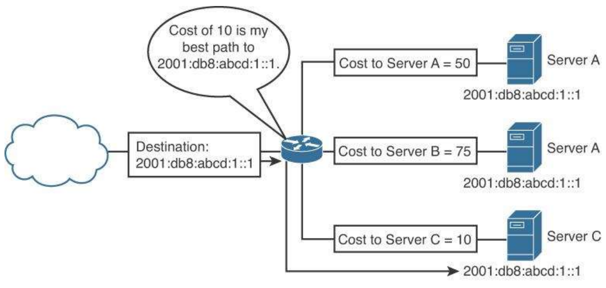
2. IPv6 Addresses

❖**Anycast addresses:**

➢Assigned to each of a set of routers.

➢A packet addressed to this anycast address would be delivered to only one member of this set.

➢It is up to the local routing infrastructure to decide which member of the anycast group would receive the packet; normally it would be sent to the "closest" member.



https://www.ciscopress.com/articles/article.asp?p=2803866&seqNum=6

3 Network Prefixes

3. Network Prefixes

❖IPv6 address is composed of a 64-bit network prefix and a 64-bit interface identifier.

❖Routers still uses **CIDR** (10.1 Classless Internet Domain Routing: CIDR) and still bases forwarding decisions on prefixes shorter than /64.

❖64-bit network prefixes are supplied by a provider, and which represent the first half of globally routable IPv6 addresses.

➢These are the prefixes that will be visible to the outside world.

3. Network Prefixes

❖IPv6 customers will typically be assigned a relatively large block of addresses, *e.g.,* "/48" or "/56".

➢The former allows 64–48=16 bits for local "subnet" specification within a 64-bit network prefix

➢The latter ("/56") allows 8 subnet bits.

2. IPv6 Addresses

❖**Unique Local** Unicast Address:

- Corresponding to IPv4 private address blocks like 192.168.0.0/16, 172.16.0.0/12, and 10.0.0.0/8.
- The first 8 bits of a unique-local prefix are 1111 1101 (fd00::/8).
- The related prefix 1111 1100 (fc00::/8) is reserved for future use.
- The last 16 bits of a 64-bit unique-local prefix represent the subnet ID, and are assigned either administratively or via autoconfiguration.
- The 40 bits in between, from bit 8 up to bit 48, represent the Global ID.
  - A site is to set the Global ID to a pseudorandom value.

4 IPv6 Multicast

4. IPv6 Multicast

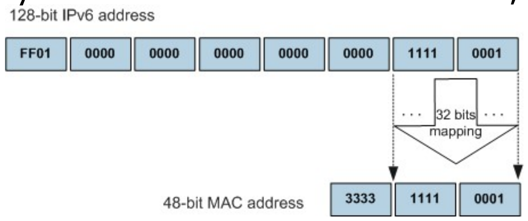
❖IPv6 has no LAN-layer broadcast.

- Providing a wide range of LAN-layer multicast groups.
- Intended to limit broadcast traffic in general, though many switches still propagate LAN multicast traffic everywhere, like broadcast.
- **ff00::/8**

4. IPv6 Multicast

❖For actual delivery, IPv6 multicast addresses correspond to LAN-layer (e.g., Ethernet) multicast addresses through a well-defined static correspondence.

- If x, y, z and w are the last four bytes of the IPv6 multicast address, in hex,
  - →Ethernet multicast address is **33:33:**x:y:z:w.



❖**ff02::1**

- All-nodes
- Ethernet multicast address: **33:33:**00:00:00:01.

❖**ff02::2**

- All-routers.
- Ethernet multicast address: **33:33:**00:00:00:02.

4. IPv6 Multicast

- IPv6 nodes on Ethernets send LAN-layer Multicast Listener Discovery (MLD) messages to multicast groups they wish to start using.
  - These messages allow multicast-aware Ethernet switches to optimize forwarding so that only those hosts that have subscribed to the multicast group in question will receive the messages.
  - Otherwise, switches are supposed to treat multicast like broadcast;
  - Worse case, some switches may simply fail to forward multicast packets to destinations that have not explicitly opted to join the group.

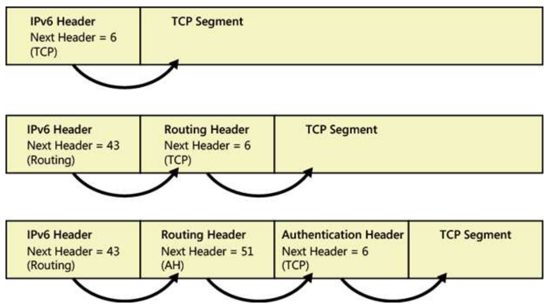
5 IPv6 Extension Headers

5. IPv6 Extension Headers

- Hop-by-Hop options header
- Destination options header
- Routing header
- Fragment header
- Authentication header
- Mobility header
- Encapsulated Security Payload header

5. IPv6 Extension Headers

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Next Header  |  Hdr Ext Len  |                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+                               +
|                                                               |
.                                                               .
.                  Header Specific Data                         .
.                                                               .
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```



5. IPv6 Extension Headers

❖**Hop-by-Hop options header**

- Consists of a set of ***<type,value>*** pairs which are intended to be processed by each router on the path.
  - The only Hop-by-Hop options provided by RFC 2460 were for padding, so as to set the alignment of later headers.
  - RFC 2675 later defined a Hop-by-Hop option to support IPv6 **jumbograms**: datagrams larger than 65,535 bytes.
- Because this options headers must be processed by each router encountered, they have the potential to overburden the Internet routing system. As a result, RFC 6564 strongly discourages new Hop-by-Hop Option headers, unless examination at every hop is essential.

5. IPv6 Extension Headers

❖**Destination Options Header**

- Consists of a set of ***<type,value>*** pairs, and the original RFC 2460 specification only defined options for padding. (similar to the Hop-by-Hop Options header)
- Since **RFC 2460**, a few more Destination Options header types have been defined, though none is in common use.

5. IPv6 Extension Headers

❖**Destination Options Header**

- **RFC 2473** defined a Destination Options header to limit the nesting of tunnels, called the Tunnel Encapsulation Limit.
  - Specifies how many additional levels of encapsulation are permitted to be prepended to the packet

✓*One node encapsulates original packets received from other nodes or from itself and forwards the resulting tunnel packets through the tunnel.*

5. IPv6 Extension Headers

❖**Destination Options Header**

- **RFC 6275** defines a Destination Options header for use in Mobile IPv6.
- **RFC 6553**, on the Routing Protocol for Low-Power and Lossy Networks (RPL), has defined a Destination (and Hop-by-Hop) Options type for carrying RPL data.

5. IPv6 Extension Headers

❖Routing Header

- ➢The original, or **Type 0**, Routing header contained a list of IPv6 addresses through which the packet should be routed. These did not have to be contiguous.
  - ○Ex:
    - ▪ The list to be visited enroute to destination ***D*** was $R_1, R_2, \ldots, R_n$.
    - ▪ Then this option header contained $\langle R_2, R_3, \ldots, R_n, D \rangle$ with ***R1*** as the initial destination address;
    - ▪ ***R1*** then would update this header to $\langle R_1, R_3, \ldots, R_n, D \rangle$, and would send the packet on to ***R2***.
    - ▪ This was to continue on until R_n addressed the packet to the final destination ***D***.

5. IPv6 Extension Headers

❖Routing Header

- ➢The original, or **Type 0**, Routing header contained a list of IPv6 addresses through which the packet should be routed. These did not have to be contiguous.
  - ○Ex: (continue)
    - ▪ The header contained a Segments Left pointer indicating the next address to be processed, incremented at each R_i. When the packet arrived at ***D*** the ***Routing Header*** would contain the routing list $\langle R_1, R_2, \ldots, R_n \rangle$.
    - ▪ Note, however, that routers between the listed routers $R_1 \ldots R_n$ did not need to examine this header; they processed the packet based only on its current destination address.

5. IPv6 Extension Headers

❖Routing Header (cont.)

- ➢This form of routing header was deprecated by **RFC 5095**, due to concerns about a traffic-amplification attack.
  - ○An attacker could send off a packet with a routing header containing an alternating list of just two routers $\langle R_1, R_2, R_1, R_2, \ldots, R_1, R_2, D \rangle$
    - ▪ This would generate substantial traffic on the R1–R2 link.

5. IPv6 Extension Headers

❖Routing Header (cont.)

- ➢**RFC 6275** and **RFC 6554** define more limited routing headers.
  - ○**RFC 6275** defines a quite limited routing header to be used for IPv6 mobility (and also defines the IPv6 Mobility header).
  - ○**RFC 6554** routing header used for RPL (Routing Protocol for Low-Power and Lossy Networks), has the same basic form as the Type 0 header described above, but its use is limited to specific low-power routing domains.

5. IPv6 Extension Headers

❖ **IPv6 Fragment Header**

- Contains a 13-bit Fragment Offset field (as in IPv4) and a 32-bit Identification field.
- IPv6 fragmentation is done only by the **original sender**.
- Generally speaking, fragmentation should be avoided at the application layer when possible.

6 Neighbor Discovery

6. Neighbor Discovery

❖ A set of related protocols that replaces several IPv4 tools, most notably ARP, ICMP redirects and most non-address-assignment parts of DHCP.

❖ Provides the following services:

- Finding the local router(s)
- Finding the set of network address prefixes that can be reached via local delivery.
- Finding a local host's LAN address (e.g., MAC address), given its IPv6 address.
- Detecting duplicate IPv6 addresses.
- Determining that some neighbors are now unreachable

6. Neighbor Discovery

❖ **Router Discovery**

- IPv6 routers periodically send Router Advertisement (RA) packets to the all-nodes multicast group.
  - Hosts can request an RA packet immediately by sending a Router Solicitation (RS) request to the all-routers multicast group.
- RA packets contain:
  - Identification of the routers,
  - A list of all network address prefixes in use on the LAN.
  - An agreed-on MTU.

6. Neighbor Discovery

❖ **Prefix Discovery**

- ➢Support hosts to learn the network-address prefixes.
- ➢Router Advertisement packets contain a complete list of valid network-address prefixes, as the Prefix Information option.
- ➢Each prefix will have an associated lifetime.
  - o Nodes receiving a prefix from an RA packet are to use it only for the duration of this lifetime.
  - o On expiration a node must obtain a newer RA packet with a newer prefix list.

6. Neighbor Discovery

❖ **Neighbor Solicitation** (Similar to IPv4 ARP requests)

- ➢Sent to the solicited-node multicast address.
  - o ff02::0001:x.y.z.w.
    - ▪ x, y, z and w are the low-order 32 bits of the IPv6 address the sender is trying to look up.
  - o Each IPv6 host on the LAN will need to subscribe to all the solicited-node multicast addresses corresponding to its own IPv6 addresses.
- ➢Neighbor Solicitation messages are repeated regularly but follow up verifications are initially sent to the unicast LAN address on file.
- ➢The target host's response to a Neighbor Solicitation message is called **Neighbor Advertisement**.

6. Neighbor Discovery

7 IPv6 Host Address Assignment

7. IPv6 Host Address Assignment

❖IPv6 provides two competing ways for hosts to obtain their full IP addresses.

➢DHCPv6.

➢StateLess Address Auto Configuration (SLAAC)

7. IPv6 Host Address Assignment

❖**Duplicate Address Detection**

➢Whenever an IPv6 host obtains a unicast address it goes through a duplicate-address detection (DAD) process.

➢The host sends one or more Neighbor Solicitation messages, asking if any other host has this address.

- If anyone answers, then the address is a duplicate.

7. IPv6 Host Address Assignment

❖**Duplicate Address Detection**

➢A host is not allowed to use an IPv6 address if the DAD process has failed.

- If the DAD process fails for an address based on an EUI-64 identifier, then some other node has the same Ethernet address and you have bigger problems than just finding a working IPv6 address.

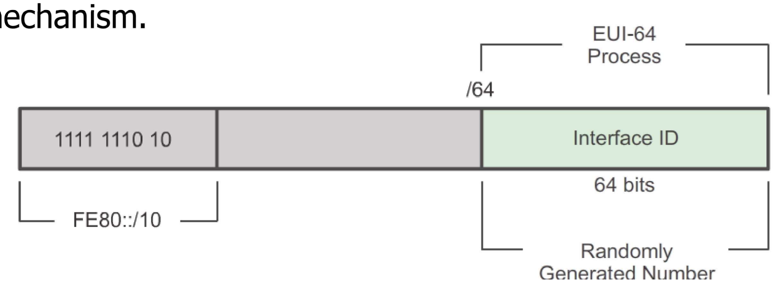
- If the DAD process fails for an address constructed with the Interface identifiers, the host is able to generate a new interface identifier and try again.

7. IPv6 Host Address Assignment

❖**Stateless Autoconfiguration (SLAAC)**

➢Host generates its link-local address, appending the standard 64-bit link-local prefix fe80::/64 to its interface identifier.

➢Derived from the host's LAN address using either EUI-64 or the RFC 7217 mechanism.



➢Do DAD.

7. IPv6 Host Address Assignment

❖**Stateless Autoconfiguration (SLAAC)**

➢If there is a router available.

- The **host** send a Router Solicitation (RS) message.
- A **router** answers with a Router Advertisement (RA) message that contains a Prefix Information option.
  - RA message will mark with a flag those prefixes eligible for use with SLAAC.
  - All prefixes will also be marked with a lifetime.
- The **host** chooses an appropriate prefix, stores the prefix-lifetime information, and appends the prefix to the front of its interface identifier
  - This is a routable address.
- Do DAD.

7. IPv6 Host Address Assignment

❖**Stateless Autoconfiguration (SLAAC)**

➢The **host** knows its IPv6 address and its default router but no DNS server.

- In **RFC 6106** now defines a process by which IPv6 routers can include DNS-server information in the RA packets they send to hosts as part of the SLAAC process.

7. IPv6 Host Address Assignment

❖**DHCPv6**

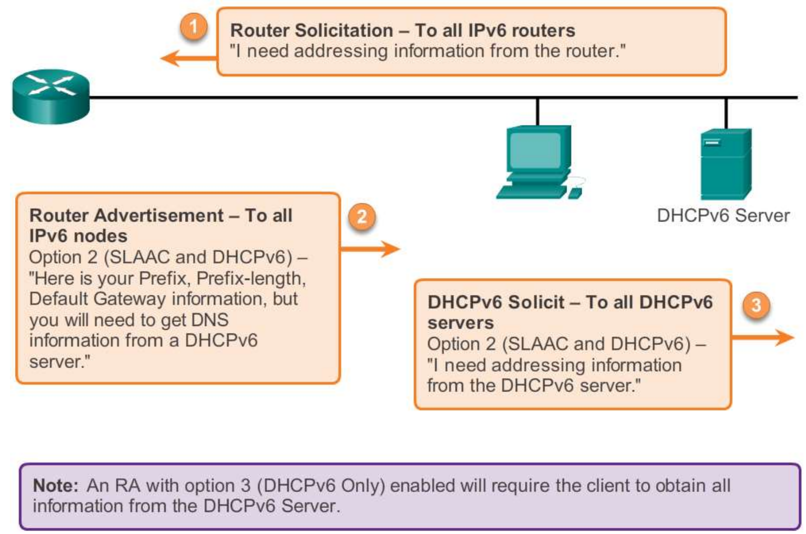
➢Similar to IPv4, host automatically receives addressing information including a global unicast address, prefix length, default gateway address and DNS server addresses

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

➢A device may obtain its IPv6 global unicast address dynamically and also be configured with multiple static IPv6 addresses on the same interface.

7. IPv6 Host Address Assignment

❖**DHCPv6**



8 ICMPv6

8. ICMPv6

- As part of the Neighbor Discovery Protocol.
- Messages are identified by 8-bit type and code (subtype) fields.
- Distinguishes between informational and error messages by the first bit of the type field.
- ICMPv6 includes an IPv6 version of Echo Request/Echo Reply, upon which the "ping6" command.

8. ICMPv6

- **Destination Unreachable**
  - In this case, one of the following numeric codes is returned:

    0: No route to destination, returned when a router has no *next_hop* entry.

    1: Communication with destination administratively prohibited, returned when a router has a *next_hop* entry, but declines to use it for policy reasons. Codes 5 and 6, below, are special cases of this situation; these more-specific codes are returned when appropriate.

    2: Beyond scope of source address, returned when a router is, for example, asked to route a packet to a global address, but the return address is not, e.g., is unique-local. In IPv4, when a host with a private address attempts to connect to a global address, NAT is almost always involved.

8. ICMPv6

- **Destination Unreachable**
  - In this case, one of the following numeric codes is returned:

    3: Address unreachable, a catchall category for routing failure not covered by any other message. An example is if the packet was successfully routed to the last_hop router, but Neighbor Discovery failed to find a LAN address corresponding to the IPv6 address.

    4: Port unreachable, returned when, as in ICMPv4, the destination host does not have the requested UDP port open.

    5: Source address failed ingress/egress policy, see code 1

    6: Reject route to destination, see code 1.

8. ICMPv6

❖**Packet Too Big**

➢This is like ICMPv4's "Fragmentation Required but Don't Fragment flag set"; IPv6 however has no router-based fragmentation.

❖**Time Exceeded**

➢This is used for cases where the Hop Limit was exceeded, and also where *source*-based fragmentation wasused and the fragment-reassembly timer expired.

❖**Parameter Problem**

➢This is used when there is a malformed entry in the IPv6 header, an unrecognized Next Header type, or an unrecognized IPv6 option.

9

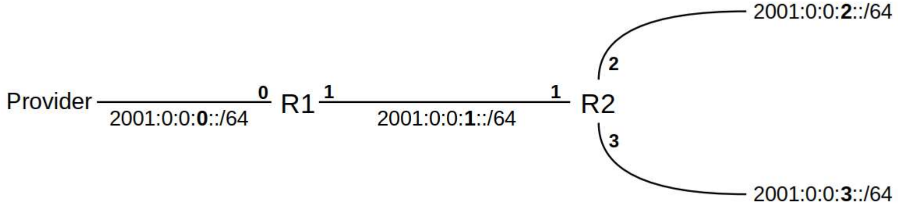
IPv6 Subnets

9. IPv6 Subnets

❖In IPv6, this is much simpler: all subnets are of size /64.

➢There is one common exception: RFC 6164 permits the use of 127-bit prefixes at each end of a point-to-point link. The 128th bit is then 0 at one end and 1 at the other.

❖A site receiving from its provider an address prefix of size /56 can assign up to 256 "/64 subnets".



9. IPv6 Subnets

❖If users *are* given only "/64" blocks, and they want to use subnets.

➢They have to break the 64/64 rule locally.

- Perhaps they can create four subnets each with a prefix of length 66 bits, and each with only 62 bits for the host identifier.
- Wanting to do that in a standard way would dictate more flexibility in the prefix/host division.

QA

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