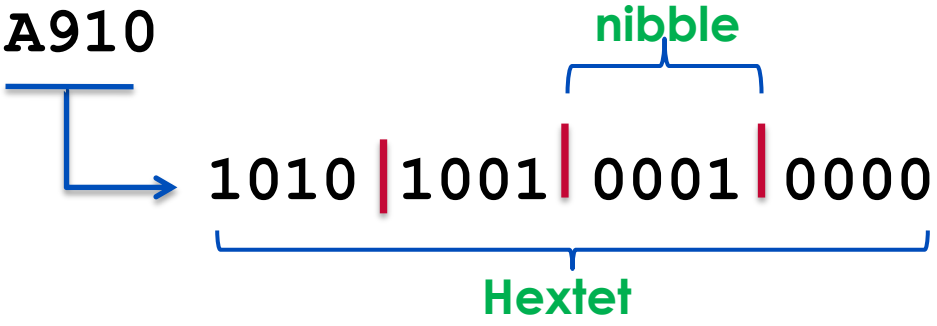
IPv6 Address Representation and Types

IPv6 Address Representation

- IPv6 address is 128 bits
- Number of IPv6 addresses : 2^128 ~ 3.4 x 10^{38}
- IPv6 address is represented in hexadecimal
  - 4-bits (nibble) represent a hexadecimal digit
  - 4 nibbles (16-bits) make a hextet
  - represented as eight hextets (4 nibbles or 16 bits), each separated by a colon (:)

2001:ABCD:1234::DC0:A910



IPv6 Address Representation (2)

2001:0DB8:0000:0000:0000:036E:1250:2B00

- Abbreviated form

2001:**0**DB8:**0000:0000:0000:0**36E:1250:2B00 ⇦ **Leading 0s**

  - Leading zeroes (**0**) in any hextet can be omitted
    2001:DB8:**0:0:0**:36E:1250:2B00 ⇦ **Sequence of 0s**
  - A double colon (**::**) can replace contiguous hextet segments of zeroes
    2001:DB8**::**36E:1250:2B00 ⇦ **Double colons**
  - (::) can only be used once!

IPv6 Address Representation (3)

- Double colons (::) representation
  - RFC5952 recommends that the largest set of :0: be replaced with :: for consistency

    2001:0:0:0:2F:0:0:5

    2001::2F:0:0:5 instead of 2001:0:0:0:2F::5

  - Where there is same number of :0:, the first set be replaced with ::

    2001:DB8:0:0:2F:0:0:5

    2001:DB8::2F:0:0:5 instead of 2001:DB8:0:0:2F::5

- Prefix Representation
  - Representation of prefix is similar to IPv4 CIDR

→ prefix/prefix-length

2001:DB8::/40

Quiz

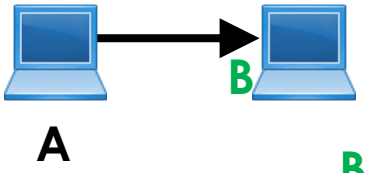
Please write the compressed format of these addresses:

1. 2001:0db8:0000:0000:0000:0000:0000:0000
2. 2001:0db8:0000:0000:d170:0000:0100:0ba8
3. 2001:0db8:0000:0000:00a0:0000:0000:10bc
4. 2001:0db8:0fc5:007b:ab70:0210:0000:00bb

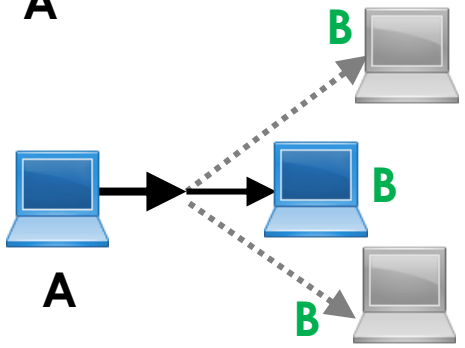
IPv6 Addressing Model

RFC 4291

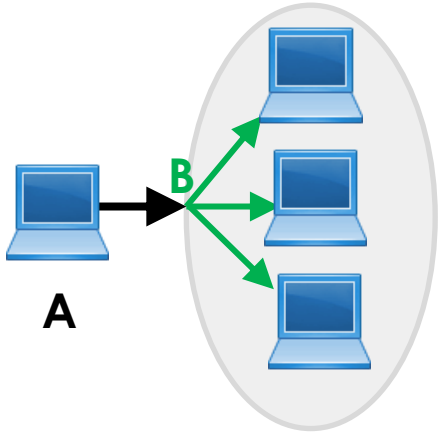
- Unicast Address
  - Assigned to a single interface
  - Packet sent only to the interface with that address



- Anycast Address
  - Same address assigned to more than one interface (on different nodes)
  - Packet for an anycast address routed to the nearest interface (routing distance)



- Multicast Address
  - group of interfaces (on different nodes) join a multicast group
  - A multicast address identifies the interface group
  - Packet sent to the multicast address is replicated to all interfaces in the group



Overview of IPv6 Address Types

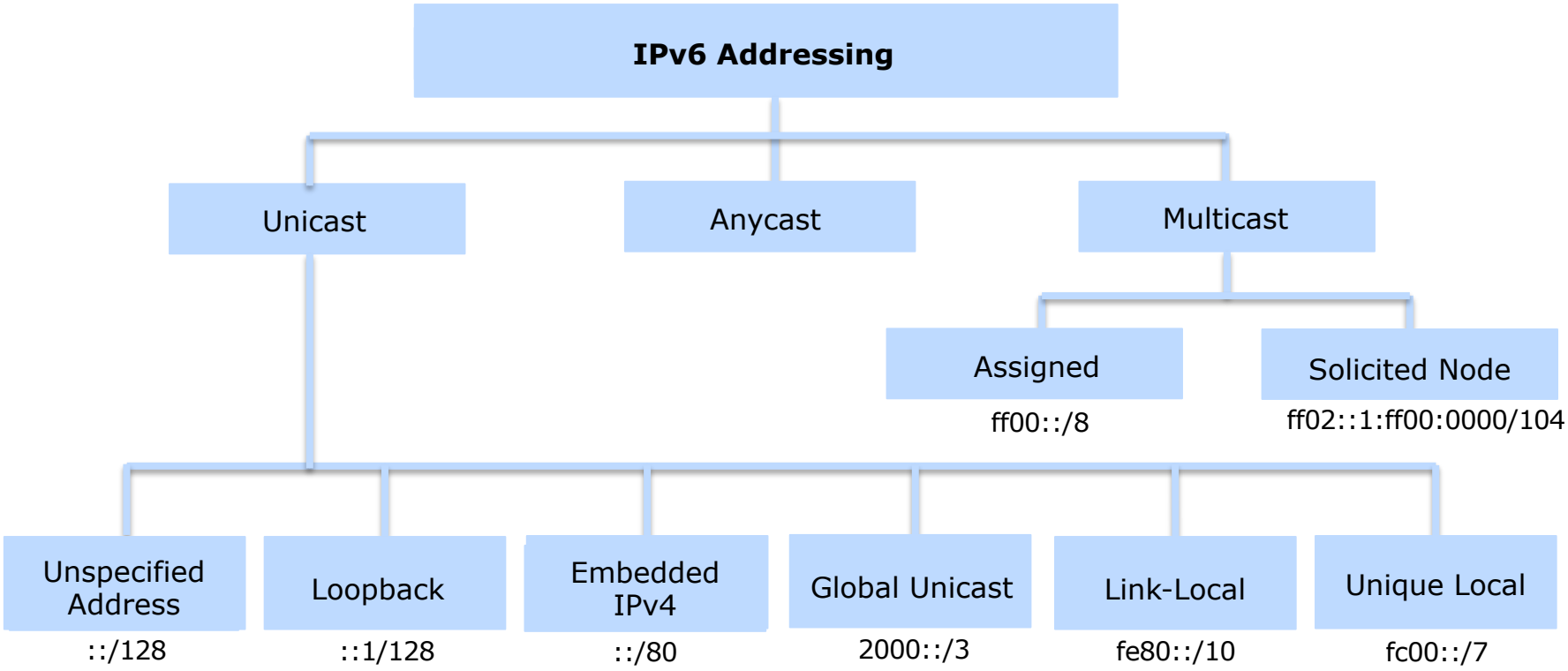


Figure 1: IPv6 Address Types

Figure 1: Adapted from Graziani, R. (2013). *IPv6 Fundamentals: A Straightforward Approach to Understanding IPv6.* USA: Cisco Press, Figure 4-1. IPv6 Address Types.

Special Unicast Addresses

- Unspecified Address (absence of a address)

  ::/128

- Loopback (test OSI/TCP-IP stack implementation)

  ::1/128

Global Unicast Addresses

- Globally unique and routable IPv6 address
- Currently, only global unicast address with first three bits of **001** have been assigned

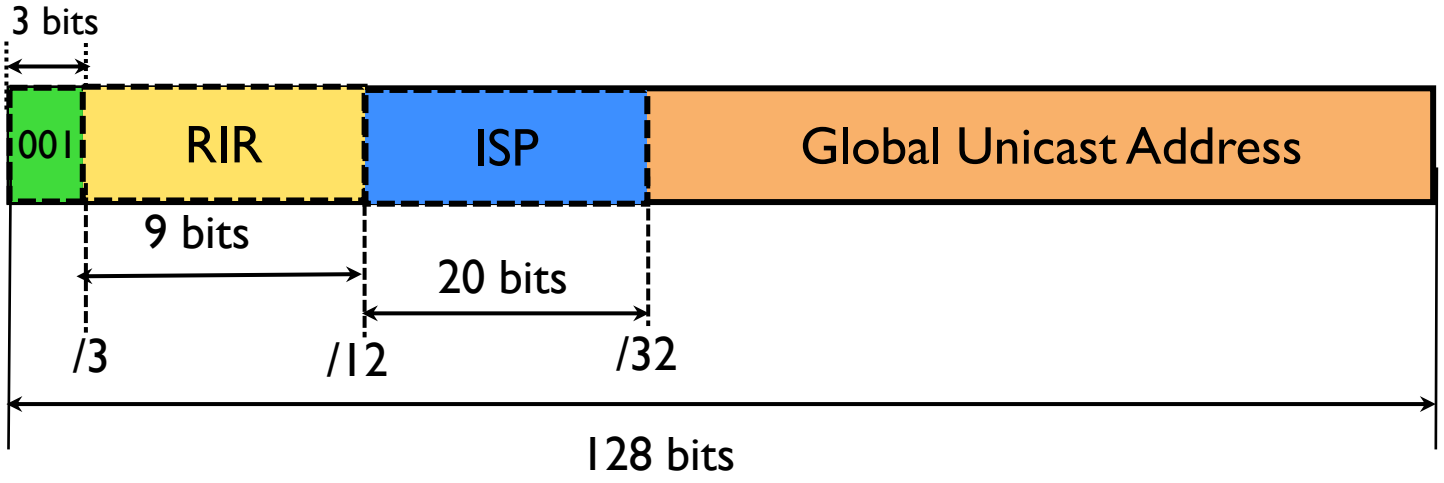
```
0010 0000 0000 0000 (2000::/3)

0011 1111 1111 1111 (3FFF::/3)
```

- IANA allocates from 2000-3FFF::/3 to each RIR

APNIC	2400::/12
ARIN	2600::/12
LACNIC	2800::/12
RIPE NCC	2A00::/12 & 2A10::/12
AfriNIC	2C00::/12

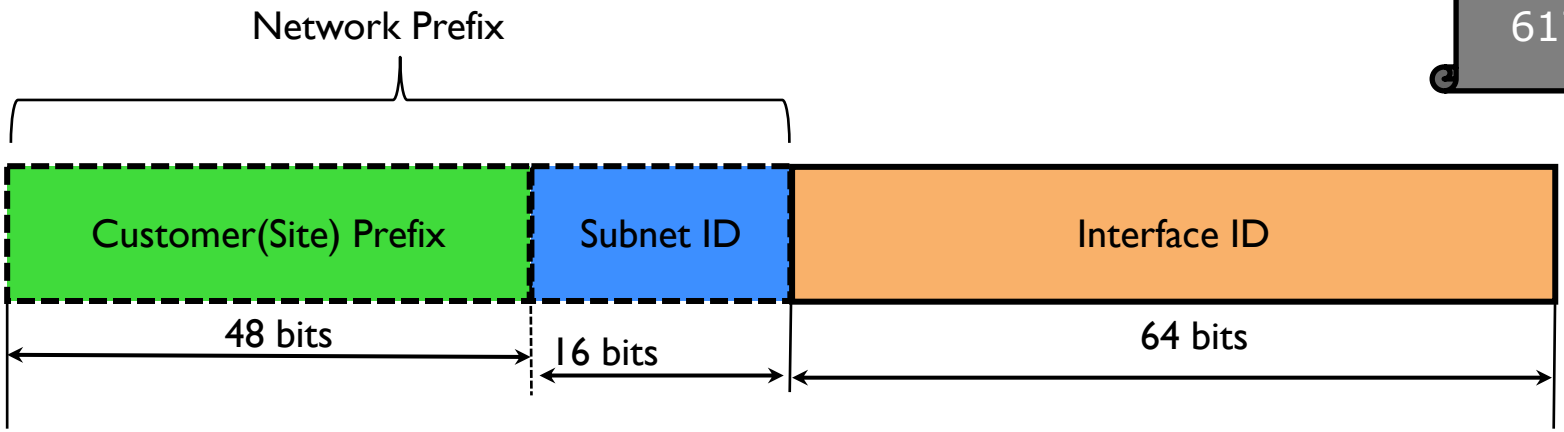
Global Unicast Addresses

- RIRs assign /32 to ISPs



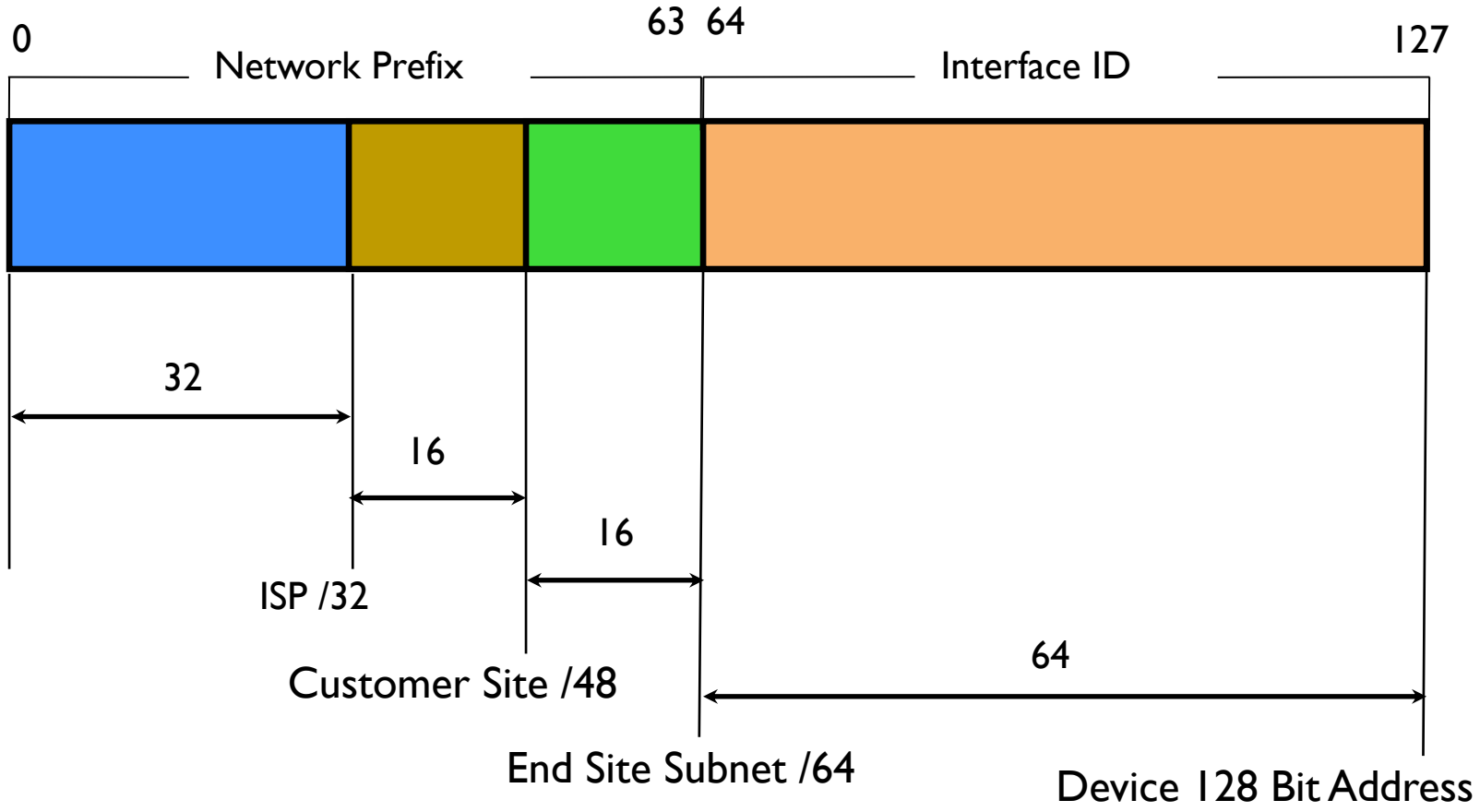
IPv6 Addressing Structure

RFC 6177



- Customer (Site) Prefix: assigned to a customer site
  - Group of subnets
  - ISPs/RIRs 'would' assign /48 (/56 to customers)
- Subnet ID: identifies the subnets (links) within a site
- Interface ID: host portion of the IPv6 address
  - how many hosts within a subnet

IPv6 Addressing Structure



Link-local Unicast Addresses

- Auto configured address (similar to APIPA)
  - Every IPv6 enabled device must have a link-local address
  - To communicate with other IPv6 devices on the same link
  - FE80::/10
- The link-local address is used by routers as the next-hop address when forwarding IPv6 packets
- All IPv6 hosts on a subnet/link, uses the router's link-local as the default gateway
  - Routers use the link-local as the source in ND-RA messages

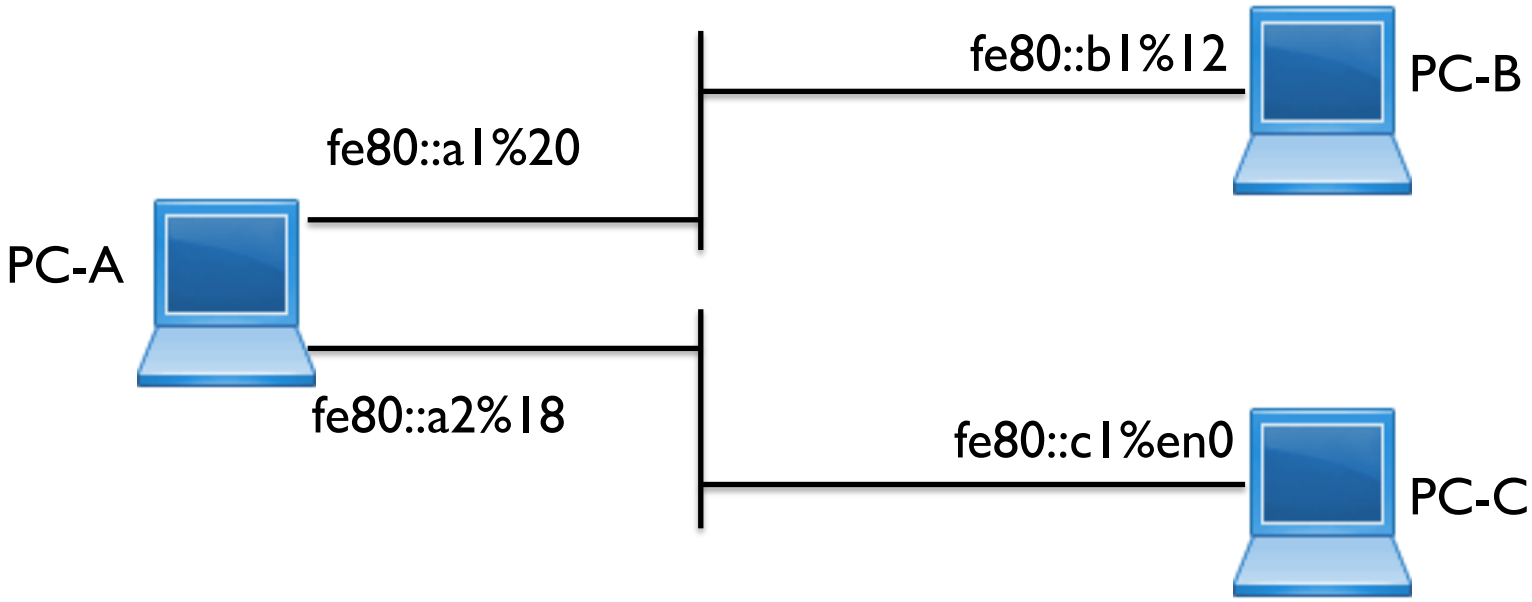
Zone IDs for Link-locals

Example 1 - `fe80::4e0:37e4:c5d1:c845`**`%en0`**
Example 2 - `fe80::aede:48ff:fe00:12`**`%15`**

- Zone IDs help uniquely distinguish which link/subnet an interface is connected to

- To ping a remote IPv6 node, use your interface zone ID (so that the response packet has a path)

Quiz - Zone ID

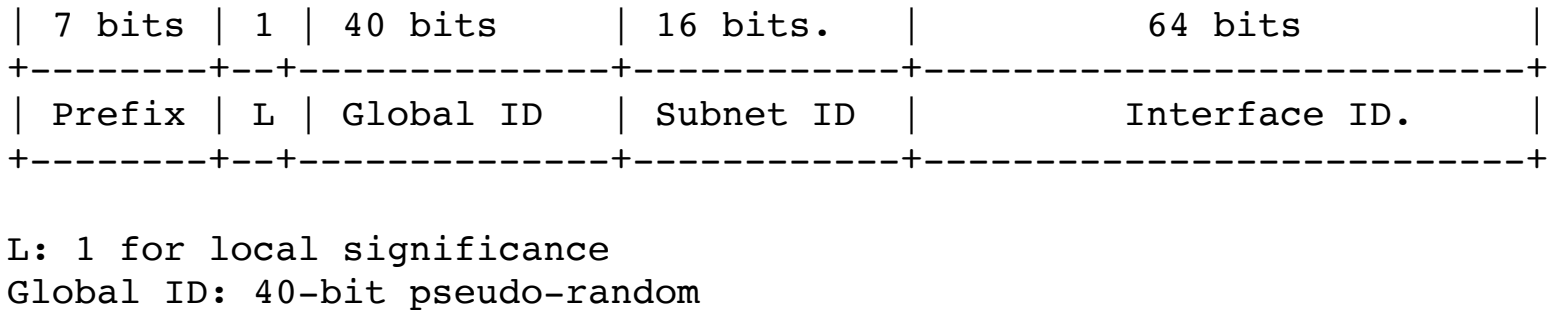


- Please write down the commands:
  - PC-A ping PC-B
  - PC-A telnet PC-C

Unique Local Unicast Addresses

- Similar to RFC1918 addresses (but within a “site”)
  - Unique within a site
  - Routable within site(s)
  - Not ‘expected’ to be routed on the internet

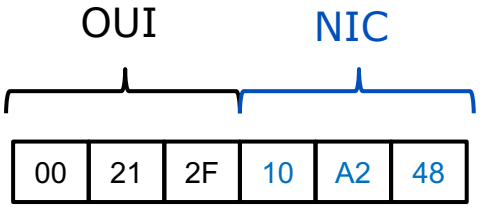
FC00::/7

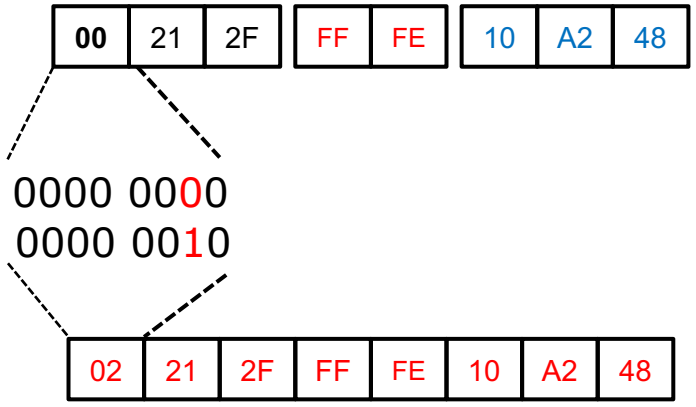


L: 1 for local significance
Global ID: 40-bit pseudo-random

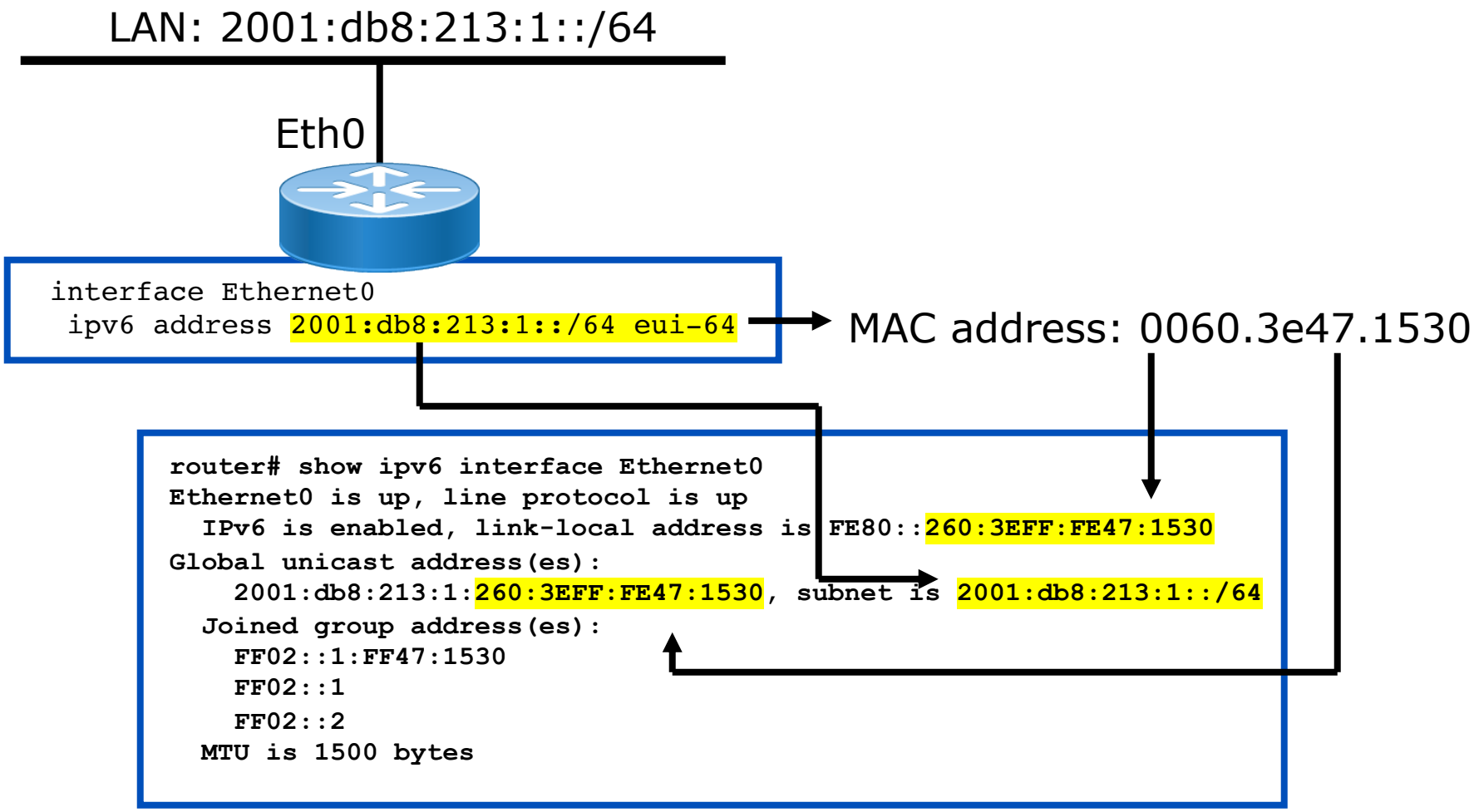
Modified EUI-64 format

- Allows IPv6 device to compute a unique 64 bit Interface ID using the interface MAC address (48 bit)
  - MAC address is split into two 24 bit halves
    - OUI and NIC
  - Then `0xFFFE` is inserted between the two halves
    - 0xFFFE is reserved value, not assigned to any OEM
  - Invert 7th bit (U/L) of the OUI to get the EUI-64 address
    - addresses assigned to OEMs have this bit set to `0` to indicate global uniqueness
    - Set to 1 (invert 0) to indicate IEEE identifier (MAC(is used, or 0 if otherwise (serials/tunnels).



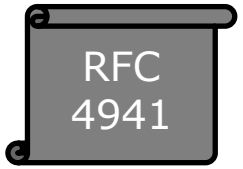


IPv6 Addressing EUI-64



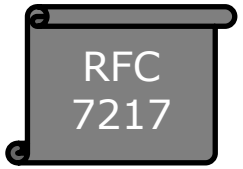
IPv6 Interface ID – Privacy

- Overcome the ability to track (interface ID based on MAC address):
  - Temporary address (changes): outgoing connections
  - Secured address: incoming connection




```
Temp    > 2001:db8:a000:4:84a3:49b6:1919:26fb
Secured> 2001:db8:a000:4:aede:48ff:fe08:112
Temp    > 2001:db8:a000:4:14e6:d4a3:815d:91dd
```

- Ease network management yet improve privacy:
  - Stable interface identifiers for each subnet




```
Temp    > 2001:db8:a000:4:84a3:49b6:1919:26fb
Secured> 2001:db8:a000:4:cbb:347c:6215:1083
```

Well-known Multicast Addresses

- Multicast addresses can only be destinations and never a source

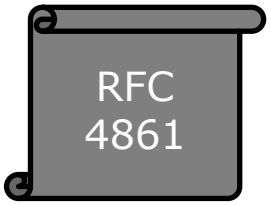
  `FF00::/8`

- Pre-defined multicast addresses:
  - `FF02::1` All nodes multicast
    - All IPv6 enabled devices join this multicast group
    - Packets sent to this address is received by all nodes
  - `FF02::2` All routers multicast
    - The moment IPv6 is enabled on a router (`#ipv6 unicast-routing`), the router becomes a member of this group
  - **`FF02::1:FF`**`XX:XXXX/104` Solicited Node multicast
    - NS messages (~ARP request) are sent to this address
    - Uses the least significant 24-bits of its unicast/anycast address
    - Must compute and join for every unicast (link-local & global) on a interface

Well-known Multicast Addresses

- Pre-defined multicast addresses:
  - `FF02::1:2` All DHCP Servers/Relay Agents
    - Clients use this multicast address to discover any DHCPv6 servers/relays on the local link (link-scoped)
  - `FF05::1:3` All DHCP servers
    - Generally used by Relays to talk to servers
    - Site-scoped

ICMPv6 Neighbor Discovery



- Router Solicitation (RS):
  - sent by IPv6 host to "all routers" multicast to request RA
- Router Advertisement (RA):
  - sent by a IPv6 router to the "all nodes" multicast (200 secs)
  - IPv6 prefix/prefix length, and default gateway
- Neighbor Solicitation (NS):
  - sent by IPv6 host to the "solicited node" multicast to find the MAC address of a given IPv6 address (~ARP request).
- Neighbor Advertisement (NA):
  - sent in response to a NS and informs of its MAC address.
- ICMPv6 Redirect:
  - informs the source of a better next-hop

IPv6 Neighbor Discovery (ND)

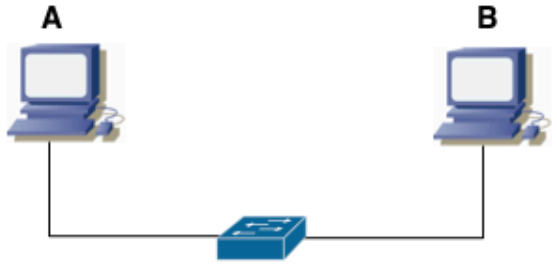
- Host **A** would like to communicate with Host B
  - Global address `2406:6400::10`
  - Link-local `fe80::226:bbff:fe06:ff81`
  - MAC address `00:26:bb:06:ff:81`

- Host **B** IPv6 global address `2406:6400::20`
  - Link-local **UNKNOWN** (if GW outside the link)
  - MAC address **UNKNOWN**

- How will Host A create L2 frame and send to Host B?

IPv6 Neighbor Discovery (ND)

Host A
IPV6 global address: 2406:6400::0010
IPv6 Link local: fe80::0226:bbff:fe06:ff81
MAC address: 00:26:bb:06:ff:81
Listen to other then above:
FF02::1 [All node multicast]
FF02:0:0:0:0:1:ff00:0010 [Solicited node m.cast unicast]
FF02:0:0:0:0:1:ff06:ff81 [Solicited node m.cast link local]



Multicast enable switch: Unicast by IGMP snooping
Non multicast enable switch: broadcast, PC LAN card filter or discard

Packet S: 2406:6400::0010 D:2406:6400::0020

ICMP6 NS Type 135 S: fe80::0226:bbff:fe06:ff81 D:FF02:0:0:0:0:1:ff00:0020

Frame S: 00:26:bb:06:ff:81 D 33:33:ff:00:00:20
Ethernet reserved IPv6 m.cast: 33:33:xx:xx:xx:xx

Host B
IPV6 global address: 2406:6400::0020
IPv6 Link local: fe80::0226:bbff:fe06:ff82 [Unknown to A]
MAC address: 00:26:bb:06:ff:82 [Unknown to A]
Listen to other then above:
FF02::1 [All node multicast]
FF02:0:0:0:0:1:ff00:0020 [Solicited node m.cast unicast]
FF02:0:0:0:0:1:ff06:ff82 [Solicited node m.cast link local]

Packet S: 2406:6400::0020 D:2406:6400::0010

ICMP6 NA Type 136 S: fe80::0226:bbff:fe06:ff82 D:fe80::0226:bbff:fe06:ff81

Frame S: 00:26:bb:06:ff:82 D 00:26:bb:06:ff:81

IPv6 Address Resolution

1

ICMPv6 NS Type135 — Multicast →

SMAC: 00:26:BB:06:FF:81	**DMAC:** 33:33:FF:00:00:20
Source IPv6: 2406:6400::0010	**Destination IPv6:** FF02:0:0:0:0:1:FF00:0020

RFC2464 – 33:33:xx:xx:xx:xx

2

← Unicast ICMPv6 NA Type136

SMAC: 00:26:BB:06:FF:82	**DMAC:** 00:26:BB:06:FF:81
Source IPv6: 2406:6400::0020	**Destination IPv6:** 2406:6400::0010

IPv6 Address Resolution

3

IPv6 Packet

Unicast

SMAC: 00:26:BB:06:FF:81	**DMAC:** 00:26:BB:06:FF:82
Source IPv6: 2406:6400::0010	**Dest IPv6:** 2406:6400::0020
Payload	

Unicast

4

IPv6 Packet

SMAC: 00:26:BB:06:FF:82	**DMAC:** 00:26:BB:06:FF:81
Source IPv6: 2406:6400::0020	**Dest IPv6:** 2406:6400::0010
Payload	

Address Resolution Packets

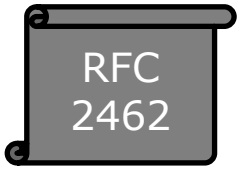
- Click this link to check the address resolution packets
- https://www.cloudshark.org/captures/eb1b377ffcad

IPv6 Address Auto-configuration

- Stateless address auto-configuration (SLAAC)
  - No manual configuration required
  - Gets the IPv6 prefix and prefix length through RA (local router)
  - EUI-64 for interface ID (pseudo random)

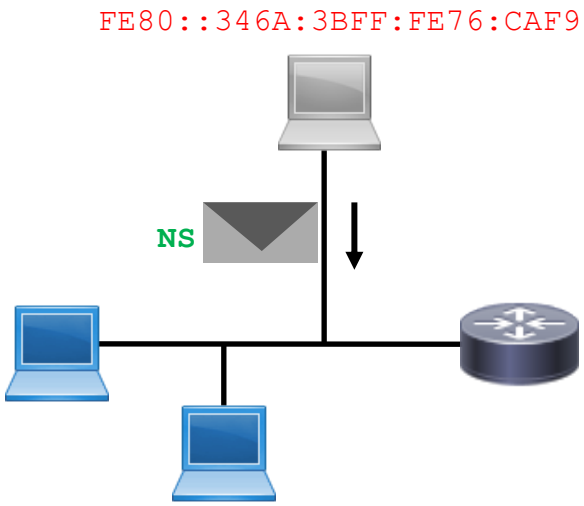
- Stateful - DHCPv6
  - To track address assignments

Stateless Address Autoconfig (1)



When a host joins a link/subnet:

- It auto-generates a link-local using the `FE80::/10` prefix and EUI-64:
  - Ex: `FE80::346A:3BFF:FE76:CAF9`

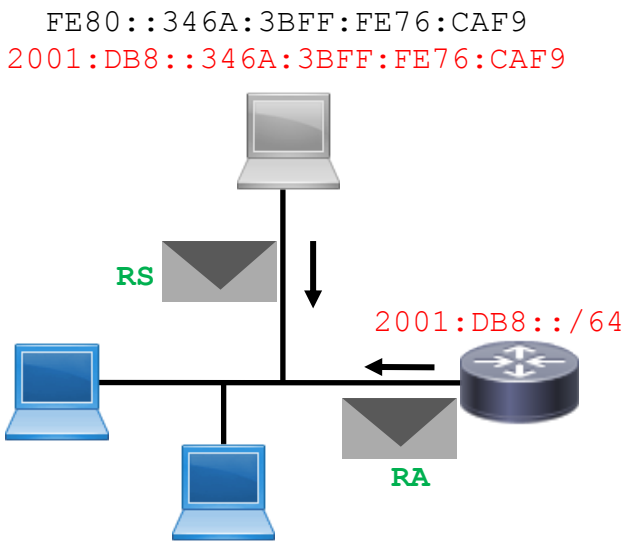


- DAD is performed on the link-local:
  - NS message is sent to the "solicited-node" multicast (`FF02::1:FF76:CAF9`), with `::/128` as the source
  - If no NA message is received back, the generated address is unique and can be used

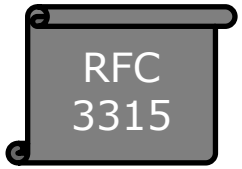
Stateless Address Autoconfig (2)

Once the node has a link-local address:

- sends a RS message to the "all-routers" multicast (FF02::2)
  - link-local as the source address
- The router responds with a RA message
  - IPv6 prefix and prefix length
  - link-local as the source
  - Auto flag by default (*Managed and Other flags are not set!*)
- The node generates the IPv6 address
  - uses the received prefix (2001:DB8::/64)
  - Interface ID (EUI-64)
  - 2001:DB8::346A:3BFF:FE76:CAF9
  - DAD not necessary (link-local validated for the same interface!)



DHCPv6 (1)



DHCPv6 is used:

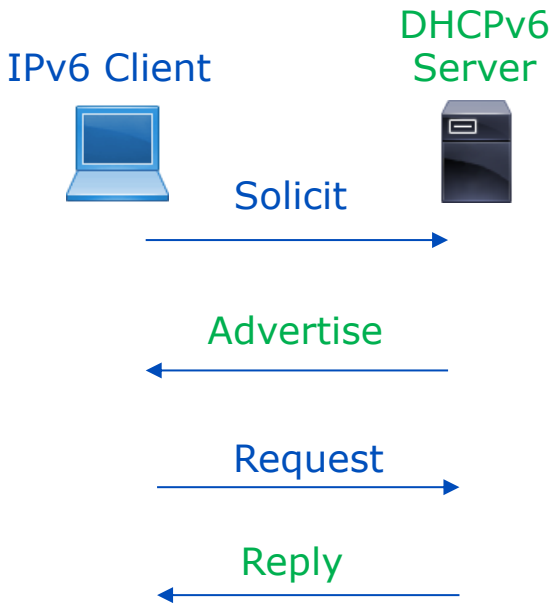
- If there are no router(s) on the subnet/link, OR
- If the RA message specifies to get addressing information via DHCPv6

If the router's RA message has the:

- O (other) flag set: ***stateless DHCPv6***
  - auto-generate IPv6 address using IPv6 prefix & prefix length in the RA
  - obtain other information (DNS server, domain) via DHCPv6
- M (managed) flag set:
  - obtain all addressing information via DHCPv6
  - 'O' flag is redundant

Stateful Autoconfig – DHCPv6 (2)

1. Client sends Solicit message to `FF02::1:2` to find any available DHCPv6 servers
2. Server responds with an Advertise message
   - the tentative IPv6 address/prefix
   - Other parameters (DNS, domain, default gateway, lease time)
   - *could receive multiple Advertise messages*
3. Client selects the server, and sends a Request asking to formally request the indicated IPv6 address
4. Server responds with a Reply to confirm the assignment
5. Performs DAD before using!




Questions