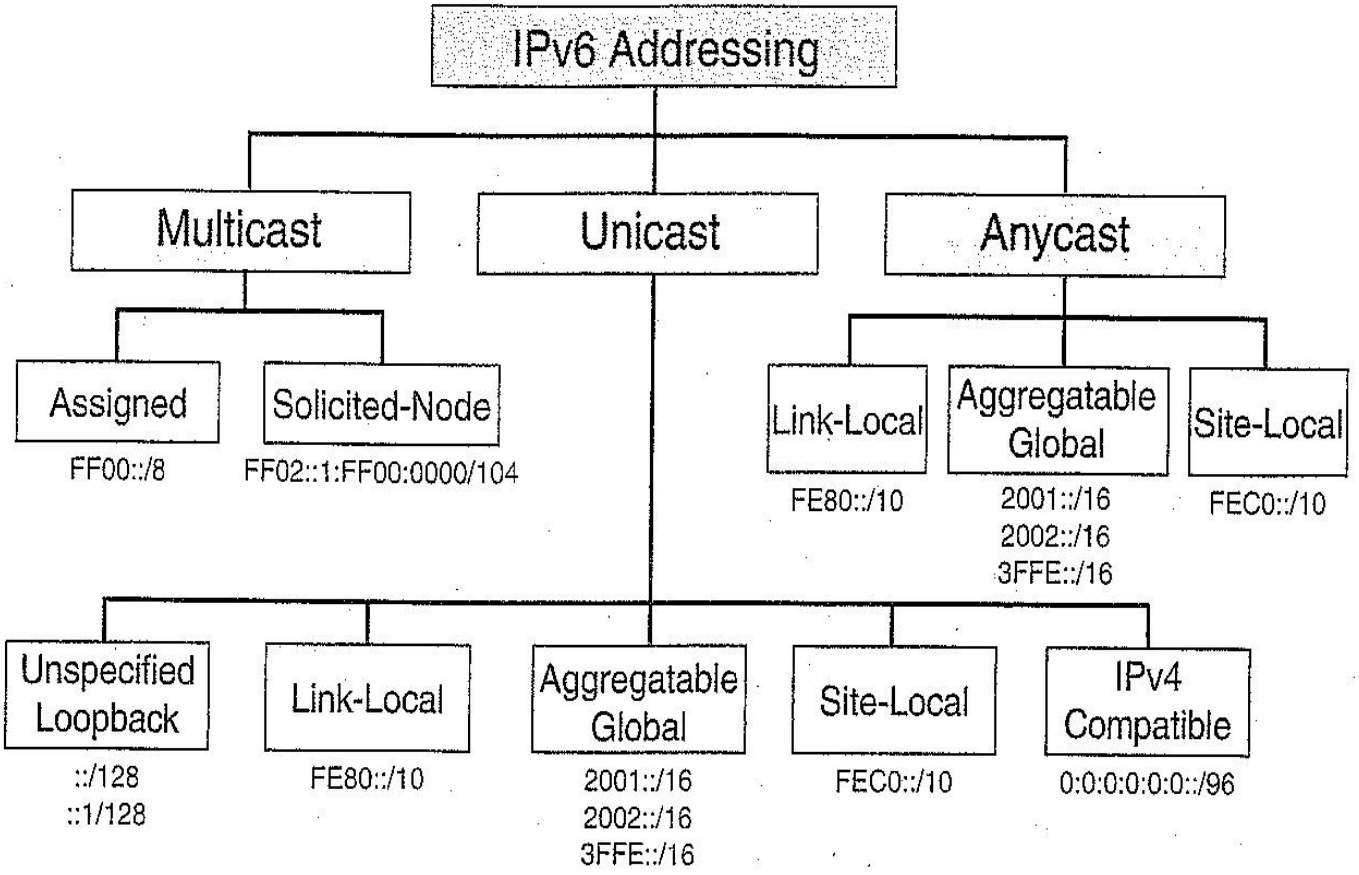
Module II
IPv6 Operation

- **Module 2.1: IPv6 Addressing Architecture**
- **Module 2.2: IPv6 Data Link Layer Support**
- **Module 2.3: ICMPv6 and Neighbor Discovery Protocols**

Module 2.1:
IPv6 Addressing Architecture

IPv6 Addressing Architecture

Types of Addresses of the IPv6 Addressing Architecture



Address Representation

Format:

- **x:x:x:x:x:x:x:x where x is a 16-bit hexadecimal field**
  - **2031:0000:130F:0000:0000:09C0:876A:130B**
  - **Case insensitive**
- **Leading zeros in a field are optional:**
  - **2031:0:130F:0:0:9C0:876A:130B**
- **Successive fields of 0 are represented as ::, but only once in an address:**
  - **2031:0:130F::9C0:876A:130B**
  - **2031::130F::9C0:876A:130B**
  - **FF01:0:0:0:0:0:0:1 => FF01::1**
  - **0:0:0:0:0:0:0:1 => ::1**
  - **0:0:0:0:0:0:0:0 => ::**

IPv6 Address Types

- **Unicast Address (2000::/3, one to one)**
  A unicast address defines a single interface.
- **Anycast Address (one to nearest)**
  An anycast address defines a group of computers that all share a single address. An anycast packet is delivered to only one member of the group, the most reachable one.
- **Multicast Address (FF00::/8, one to group)**
  A multicast address also defines a group of computers. In multicasting, each member of the group receives a copy.

Unicast Addresses

Unicast addresses are used in a one-to-one context.

IPv6 unicast addresses are:

- **Global unicast addresses**
- **Site-local addresses**
- **Link-local addresses**
- **Special purpose unicast**
  - **Unspecified, loopback, IPv4 compatible, IPv4 mapped**

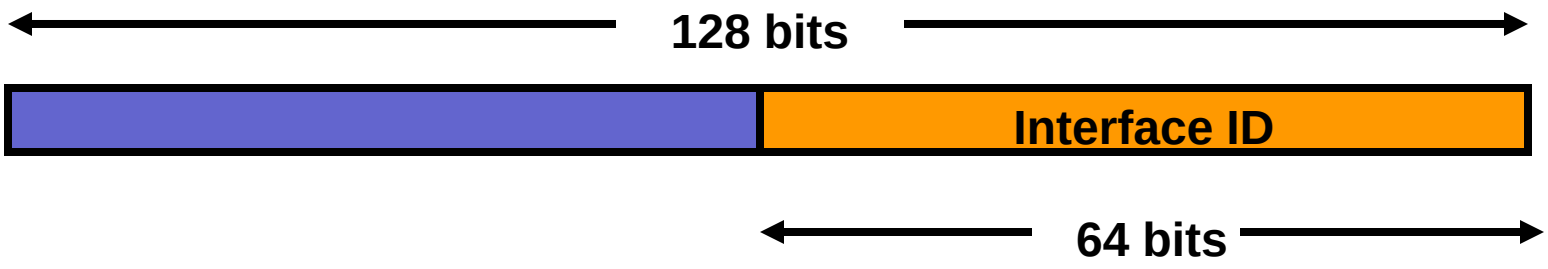
Interface Identifiers

Used to identify interfaces on a link

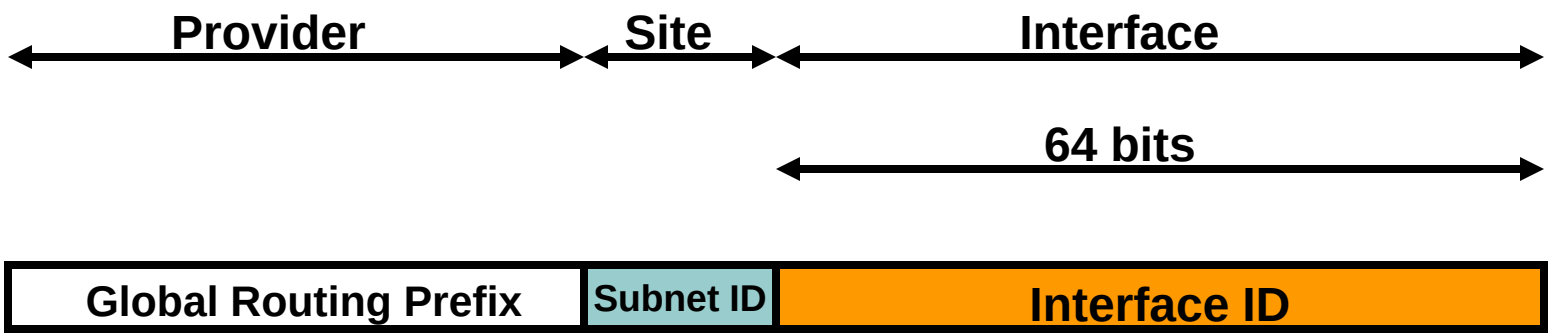
- Must be unique on that link
- Can be globally unique

All unicast addresses have 64-bit interface ID

- Except for unicast addresses that start with binary 000
- Interface ID constructed in Modified EUI-64 format



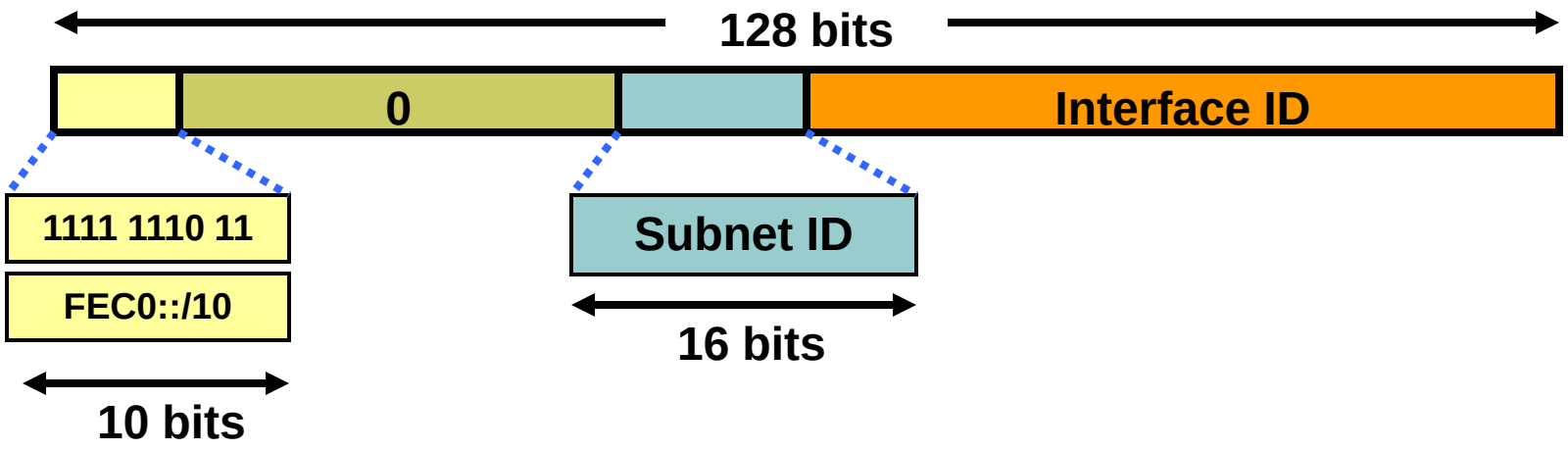
Global Unicast Addresses



Global unicast addresses are:

- Addresses for generic use of IPv6

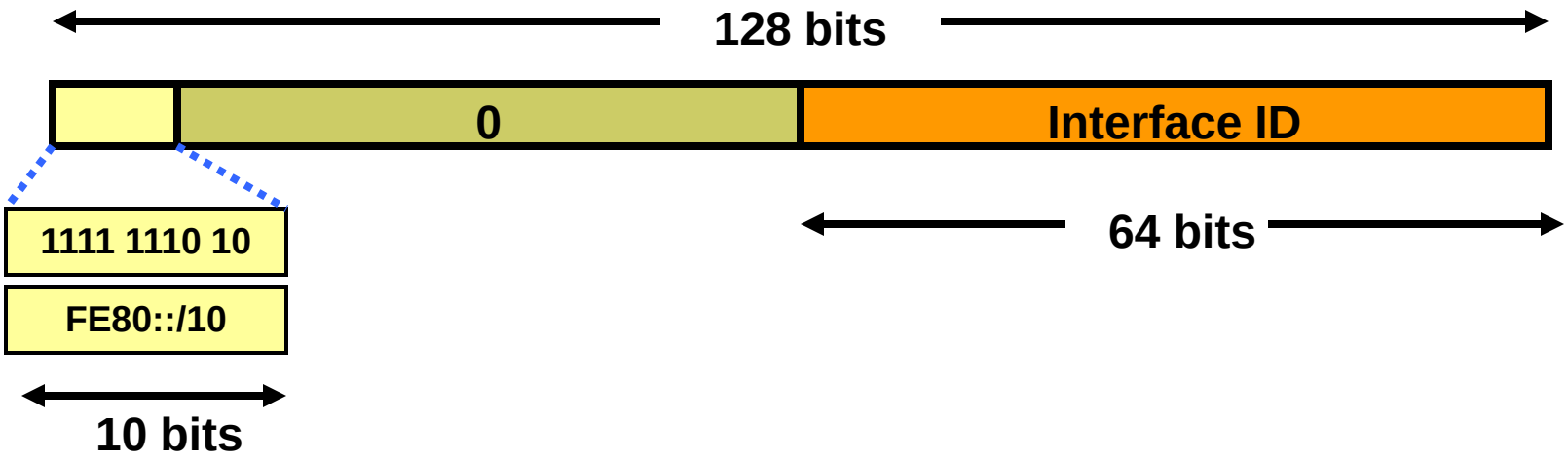
Site-Local Addresses



Site-local addresses:

- Have a scope limited to the site
- Contain the inside topology of the site with the subnet ID

Link-Local Addresses



Link-local addresses:

- Have a scope limited to the link
- Are automatically configured with the interface ID

Unspecified and Loopback Addresses

Unspecified address:

- 0:0:0:0:0:0:0:0
- Used as a placeholder when no address is available (initial DHCP request, DAD)

Loopback address:

- 0:0:0:0:0:0:0:1
- Same as 127.0.0.1 in IPv4
- Identifies self

IPv4-Compatible Addresses

0:0:0:0:0:0:192.168.30.1

= ::192.168.30.1

= ::C0A8:1E01

IPv4-compatible addresses:

- Refer to an IPv4/IPv6 node that supports automatic tunneling

IPv4-Mapped Addresses

0:0:0:0:0:FFFF:192.168.30.1

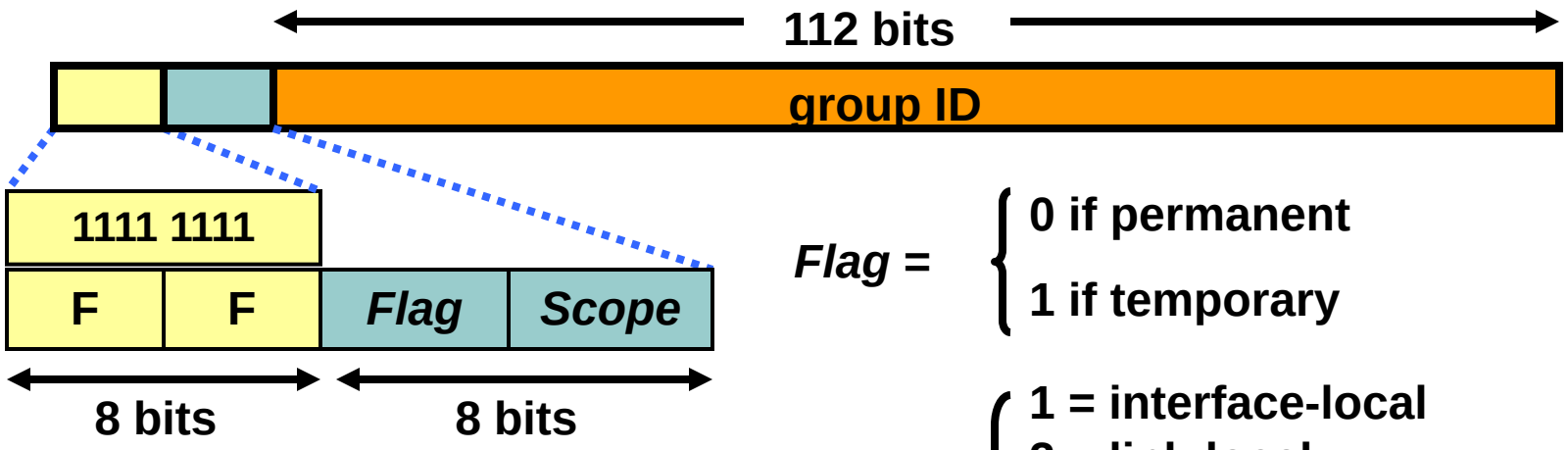
= ::FFFF:192.168.30.1

= ::FFFF:C0A8:1E01

IPv4-mapped addresses:

- Used to represent the addresses of IPv4 nodes as IPv6 addresses

Multicast Addresses



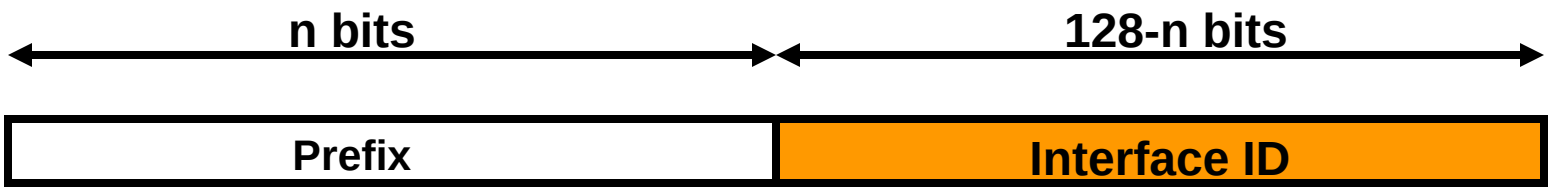
Multicast is used in the context of one-to-many. A multicast scope is new in IPv6.

Multicast Assigned Addresses

- **FF0X:: is reserved (X=0..F)**
- **Inside this range, the following are assigned:**

	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
FF05::101	All NTP servers	Site-local

Anycast Addresses



Anycast:

- Assigned to more than one interface
- Is one-to-nearest type of address
- Allocated from the unicast address space
- Has a current limited use

IPv6 Addressing per Device

In IPv4, devices were restricted to one IPv4 address per interface

In IPv6, devices have multiple addresses per interface

```
Ethernet0/1 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::201:96FF:FE5B:E161
  Global unicast address(es):
        2001:0DB8:DEEE:19::1, subnet is 2001:0DB8:DEEE:19::/64
  Joined group address(es):
        FF02::1 "All nodes link local multicast"
        FF02::2 "All routers link local multicast"
        FF02::9 "All RIP routers link local multicast"
```

Required Host Addresses

An IPv6 host requires the following IPv6 addresses for proper operation:

- **Its required link-local address for each interface**
- **Any additional unicast and anycast addresses configured (automatically or manually)**
- **Loopback address**
- **All-nodes multicast address**
- **Solicited-node multicast address for each of its unicast and anycast addresses**
- **Multicast address of all other groups to which the host belongs**

Required Router Addresses

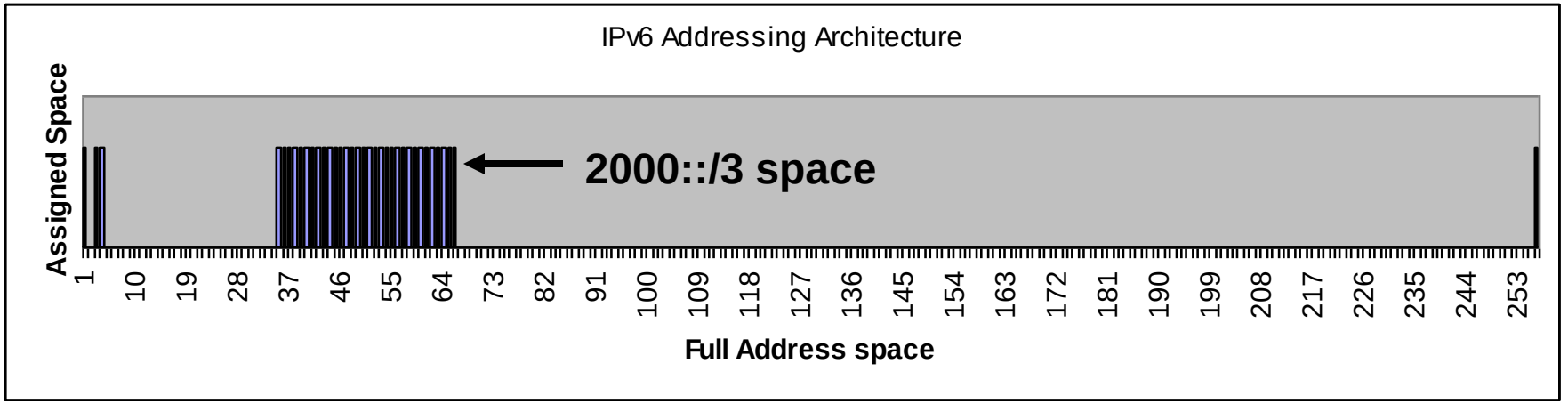
An IPv6 router requires the following IPv6 addresses for proper operation :

- **All the required host addresses**
- **Subnet-router anycast addresses for all interfaces for which it is configured to act as a router**
- **Other anycast configured addresses**
- **All-routers multicast addresses**

Addressing Architecture

	Binary prefix	IPv6 notation
Unspecified	00 … 0 (128 bits)	::/128
Loopback	00 … 1 (128 bits)	::1/128
Multicast	1111 1111	FF00::/8
Link-local unicast	1111 1110 10	FE80::/10
Site-local unicast	1111 1110 11	FEC0::/10
Global unicast	Everything else	

Addressing Architecture (Cont.)



- This graph shows the IANA assignments of IPv6 addresses
- X axis = full address space
- Y axis = 0 or 1 if space is allocated
- 1 does not mean that space is used, only reserved by IANA

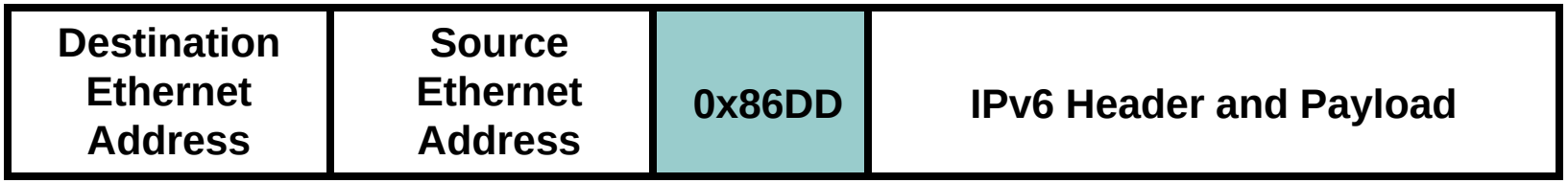
Module 2.2:
IPv6 Data Link Layer Support

IPv6 over Data Link Layers

IPv6 is defined for most data link layers:

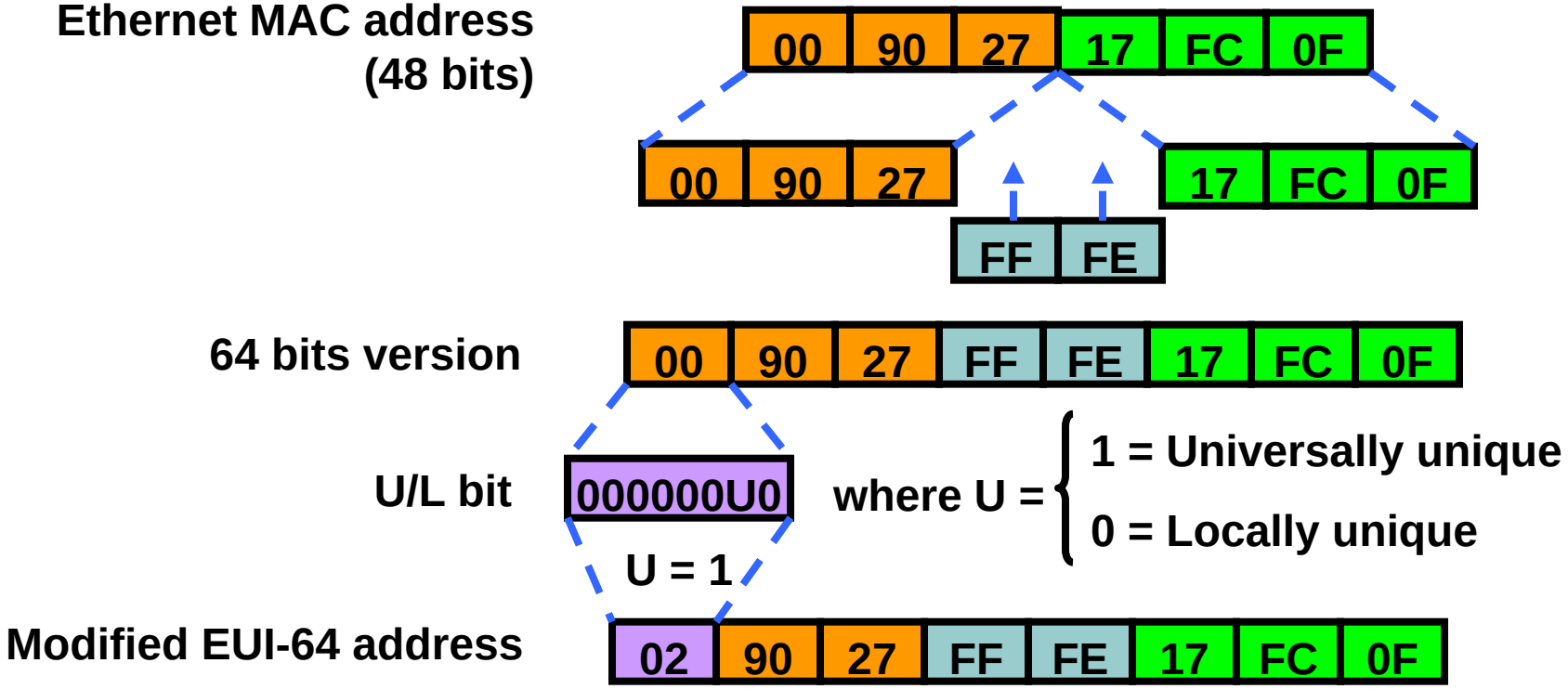
- Ethernet
- FDDI
- Token Ring
- ARCnet
- PPP
- Nonbroadcast multiaccess (NBMA)
- ATM
- Frame Relay
- IEEE 1394

IPv6 over Ethernet



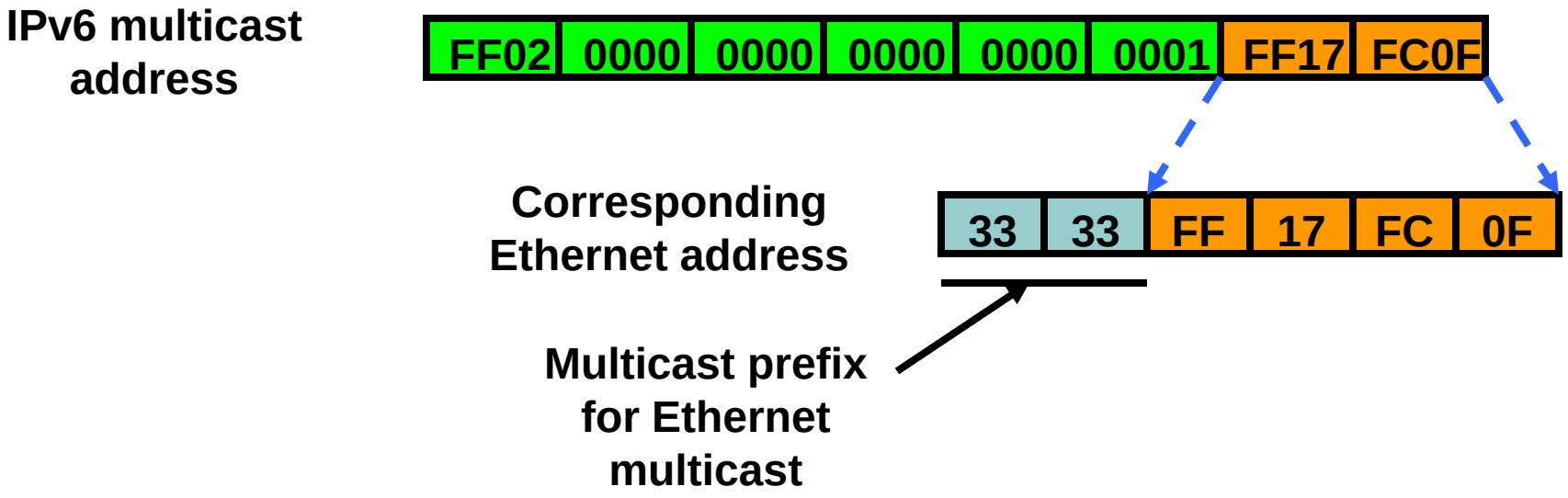
- **IPv6 has a specific Ethernet protocol ID**
- **Different from the IPv4 one**

IPv6 EUI-64 Interface Identifier



- This format expands the 48-bit MAC address to 64 bits by inserting “FFFE” into the middle 16 bits.
- To make sure that the chosen address is from a unique Ethernet MAC address, the U/L bit is set to 1 for global scope (0 for local scope).

Multicast Mapping over Ethernet



Mapping of IPv6 multicast address to Ethernet address is:

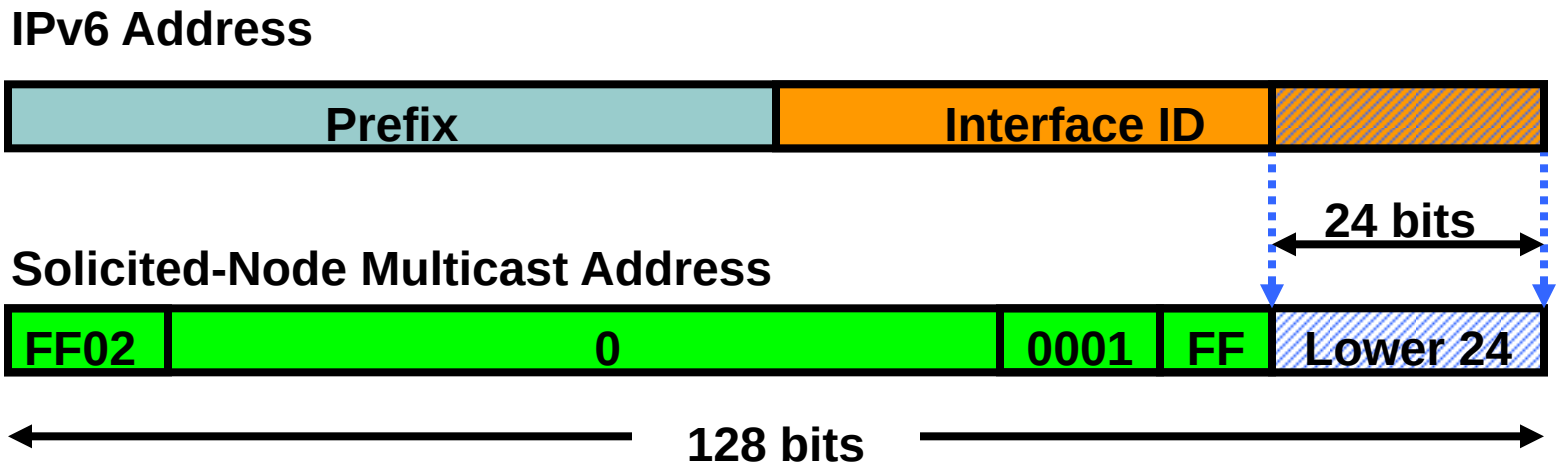
- **33:33:<last 32 bits of the IPv6 multicast address>**

Module 2.3:
ICMPv6 and Neighbor Discovery Protocols

Objectives

- **Describe the format and use of ICMPv6 packets**
- **Describe how path MTU discovery works in IPv6**
- **Describe the operation and uses of the IPv6 neighbor discovery protocol**
- **Describe how duplicate address detection and renumbering work in IPv6**
- **Configure neighbor discovery and renumbering on Cisco routers**

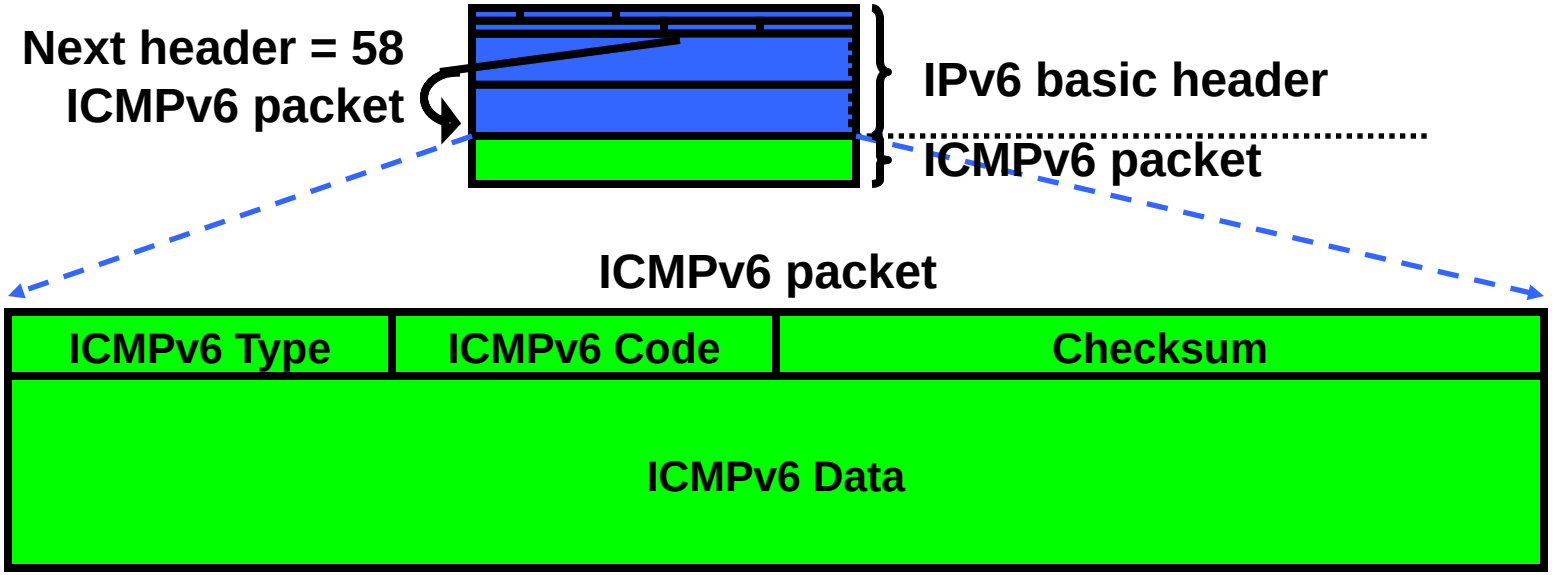
Solicited-Node Multicast Address



Solicited-node multicast address:

- **Is scoped to the local link.**
- **For each unicast and anycast address configured on an interface of a node or router, a corresponding solicited-node multicast address is automatically enabled.**
- **Is used by two fundamental IPv6 mechanisms:**
  Replacement of ARP in IPv4,
  Duplicate Address Detection (DAD)

ICMPv6



ICMPv6 is similar to IPv4:

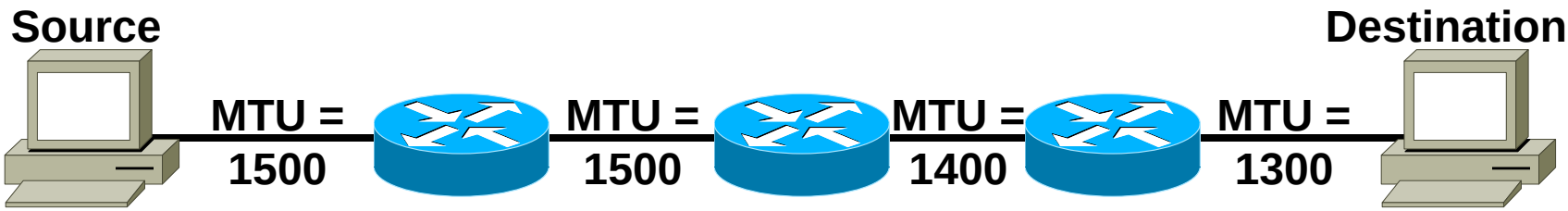
- Provides diagnostic and error messages

ICMPv6

In IPv6, several mechanisms and functionalities of the protocol use ICMPv6 messages:

- **Path MTU Discovery (PMTUD)**
- **Replacement of ARP**
- **Stateless autoconfiguration**
- **Duplicate Address Detection (DAD)**
- **Prefix renumbering**
- **Router Redirection**

Path MTU Discovery



Packet with MTU=1500

ICMP error: packet too big
Use MTU = 1400

Packet with MTU=1400

ICMP error: packet too big
Use MTU = 1300

Packet with MTU=1300

Packet received

Path MTU = 1300

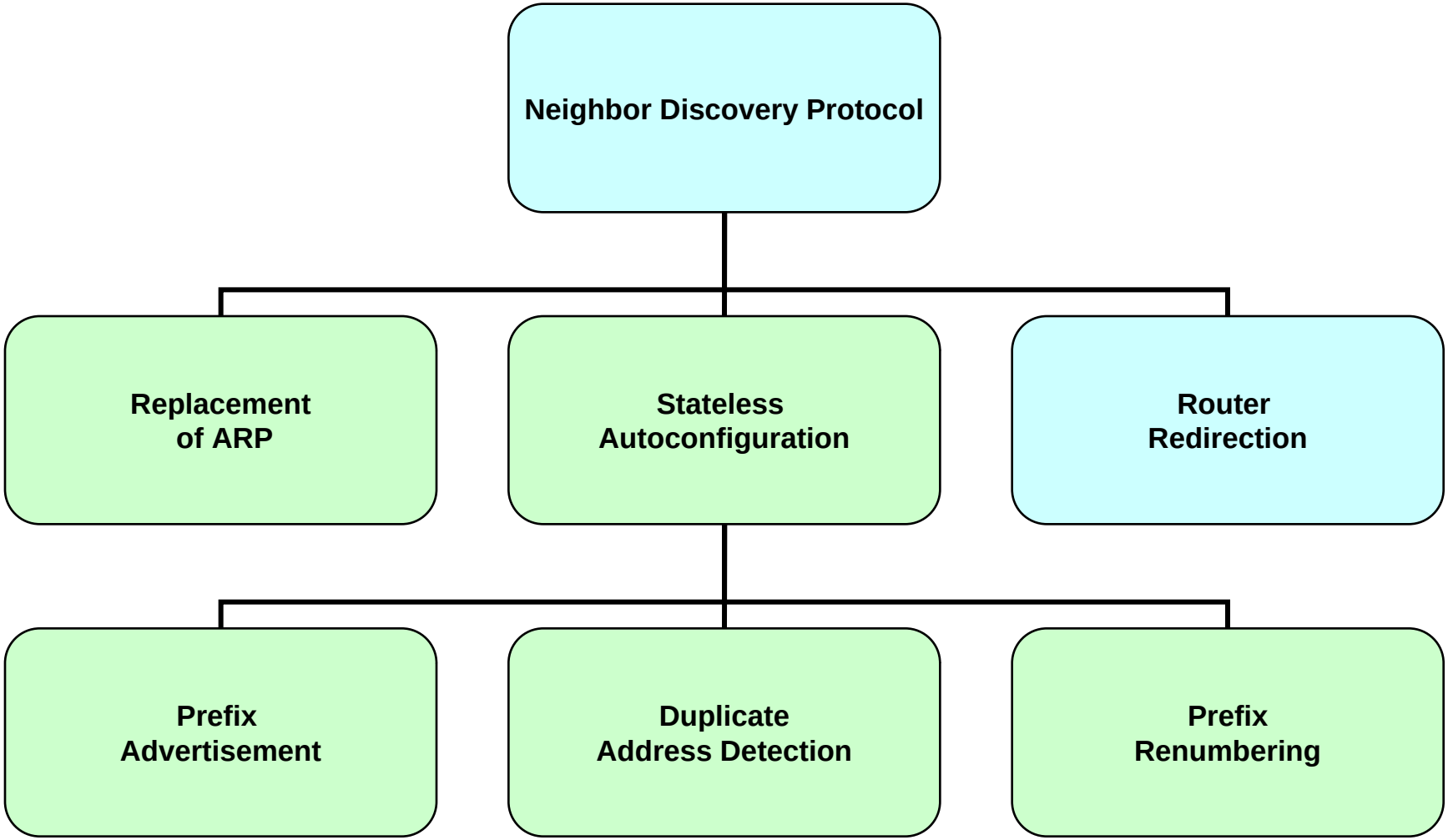
Neighbor Discovery Protocol

Neighbor Discovery:

- Determines the link-layer address of a neighbor on the same link
- Finds neighbor routers
- Keeps track of neighbors

This is achieved with the ICMP protocol with multicast addresses.

NDP is an umbrella for Mechanisms



Neighbor Discovery—Replacement of ARP by Neighbor Solicitation / Neighbor Advertisement

ICMP type = 135 (Neighbor Solicitation)
Src = A
Dst = solicited-node multicast of B
Data = link-layer address of A
Query = what is your link address?

ICMP type = 136 (Neighbor Advertisement)
Src = B
Dst = A
Data = link-layer address of B

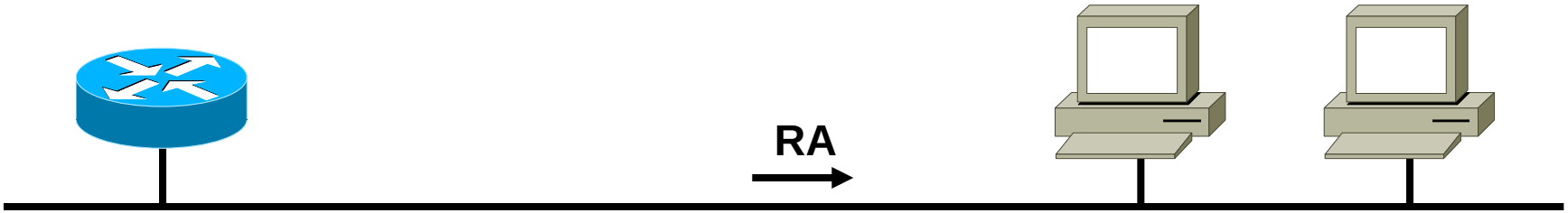
A and B can now exchange packets on this link

Neighbor Discovery—Replacement of ARP by Neighbor Solicitation / Neighbor Advertisement

ICMP type = 135 (Neighbor Solicitation)
Src = FEC0::1:0:0:1:A
Dst = FF02::1:FF01:B
Data = 00:50:3e:e4:4c:00
Src link-layer add = 00:50:3e:e4:4c:00
Dst link-layer add = 33:33:FF:01:00:0B

ICMP type = 136 (Neighbor Advertisement)
Src = FEC0::1:0:0:1:B
Dst = FEC0::1:0:0:1:A
Data = 00:50:3e:e4:4b:01
Src link-layer add = 00:50:3e:e4:4b:01
Dst link-layer add = 00:50:3e:e4:4c:00

Stateless Autoconfiguration I—Router Advertisement Messages

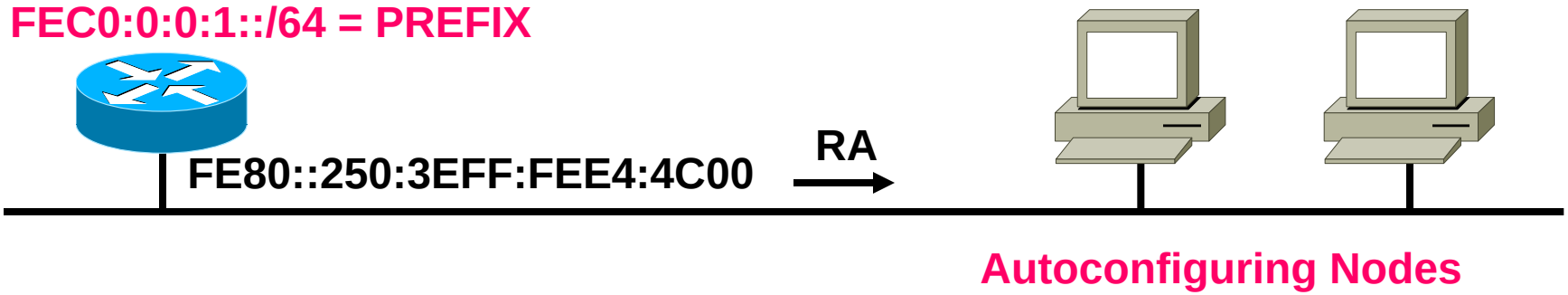


RA packet definitions:

- **ICMP type = 134**
- **Src = router link-local address**
- **Dst = all-nodes multicast address**
- **Data= options, prefix, lifetime, autoconfig flag**

Routers send periodic Router Advertisements messages (ICMPv6 Type 134) to the all-nodes multicast address.

Stateless Autoconfiguration I—Router Advertisement Messages (Example)



RA packet definitions:

ICMP type = 134

Src = FE80::250:3EFF:FEE4:4C00

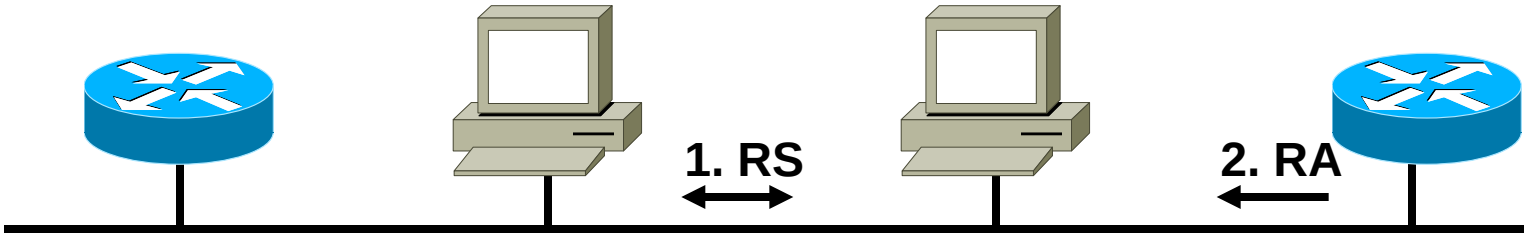
Dst = FF02::1

Prefix = FEC0:0:0:1::/64

Lifetime = Infinite (Valid/Preferred)

Routers send periodic Router Advertisements messages (ICMPv6 Type 134) to the all-nodes multicast address.

Stateless Autoconfiguration II—Router Solicitation Messages



RS packet definitions:

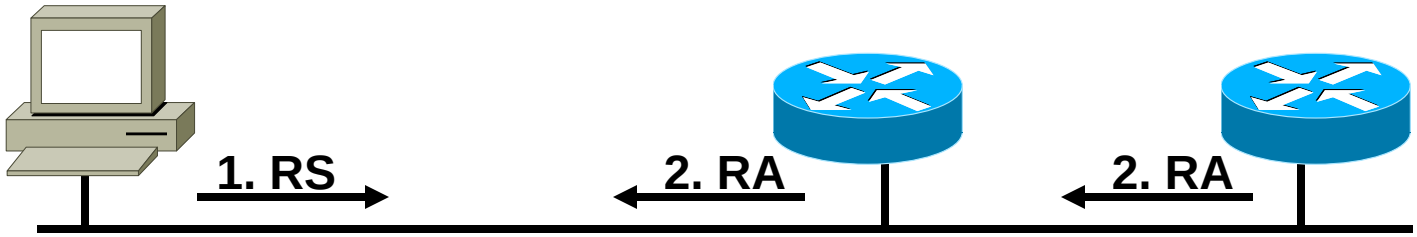
ICMP type = 133

Src = unspecified Address

Dst = all-routers multicast address

Router solicitations are sent by booting nodes to request RAs for configuring the interfaces.

Stateless Autoconfiguration II—Prefix Advertisement (Example)



1. RS:

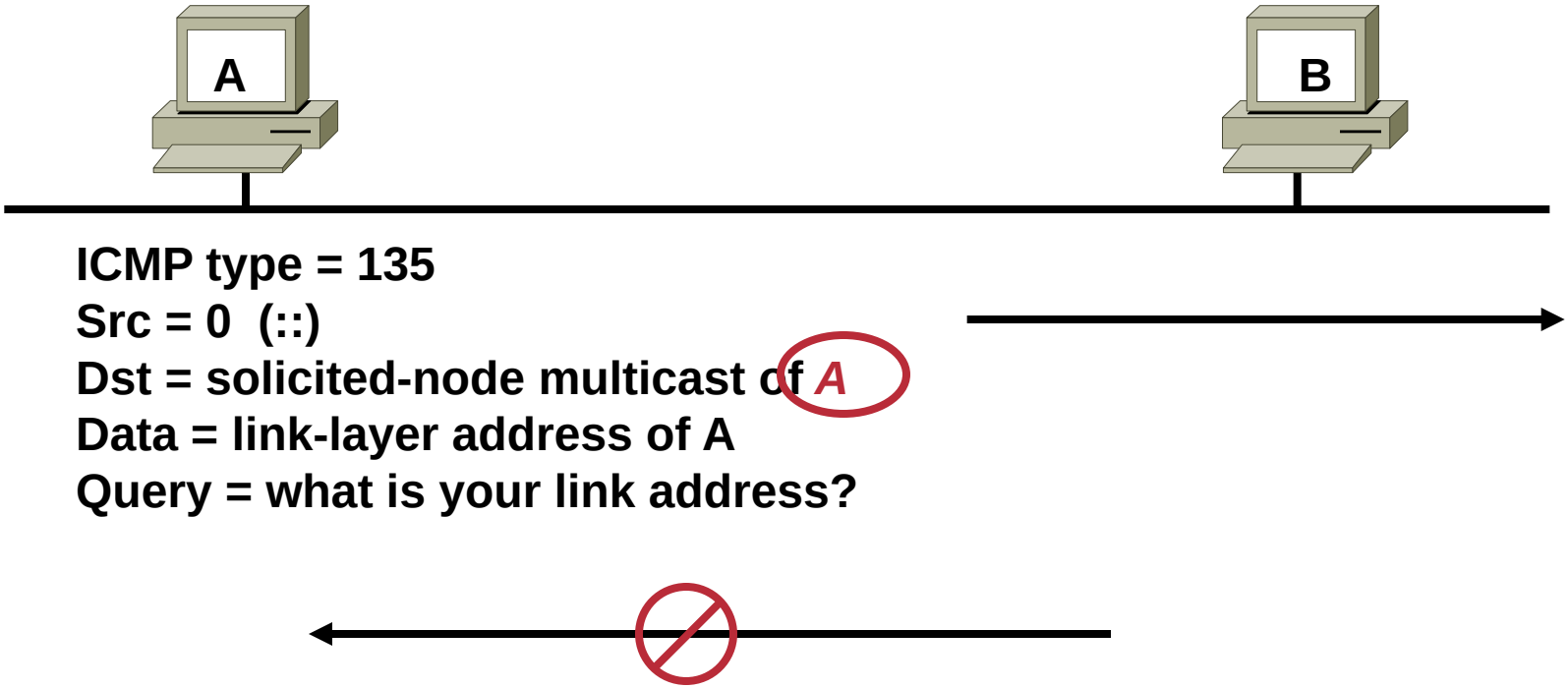
- ICMP type = 133
- Src = ::
- Dst = FF02::2 (all-routers multicast address)
- query= please send RA

2. RA:

- ICMP type = 134
- Src = router link-local address
- Dst = FF02::1 (all-nodes multicast address)
- Data= options, prefix, lifetime, autoconfig flag

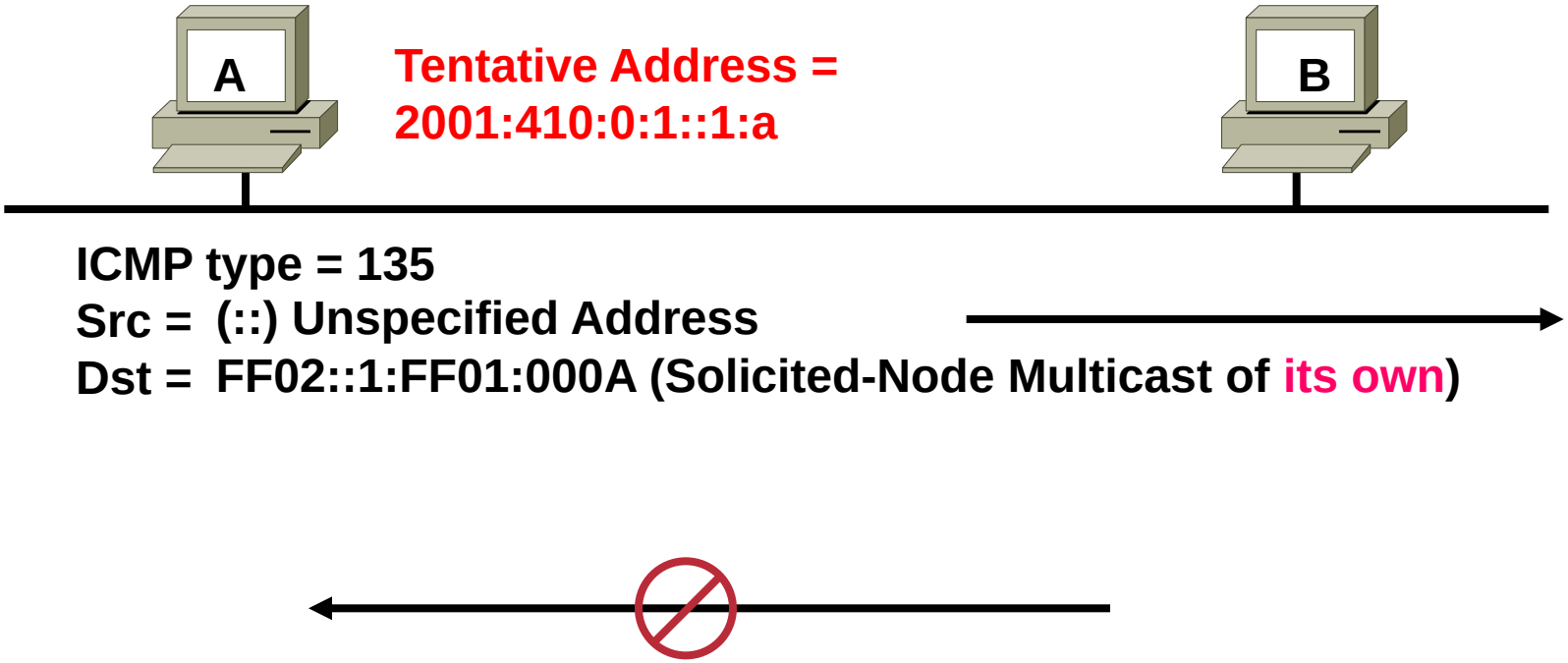
Router solicitations are sent by booting nodes to request RAs for configuring the interfaces.

Stateless Autoconfiguration—Duplicate Address Detection



Duplicate Address Detection (DAD) uses Neighbor Solicitation to verify the existence of an address to be configured.

Stateless Autoconfiguration—Duplicate Address Detection (Example)

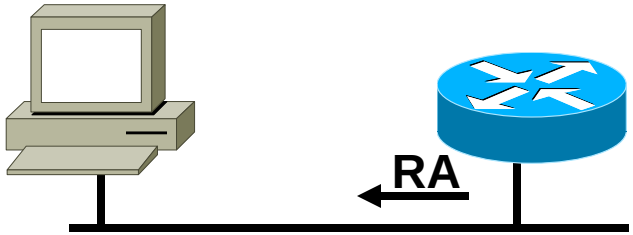


If a node responds to that request, it means the tentative address is in use by another node. In the absence of a reply, this tentative address is considered unique and can be assigned to its interface.

Stateless Autoconfiguration—Prefix Renumbering

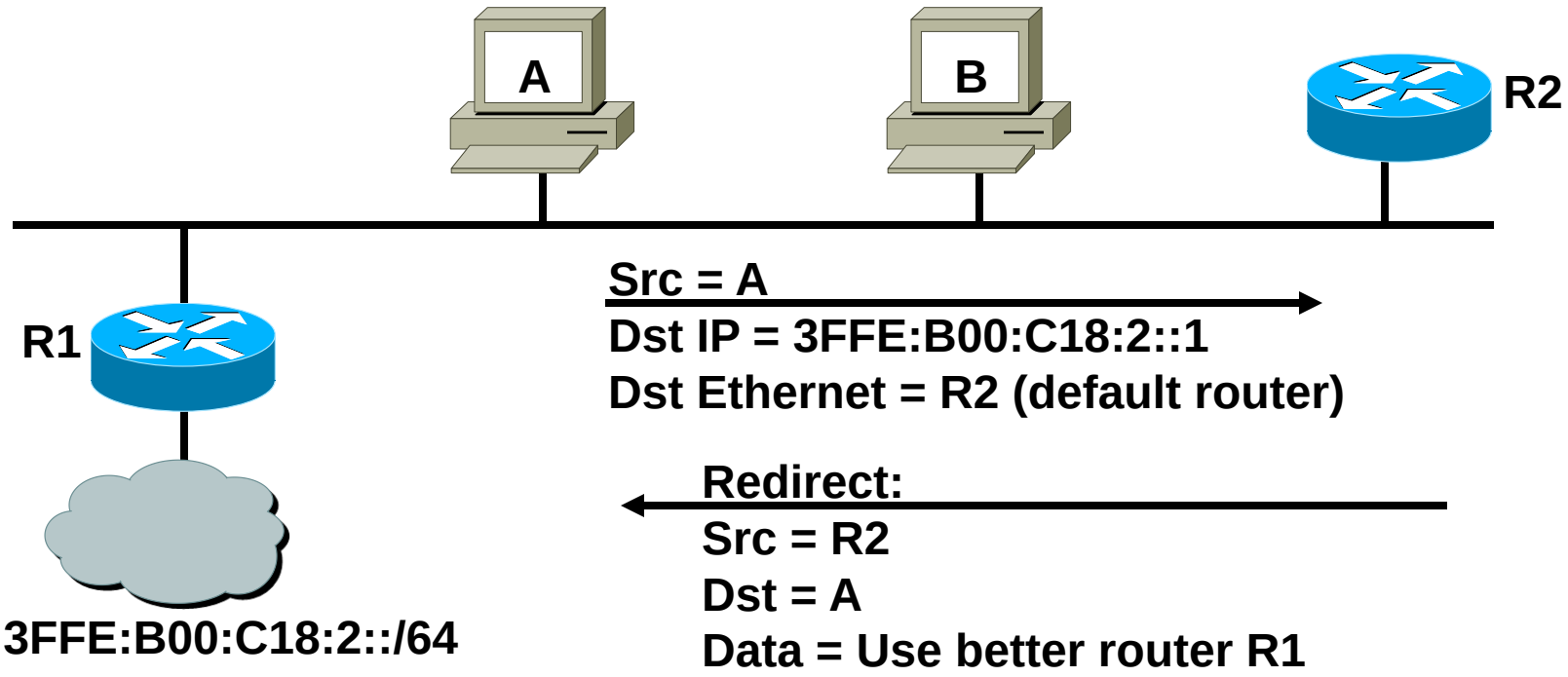
RA packet definitions:

- **ICMP type = 134**
- **Src = router link-local address**
- **Dst = all-nodes multicast address**
- **Data= 2 prefixes:**
  - **Current prefix (to be deprecated) with short lifetime**
  - **New prefix (to be used) with normal lifetime**



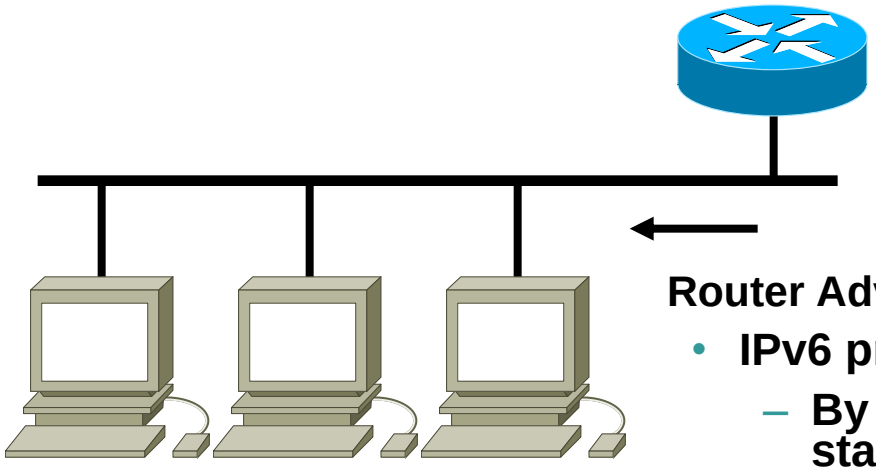
Renumbering is achieved by modifying the RA to announce the *old prefix with a short lifetime* and the *new prefix*.

Neighbor Discovery—Router Redirection



Routers use ICMPv6 Type 137 redirection messages to inform nodes on the link that a better router exists on the link to forward packets.

Neighbor Discovery Parameters



Autoconfiguring IPv6 hosts

Router Advertisements:

- **IPv6 prefix**
  - **By default, the prefix length advertised for stateless autoconfiguration is 64 bits**
- **Lifetime**
  - **Valid lifetime**
  - **Preferred lifetime**
- **Default router information**
  - **In IPv6, the default router address used by node is the router's link-local address (FE80::/10). Therefore, even if the prefix is renumbered, the router can always be reached.**
- **Flags/options**
  - **You can use a flag to instruct nodes to use stateful autoconfiguration rather than stateless autoconfiguration.**

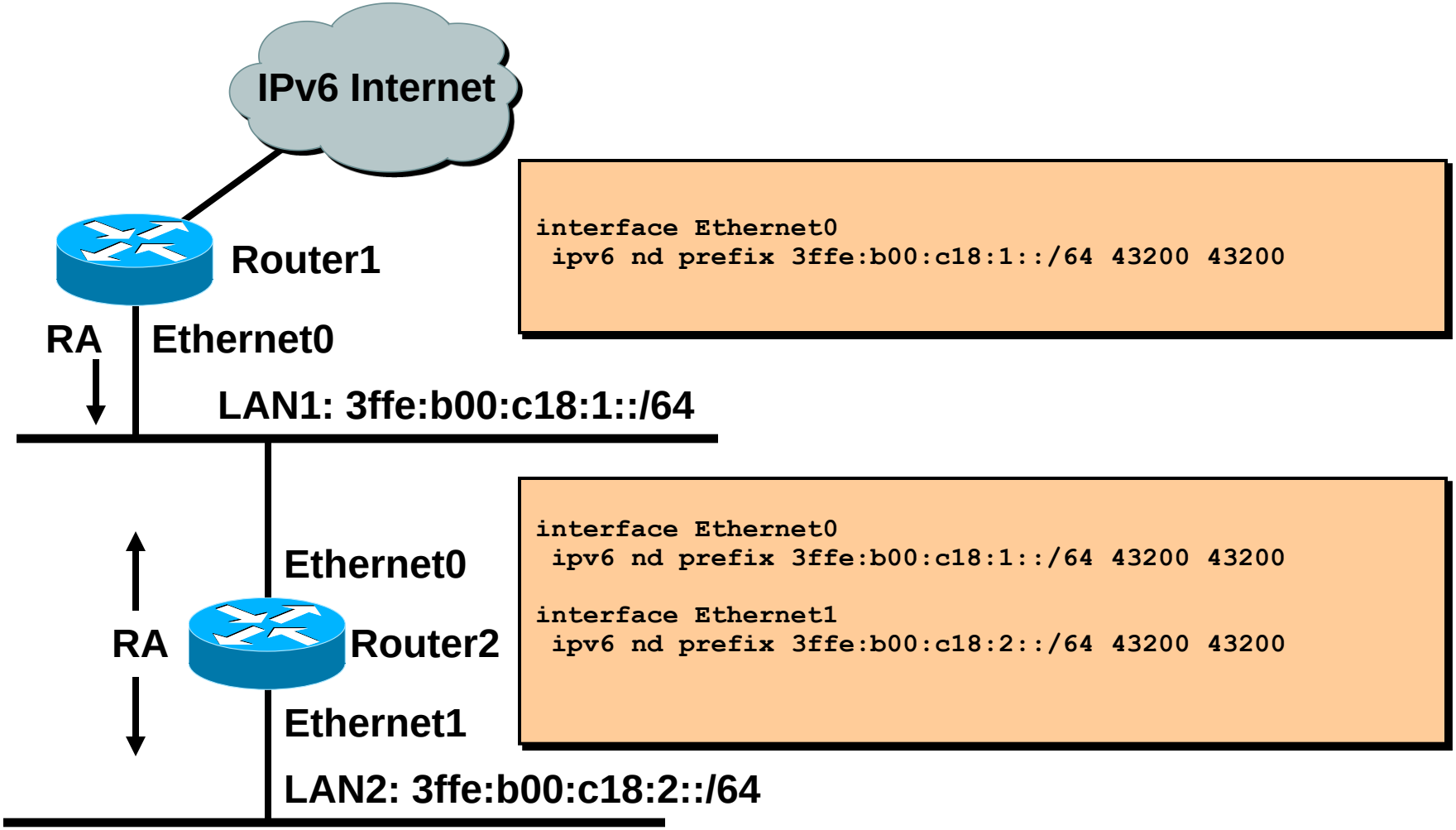
Cisco IOS Neighbor Discovery Command Syntax

```
router(config-if)#
```

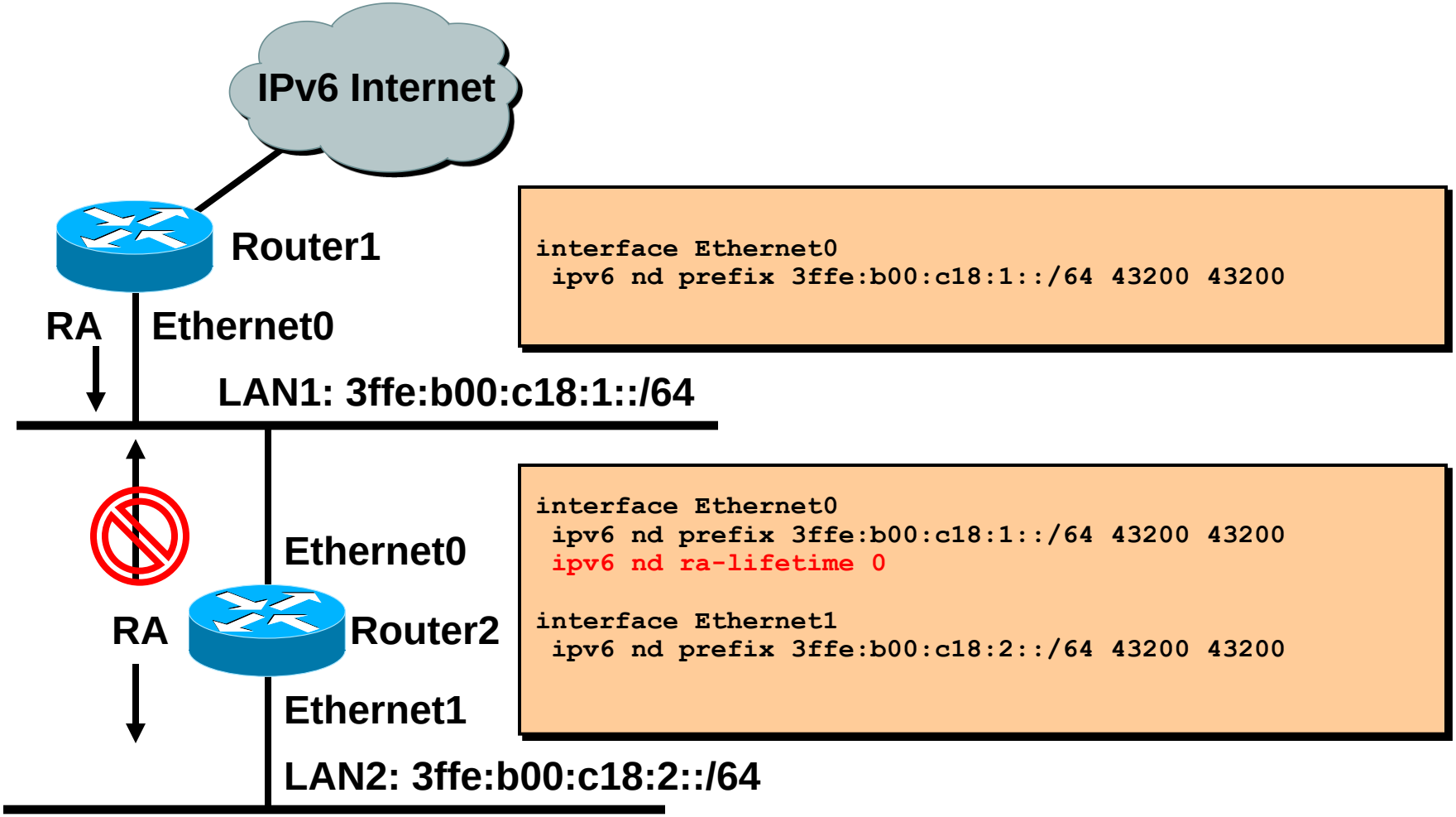
```
ipv6 nd prefix <prefix> | default
               [ [<valid-lifetime> <preferred-lifetime>] |
               [at <valid-date> <preferred-date>]
               [off-link] [no-autoconfig] [no-advertise] ]
```

- **Tune prefix advertisement parameters on an interface**

Cisco IOS Overriding the Neighbor Discovery Defaults



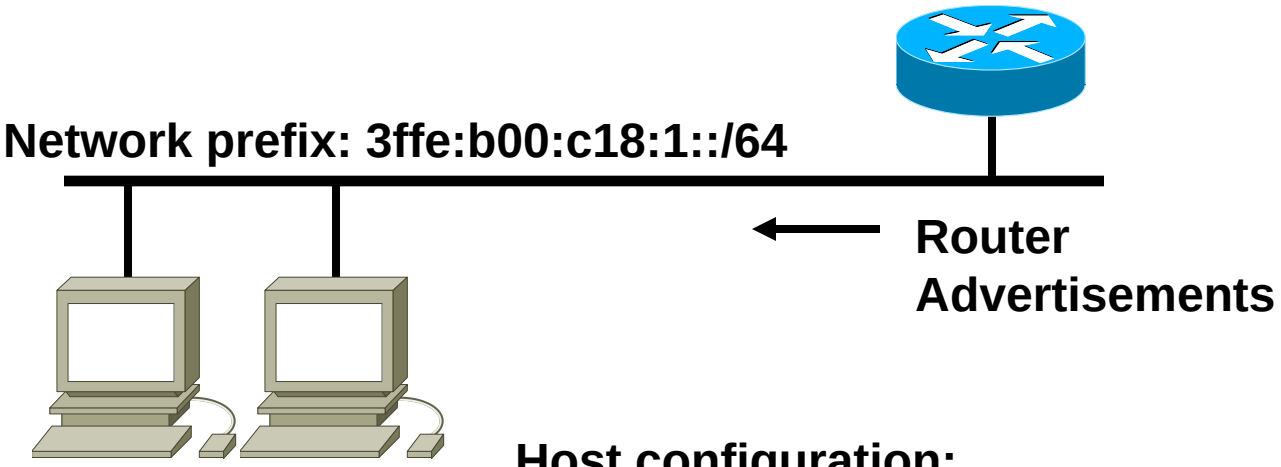
Cisco IOS Neighbor Discovery Lifetimes



Cisco IOS Network Prefix Renumbering Scenario

Router configuration before renumbering:

```
interface Ethernet0
  ipv6 nd prefix 3ffe:b00:c18:1::/64 43200 43200
```



Host configuration:

```
preferred address 3ffe:b00:c18:1:260:8ff:fede:8fbe
```

Cisco IOS Network Prefix Renumbering Scenario (Cont.)

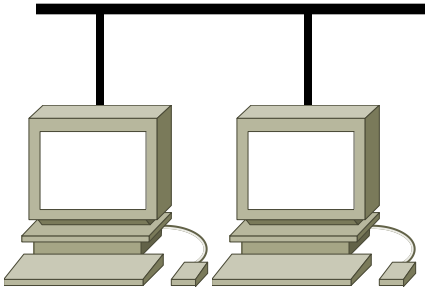
Router configuration after renumbering:

```
interface Ethernet0
  ipv6 nd prefix 3ffe:b00:c18:1::/64 43200 0
  ipv6 nd prefix 3ffe:b00:c18:2::/64 43200 43200
```

OR:

```
interface Ethernet0
  ipv6 nd prefix 3ffe:b00:c18:1::/64 at Jul 31 2002 23:59 Jul 1 2002 23:59
  ipv6 nd prefix 3ffe:b00:c18:2::/64 43200 43200
```

NEW network prefix: 3ffe:b00:c18:2::/64
Deprecated prefix: 3ffe:b00:c18:1::/64



Router advertisements

Autoconfiguring IPv6 hosts

Host configuration:

```
deprecated address 3ffe:b00:c18:1:260:8ff:fede:8fbe
preferred address 3ffe:b00:c18:2:260:8ff:fede:8fbe
```