IPv6 Operations

Understanding the IPv6 Addressing Architecture

IPv6 Addressing Architecture

IPv6 Addressing Architecture

Address Representation: Format

- x:x:x:x:x:x:x:x, where x is a 16-bit hexadecimal field:
  - Example: 2001:0DB8:010F:0001:0000:0000:0000:0ACD
  - Case-insensitive
- Leading zeros in a field are optional:
  - Example: 2001:DB8:10F:1:0:0:0:ACD
- Successive fields of 0 are represented as "::", but only once in an address:
  - Example: 2001:DB8:10F:1::ACD

IPv6 Addressing Architecture (Cont.)

Address Representation: Example

- Full address:
  - 2001:0DB8:0000:0000:FFFF:0000:0000:0ADC
- Correct representations:
  - 2001:DB8::FFFF:0:0:ADC
  - 2001:DB8:0:0:FFFF::AD
- Incorrect representation:
  - 2001:DB8::OFF::AD

IPv6 Addressing Architecture (Cont.)

Address Representation: Further Examples

Full Address	Correct Representation
FF02:0:0:0:0:0:0:1	FF02::1
FF15:0:0:0:0:0:1:c001	FF15::1:C001
0:0:0:0:0:0:0:1	::1
0:0:0:0:0:0:0:0	::

IPv6 Addressing Architecture (Cont.)

IPv4-Compatible and IPv4-Mapped Formats

- IPv4-compatible (deprecated, RFC 4291) :
  - 0:0:0:0:0:0:192.0.2.100
  - = ::192.0.2.100
  - = ::C000:0264
- IPv4-mapped:
  - 0:0:0:0:0:FFFF:192.0.2.100
  - = ::FFFF:C000:0264

IPv6 Addressing Architecture (Cont.)

URL

http://2001:DB8:1003::F:8080/index.html

- Is 8080 part of the address or a port number?

In a URL, the address is enclosed in brackets:

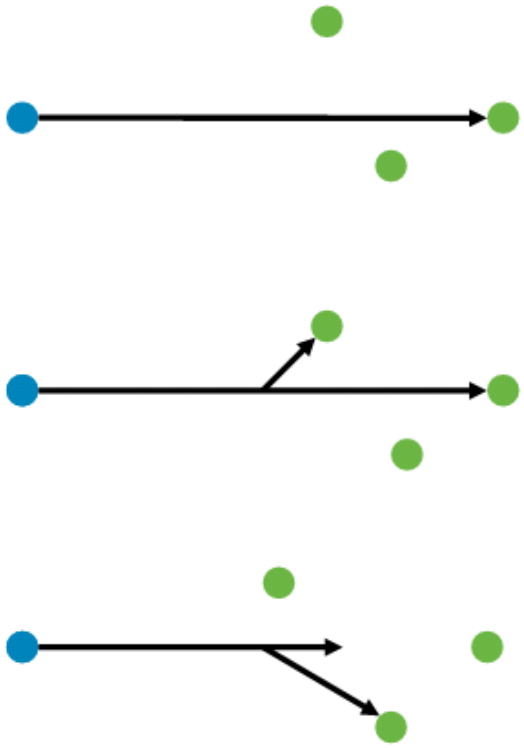
- Example: http://[2001:DB8:1003::F]:8080/index.html
- Not a new concept: works with IPv4 addresses
- Cumbersome for users
- Mostly for diagnostic purposes
- Use FQDNs whenever possible

IPv6 Address Formats and Types

IPv6 Address Formats and Types

Address Types

- Unicast
- Multicast
- Anycast
- No broadcast in IPv6



IPv6 Address Formats and Types (Cont.)

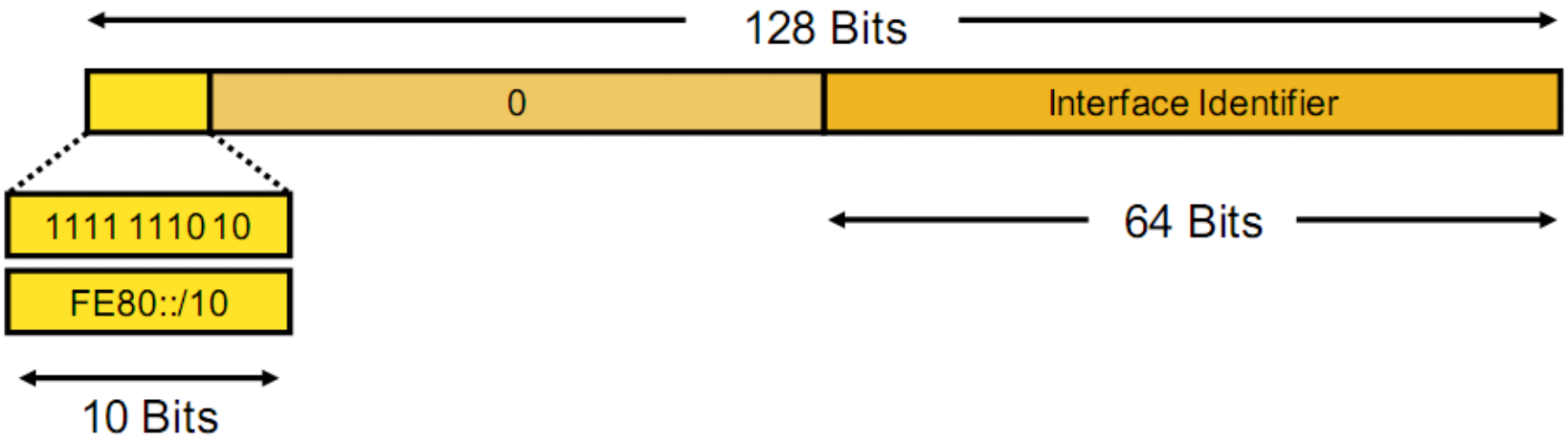
Unicast

- Unicast addresses are used in a one-to-one context.
- IPv6 unicast addresses:
  - Global unicast addresses
  - Link-local addresses
  - Unique local addresses
  - Special-purpose unicast:
    - Unspecified
    - Loopback
    - IPv4-mapped

IPv6 Address Formats and Types (Cont.)

Link-Local Addresses

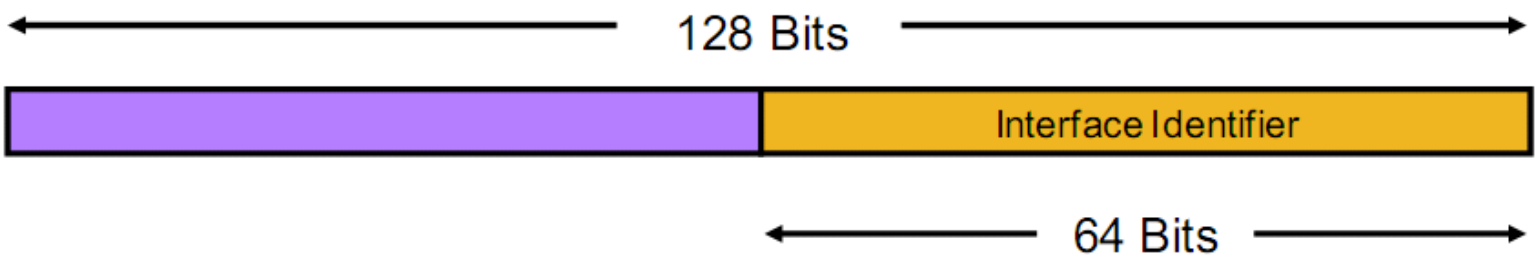
- Have a scope limited to the link
- Are automatically configured with the interface ID
- When used, must be paired with outgoing interface information



IPv6 Address Formats and Types (Cont.)

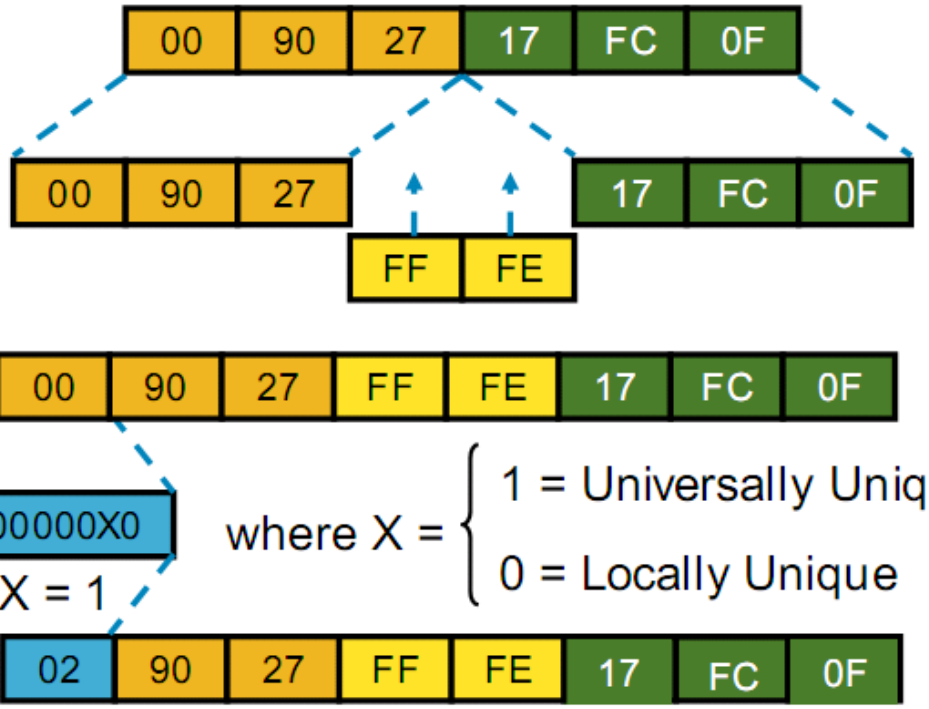
Interface Identifiers

- Used to identify interfaces on a link:
  - Must be unique on that link
  - Can be globally unique
- Unicast addresses should have a 64-bit interface ID:
  - Except for unicast addresses that start with binary 000
  - Interface ID constructed in modified EUI-64 format



Modified EUI-64 Format

Ethernet MAC Address
(48 Bits)

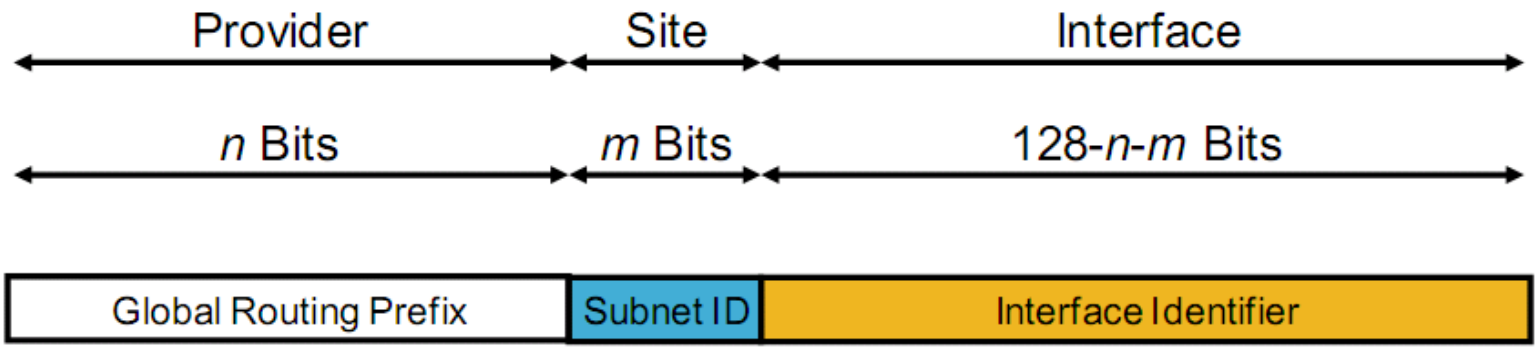


A modified EUI-64 address is formed by inserting "FFFE" and complementing a bit that identifies the uniqueness of the MAC address.

IPv6 Address Formats and Types (Cont.)

Global Unicast Addresses

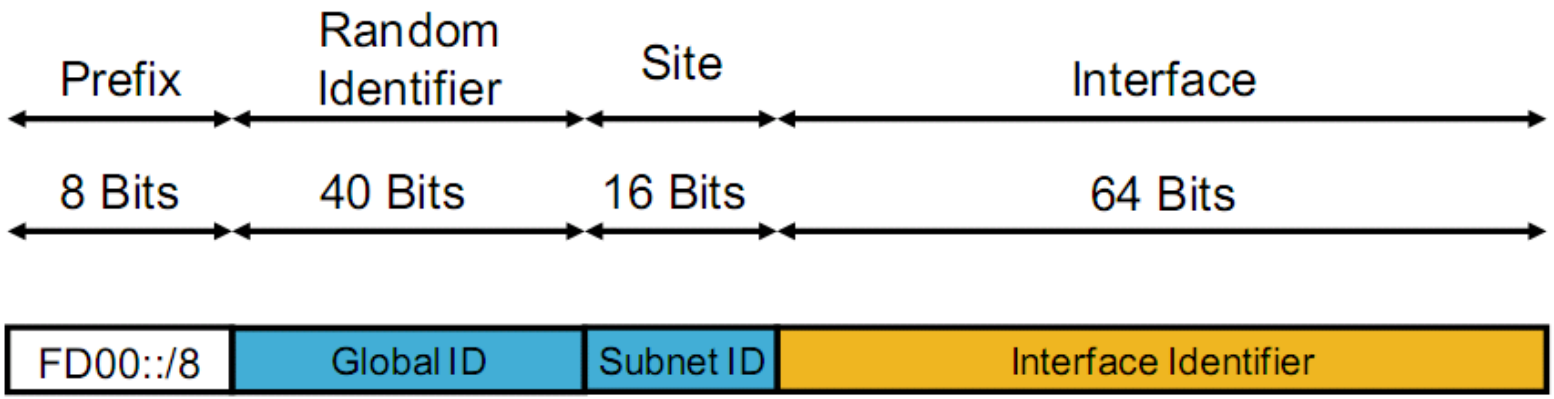
- Global unicast addresses are addresses for generic use of IPv6
- Interface identifier should be kept at 64 bits



IPv6 Address Formats and Types (Cont.)

Unique Local Unicast Addresses (RFC 4193)

- FC00::/7
  - FC00::/8 planned to be globally managed
  - FD00::/8 assigned locally by network administration
- For network in which only internal IPv6 communication is required
- Not routable on the Internet



IPv6 Address Formats and Types (Cont.)

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

IPv6 Address Uses

IPv6 Address Uses

IPv4-Mapped Addresses

- Used to represent the addresses of IPv4 nodes as IPv6 addresses
- Used for next-hop representation in 6PE and 6VPE
- Used in network stacks when both address families are processed internally as IPv6 (e.g., Linux)

0:0:0:0:0:FFFF:192.0.2.100

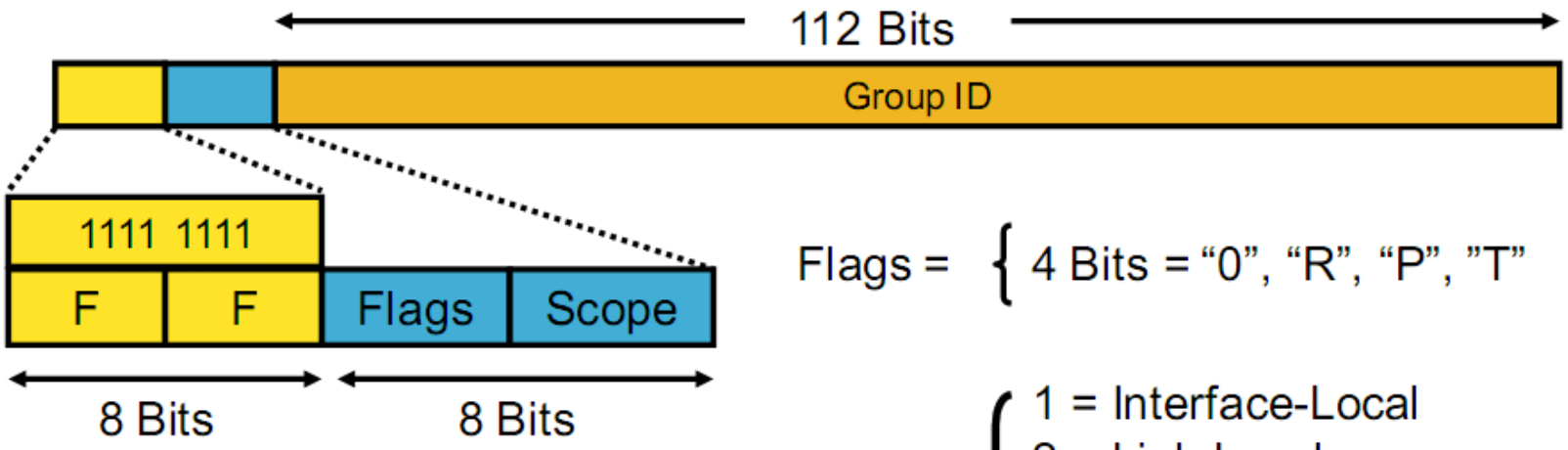
= ::FFFF:192.0.2.100

= ::FFFF:C000:0246

IPv6 Address Uses (Cont.)

Multicast Addresses

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



Flags = { 4 Bits = "0", "R", "P", "T"

Scope = {
1 = Interface-Local
2 = Link-Local
3 = Subnet-Local
4 = Admin-Local
5 = Site-Local
8 = Organization
E = Global

IPv6 Address Uses (Cont.)

Multicast Assigned Addresses (RFC 2375)

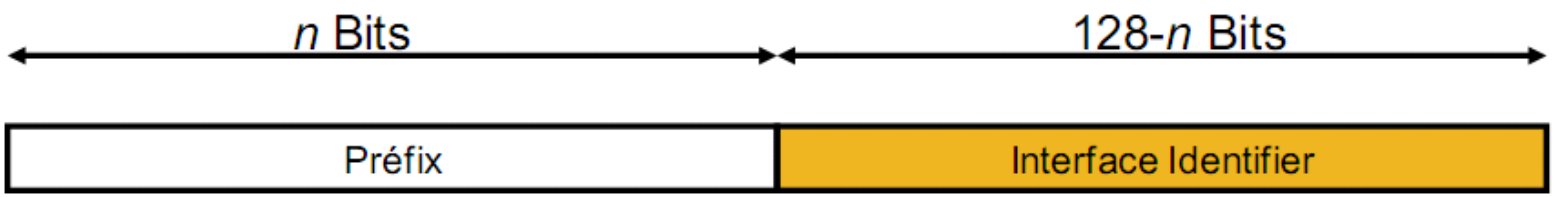
- FF0X:: is reserved (X is from the range from 0 to F).
- Inside this range, the following addresses are assigned:

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
FF05::101	All NTP servers	Site-local
FF05::1:3	All DHCP servers	Site-local
FF0X::127	CISCO-RP-ANNOUNCE	Any scope
FF0X::128	CISCO-RP-DISCOVERY	Any scope

IPv6 Address Uses (Cont.)

Anycast Addresses

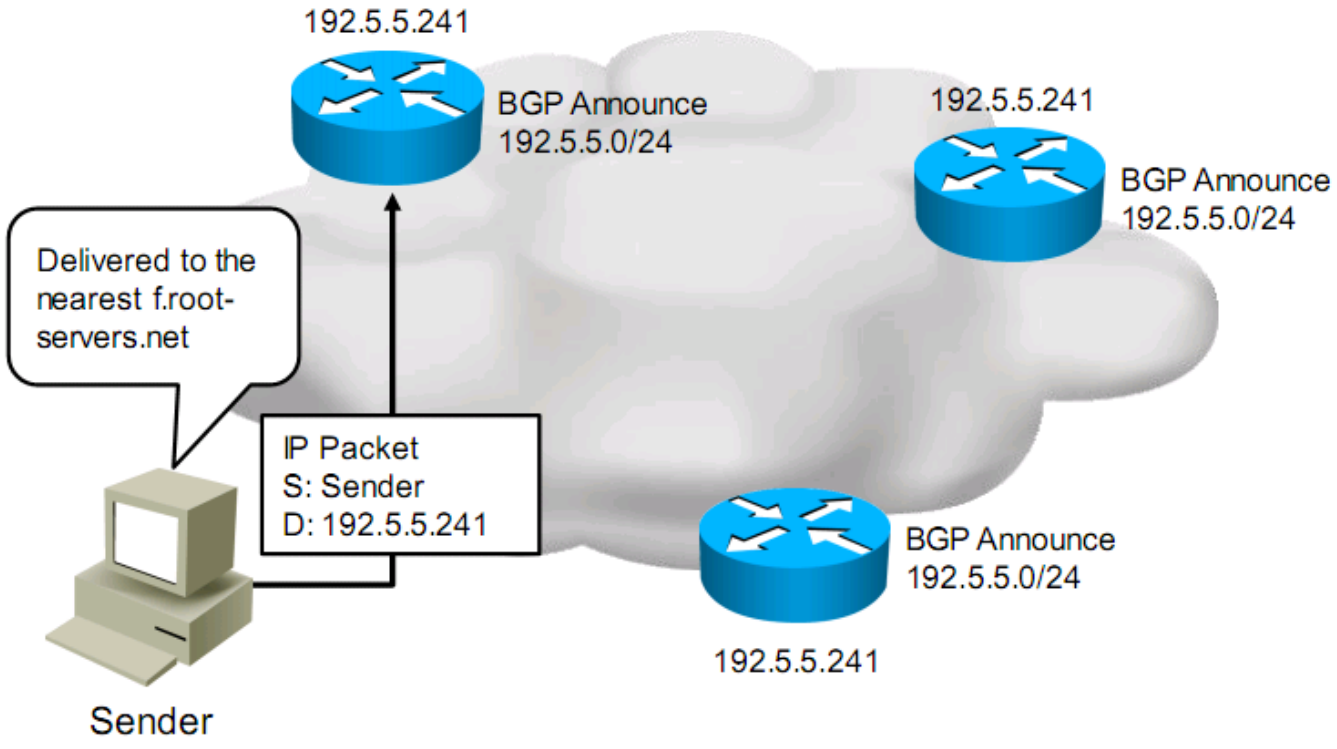
- Used in the context of one-to-nearest
- Assigned to more than one interface
- Allocated from the unicast address space
- Indistinguishable from regular unicast addresses
- Must be explicitly configured as anycast on the node
- All nodes with the same anycast address should behave the same way.



IPv6 Address Uses (Cont.)

IPv4 Anycast Example

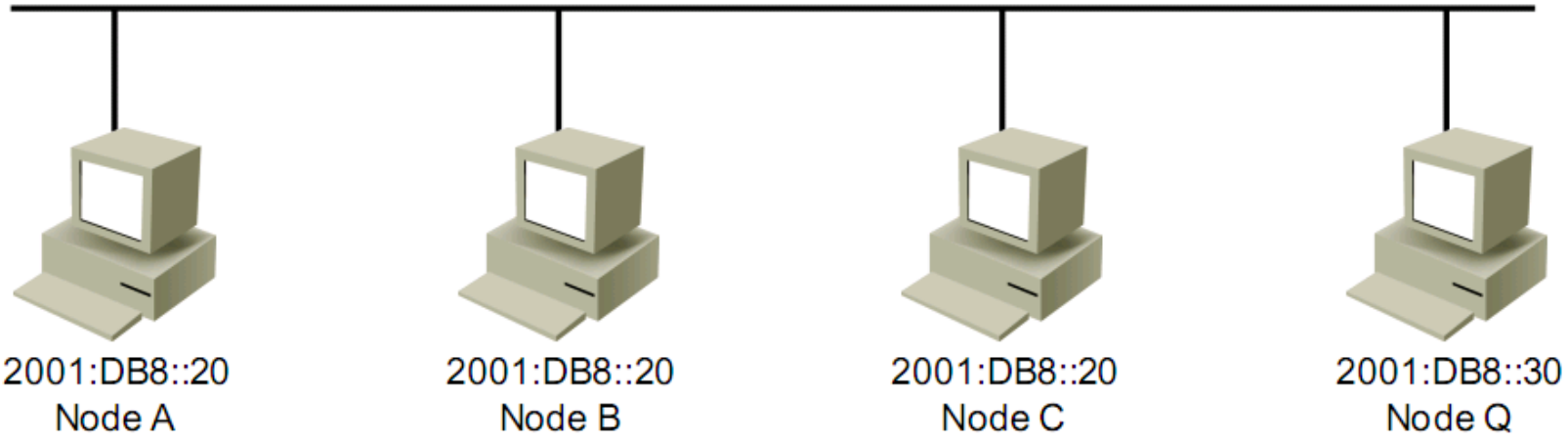
- BGP determines which destination will receive traffic.
- Used for root DNS servers, 6to4 relays, etc.



IPv6 Address Uses (Cont.)

Anycast Addresses: LAN

- Nearest anycast address is whichever host is put into Node Q neighbor cache first.
- DAD is not done for these addresses.



Required IPv6 Addresses

Required IPv6 Addresses

Required Host Addresses

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

- A link-local address
- Loopback address (::1)
- All-nodes multicast address (FF02::1)
- Any additional unicast and anycast addresses configured (automatically or manually)
- Solicited-node multicast address for each of its unicast and anycast addresses
- Multicast addresses of all other groups to which the host belongs

Required IPv6 Addresses (Cont.)

Required Router Addresses

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

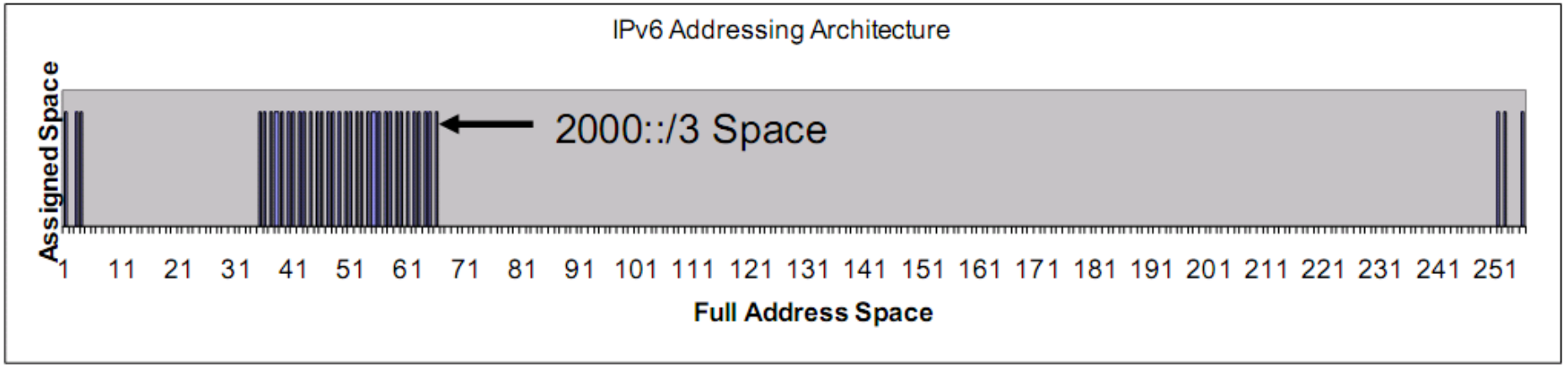
- All of the required host addresses
- All router multicast addresses (FF02::2)
- Other unicast or anycast-configured addresses

Required IPv6 Addresses (Cont.)

Addressing Architecture

The graph shows the IANA assignments of IPv6 addresses:

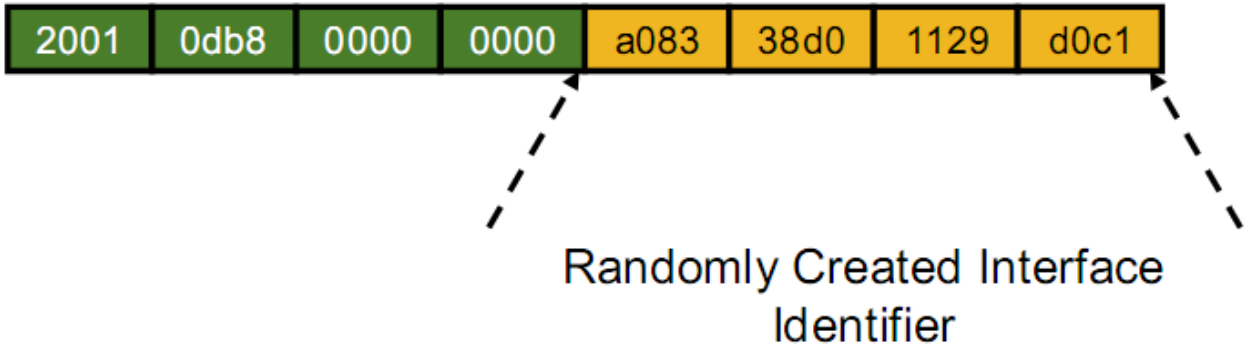
- X axis = Full address space
- Y axis = 0 or 1 if space is allocated
- 1 does not mean that space is used, only that it is reserved by IANA



Required IPv6 Addresses (Cont.)

Privacy Interface Identifier

- Defined in RFC 3041
- Supports randomly generated interface identifier
- Hides hardware information from network layer
- Can be permanent or temporary
- Temporary random interface ID prevents global device tracking.



Required IPv6 Addresses (Cont.)

IETF Prefix Allocation to IANA

IPv6 Prefix	Allocation	Reference	Note
0000::/8	Reserved by IETF	RFC 3513	[1] [5]
0100::/8	Reserved by IETF	RFC 3513	
0200::/7	Reserved by IETF	RFC 4048	[2]
0400::/6	Reserved by IETF	RFC 3513	
0800::/5	Reserved by IETF	RFC 3513	
1000::/4	Reserved by IETF	RFC 3513	
2000::/3	Global unicast	RFC 3513	[3]
4000::/3	Reserved by IETF	RFC 3513	
6000::/3	Reserved by IETF	RFC 3513	
F800::/6	Reserved by IETF	RFC 3513	
FC00::/7	Unique local unicast	RFC 4193	
FE00::/9	Reserved by IETF	RFC 3513	
FE80::/10	Link-local unicast	RFC 3513	
FEC0::/10	Reserved by IETF	RFC 3879	[4]
FF00::/8	Multicast	RFC 3513	

Summary

- IPv6 addresses are 128 bits, represented by a sequence of eight 16-bit hexadecimal fields separated by colons.
- IPv6 addresses are unicast, anycast, or multicast. Broadcast addresses are not supported in IPv6.
- Each of the three IPv6 address types has specific rules regarding its construction and use.
- Every IPv6 host and router has a set of addresses that must be configured on it to enable proper operation.


CISCO

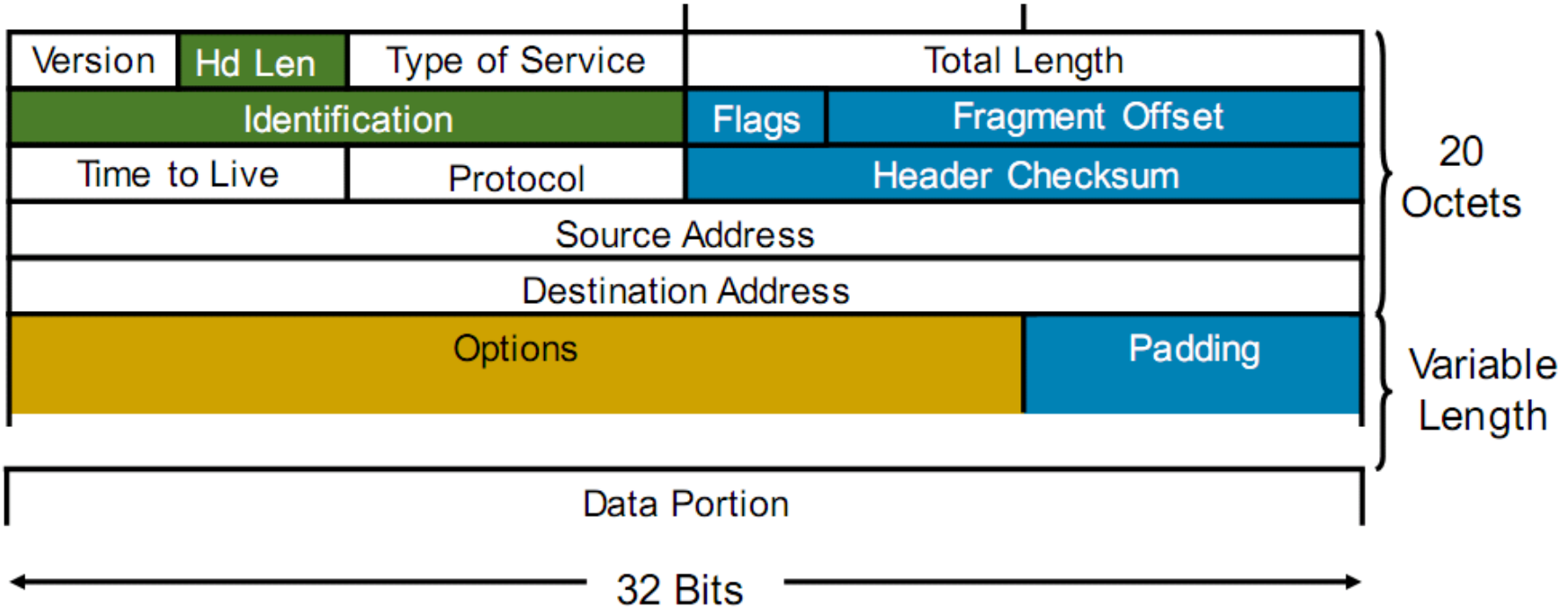
IPv6 Operations

Describing the IPv6 Header Format

IPv6 Header Changes and Benefits

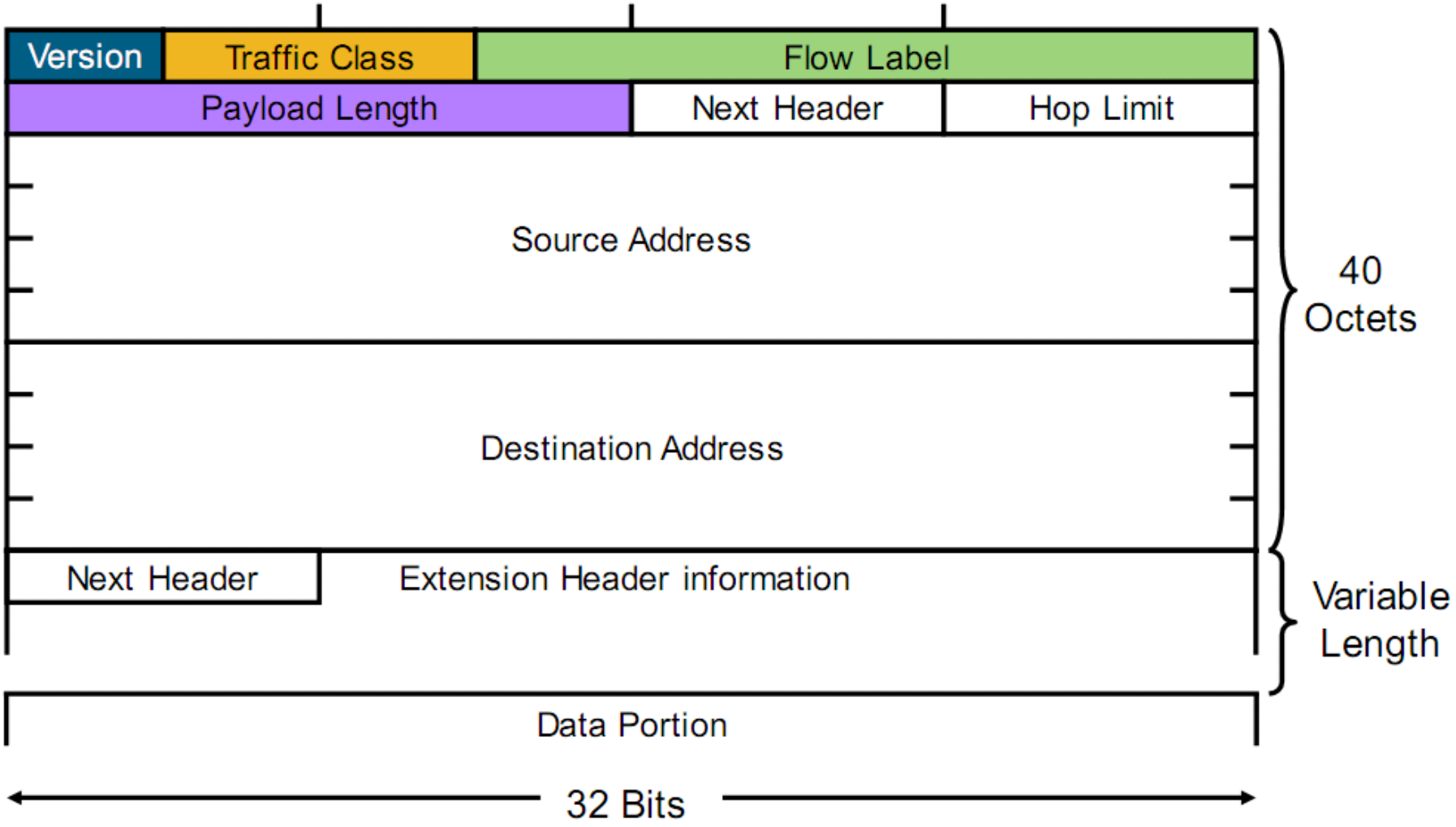
IPv6 Header Changes and Benefits

IPv4 Header Format



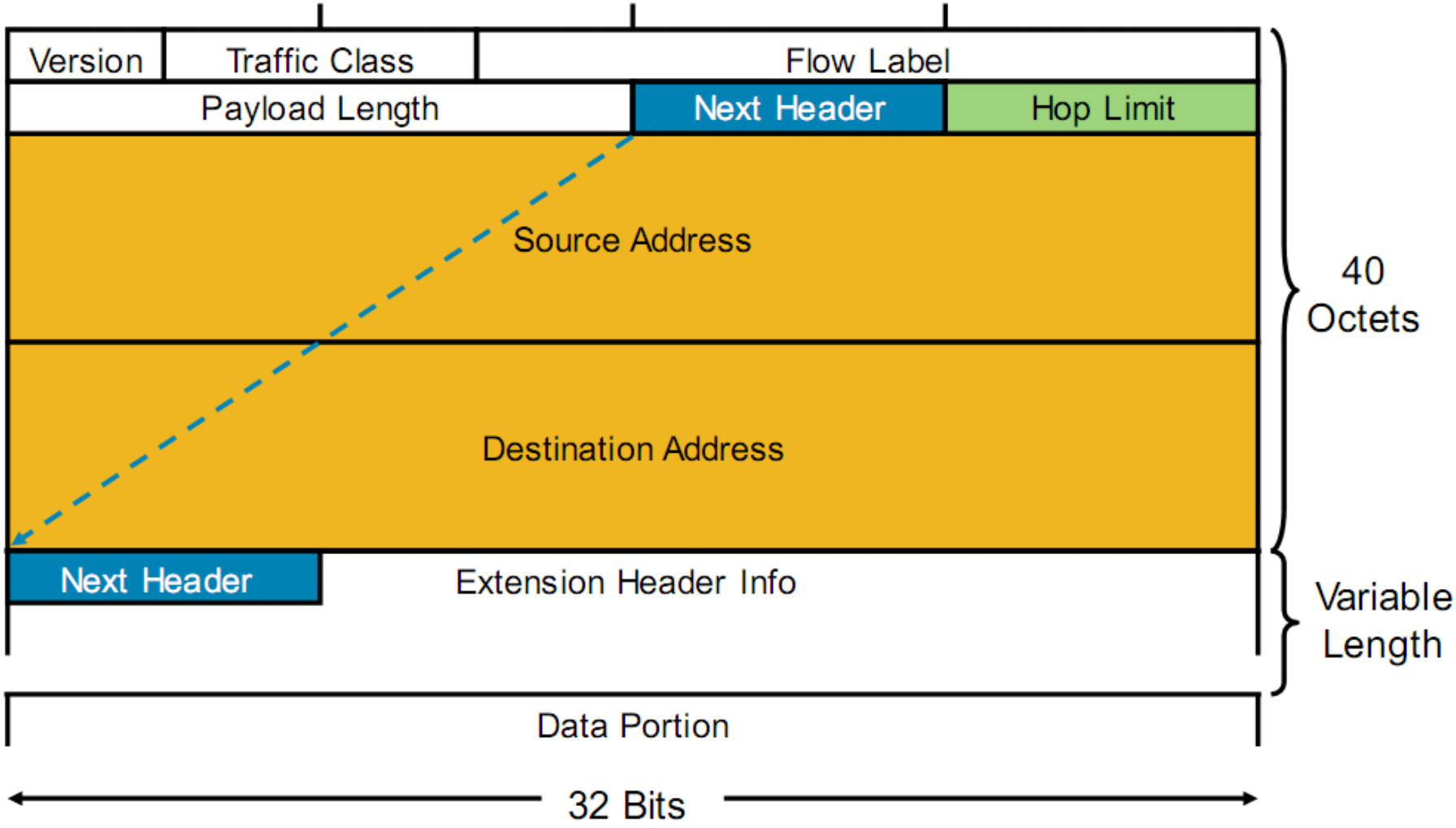
IPv6 Header Changes and Benefits (Cont.)

IPv6 Header Format



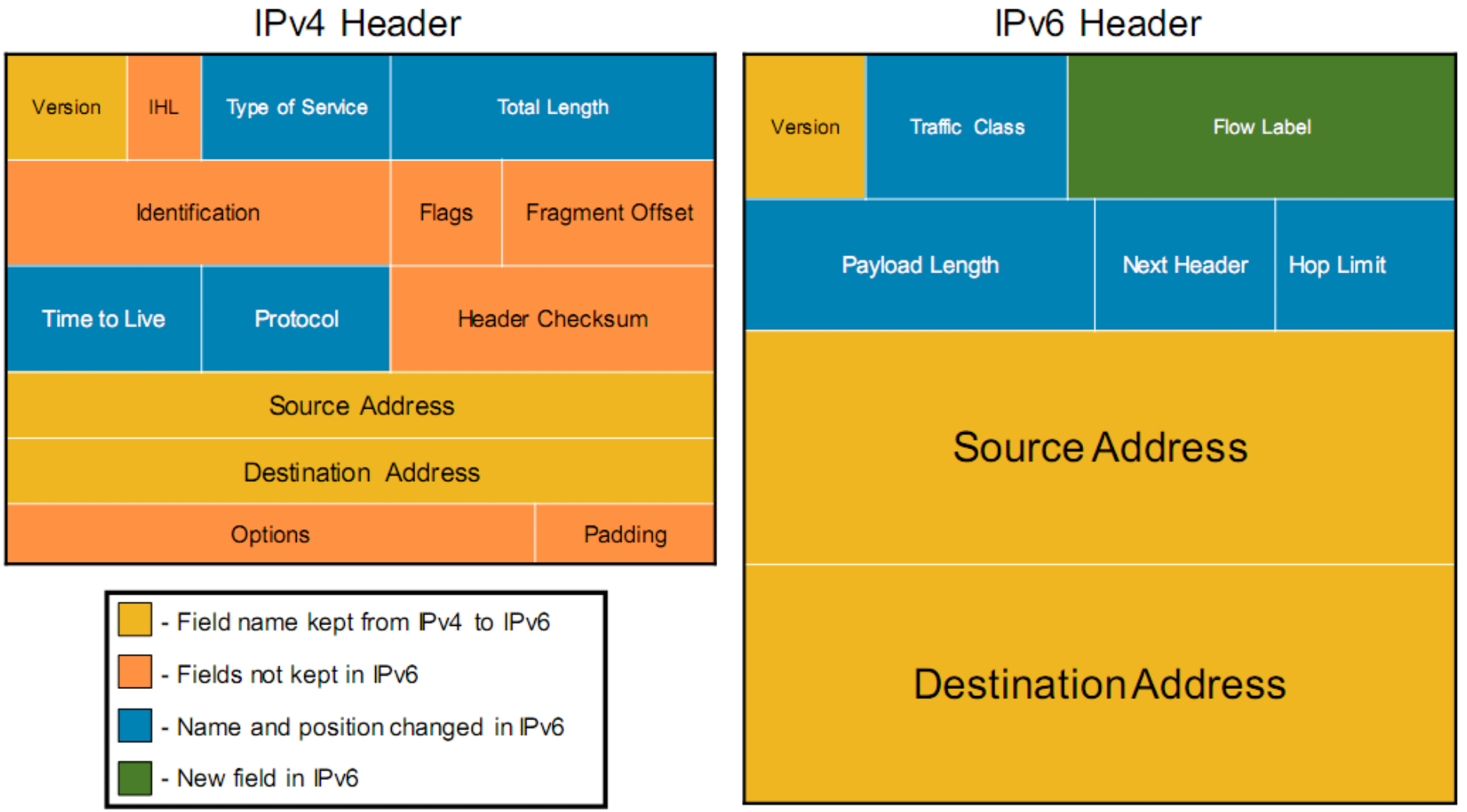
IPv6 Header Changes and Benefits (Cont.)

IPv6 Header Format (Cont.)



IPv6 Header Fields

IPv6 Header Fields



IPv6 Header Fields (Cont.)

Rationale for IP Header Changes

There were a number of reasons to make modifications to the IP header when developing IPv6, including:

- Fix problems in IPv4 headers
- Remove all optional information and leave only core fields
- Add extensibility (extension headers)
- Make the header easier to process


CISCO

IPv6 Address Configuration

IPv6 Address Configuration

The **ipv6 address** command:

- Enables IPv6 on the interface
- Configures the interface IPv6 address

```
router(config-if)#
ipv6 enable
```

- Enables IPv6 support on an interface when no explicit address has been configured

```
router(config-if)#
ipv6 address <ipv6prefix>/<prefixlength> [eui-64]
```

- Configures an IPv6 address on an interface and starts sending out route advertisements for the configured prefix

IPv6 Address Configuration (Cont.)

```
router(config-if)#
ipv6 unnumbered <interface>
```

- Assigns address from another interface

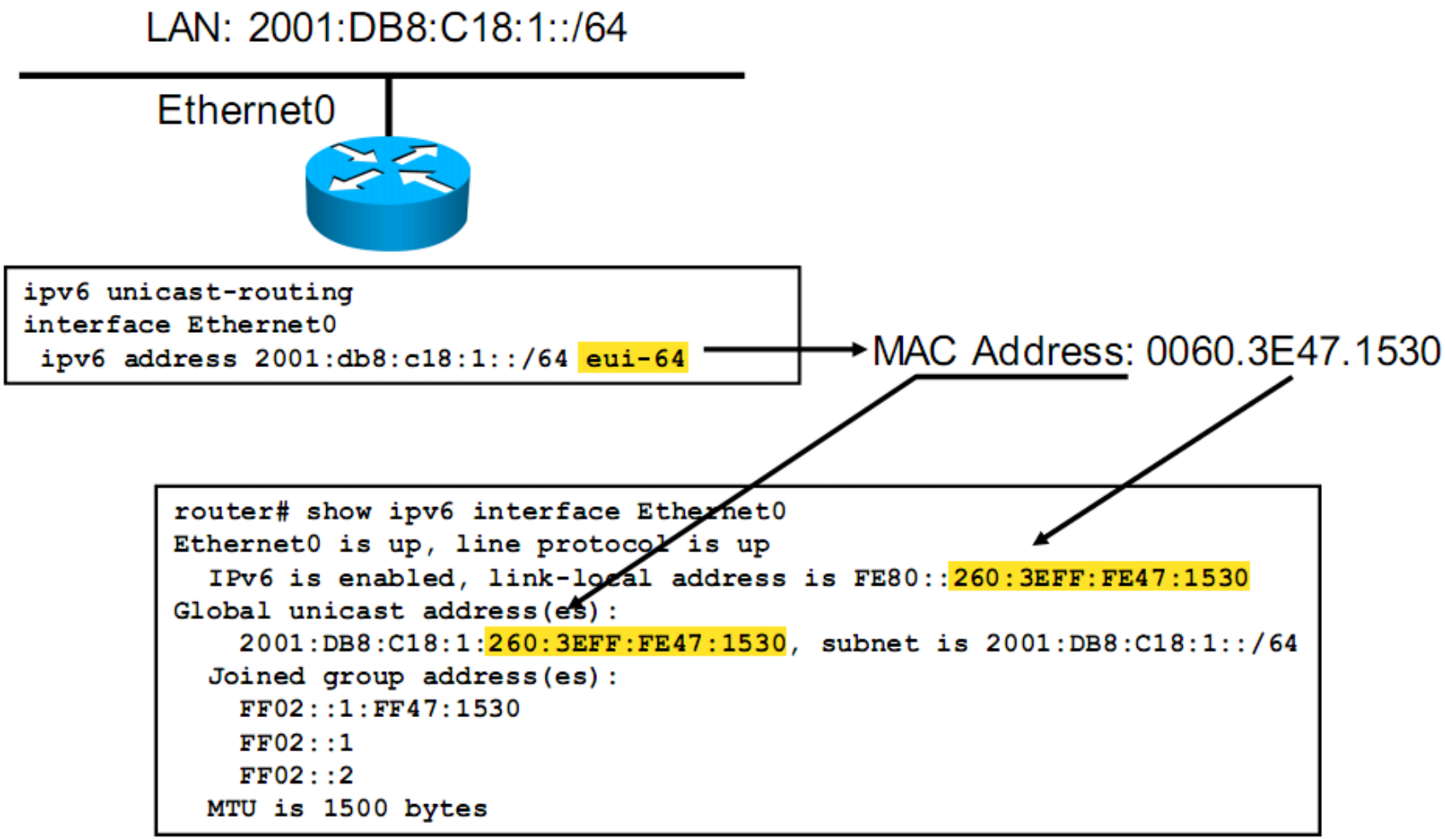
```
router(config-if)#
ipv6 address <fe80::suffix> link-local
```

- Configures link local address to an arbitrary value

```
router(config-if)#
ipv6 address autoconfig [default]
```

- Configures stateless autoconfiguration on the interface
- Default route is added, based on route advertisement information, if the **default** keyword is added.

IPv6 Address Configuration (Cont.)



Autoconfiguration

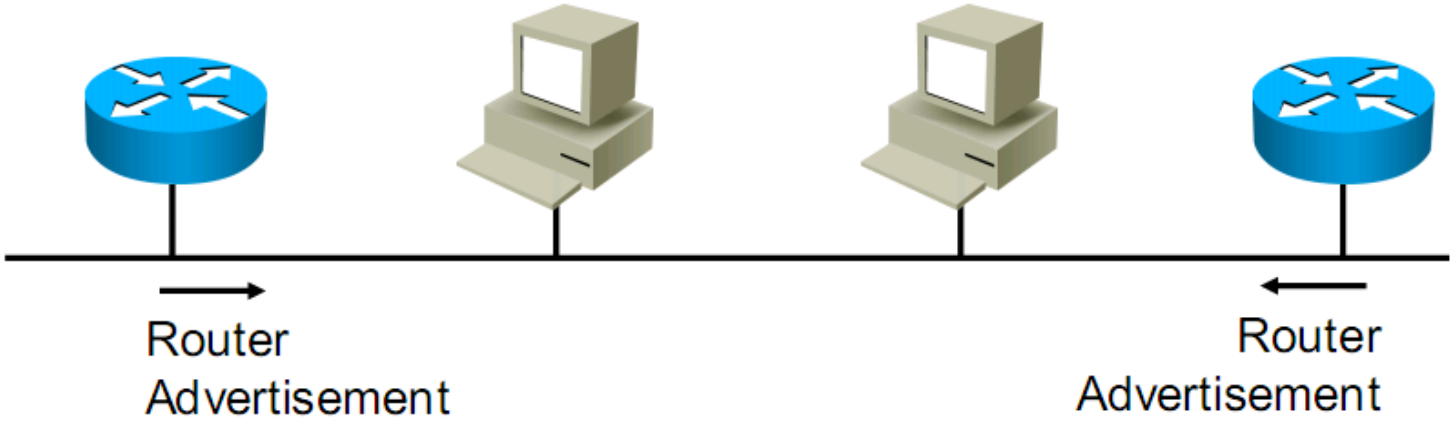
Autoconfiguration

Autoconfiguration

- Stateless
  - Uses neighbor discovery router advertisements
- Stateful
  - Uses DHCPv6 service

Router Advertisements

Routers send periodic router advertisements to the all-nodes multicast address.



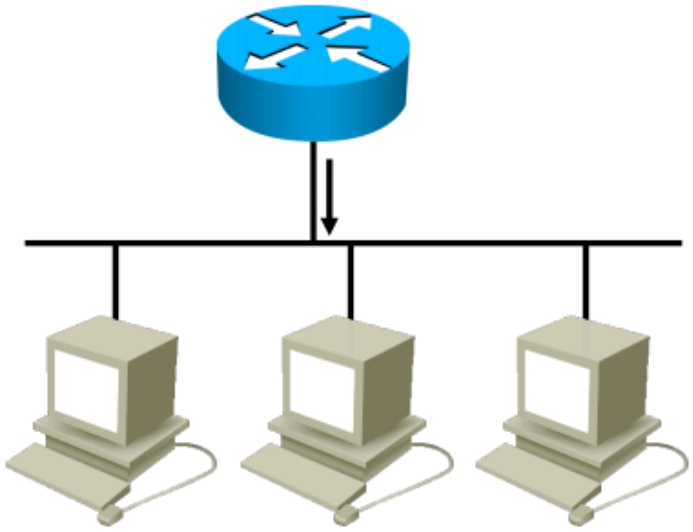
Router advertisement packet:

- ICMP type 134
- Source = Router link-local address
- Destination = FF02::1 (all-nodes multicast address)
- Data = Options, prefix, lifetime, autoconfiguration flag

Router Advertisement Parameters

Router advertisements:

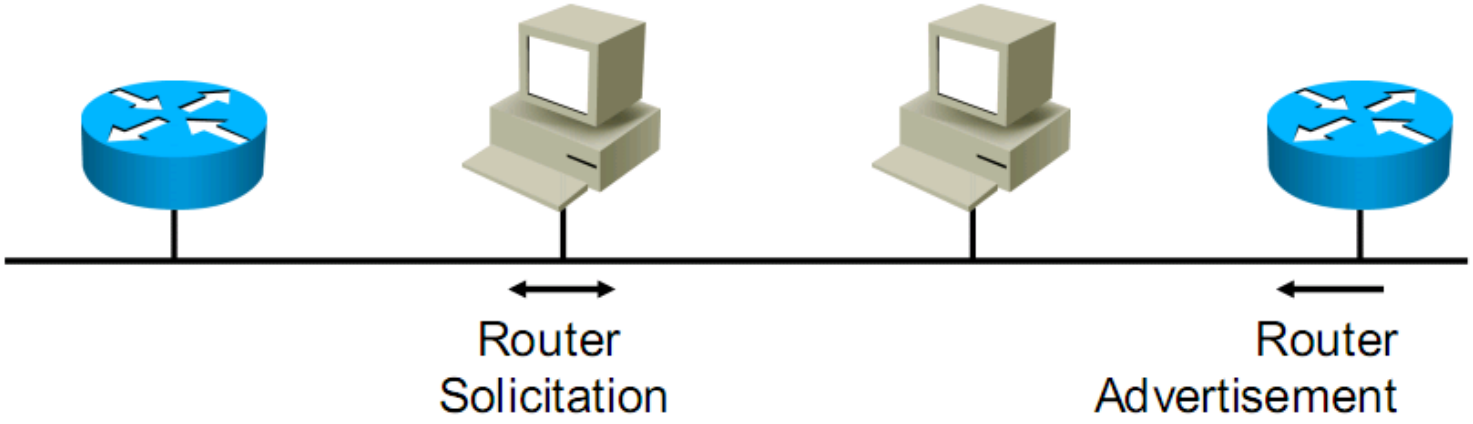
- Default router
- IPv6 network prefix
- Options:
  - Lifetime of advertisement
  - MTU
  - Prefix Length
  - Router priority
  - L-bit
  - A-bit



Autoconfiguring IPv6 Hosts

Router Advertisements

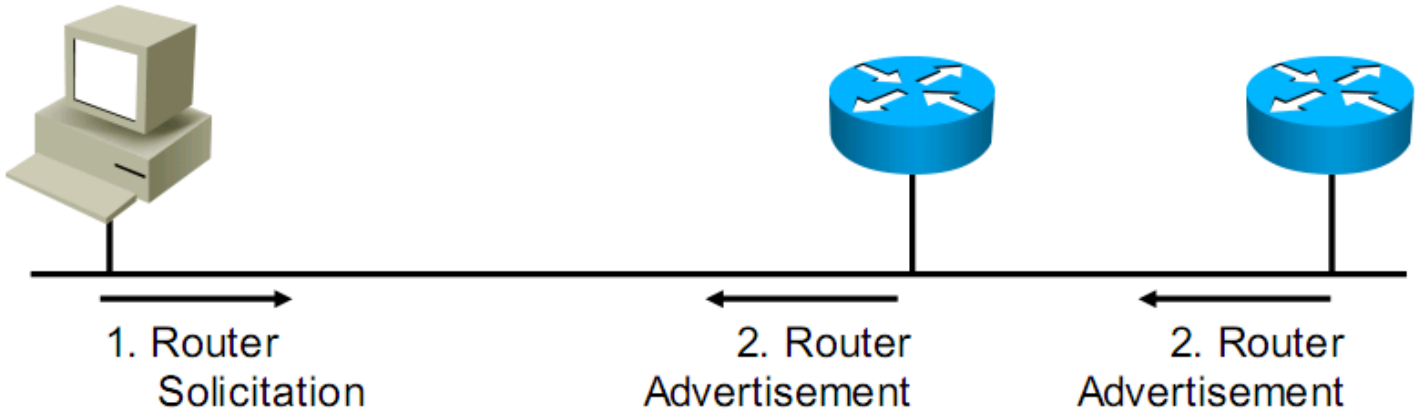
At boot time, nodes send router solicitations to promptly receive router advertisements.



Router solicitation packet:

- ICMP type 133
- Source = :: (unspecified address)
- Destination = FF02::2 (all-routers multicast address)

Stateless Autoconfiguration



1. Router Solicitation:

   ICMP Type 133

   Source = ::

   Destination = FF02::2

   Data = Please Send Router Advertisement

2. Router Advertisement:

   ICMP Type 134

   Source = Router Link-local Address

   Destination = FF02::1

   Data = Options, Prefix, Lifetime, Autoconfiguration Flag

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

Summary

- IPv6 must be enabled globally on a Cisco router and on any interface for which you want to route IPv6 packets.
- The **ipv6 unicast-routing** command is used to enable IPv6 routing on a Cisco router. Assign IPv6 addresses to interfaces by using the **ipv6 address** command.
- Autoconfiguration provides a type of network “plug-and-play” feature, in which devices can pick their own address, based on router-provided information.

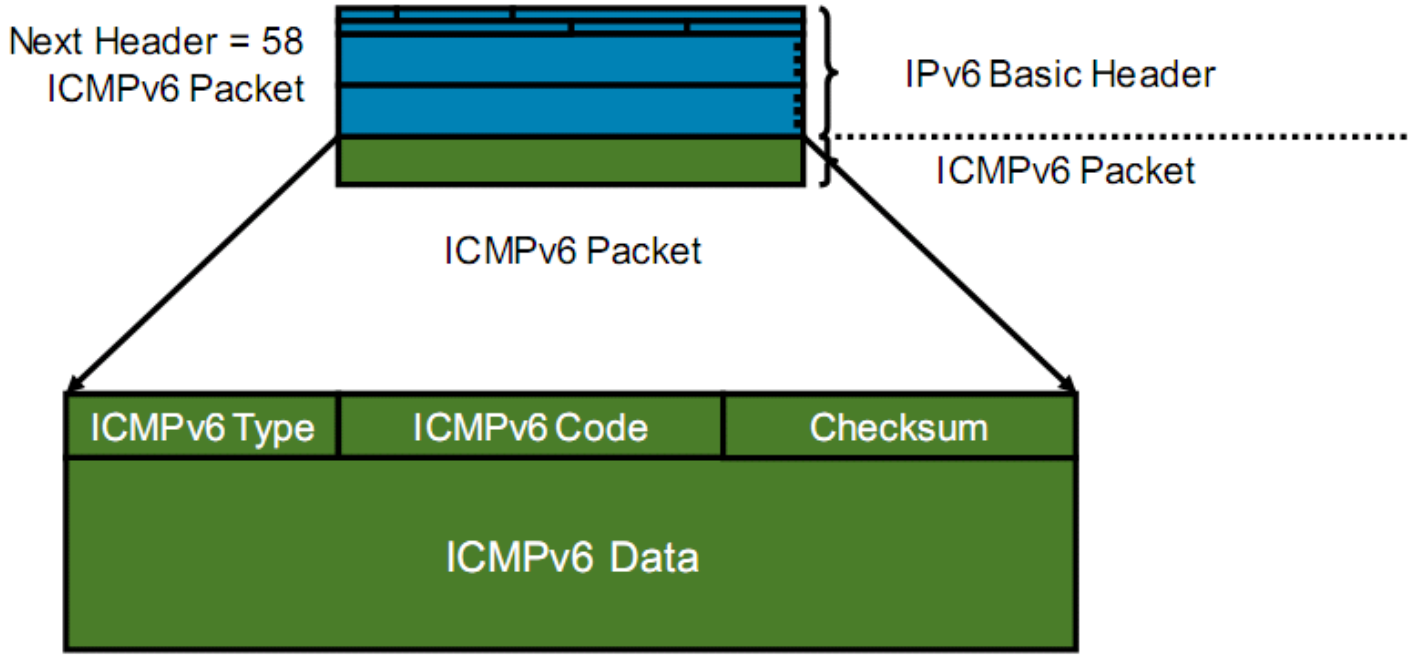

CISCO

Using ICMPv6 and Neighbor Discovery

IPv6 Operations

ICMPv6

ICMPv6



ICMPv6 is similar to ICMPv4:

- Provides diagnostic and error messages
- Is used for path MTU discovery

Echo

Echo

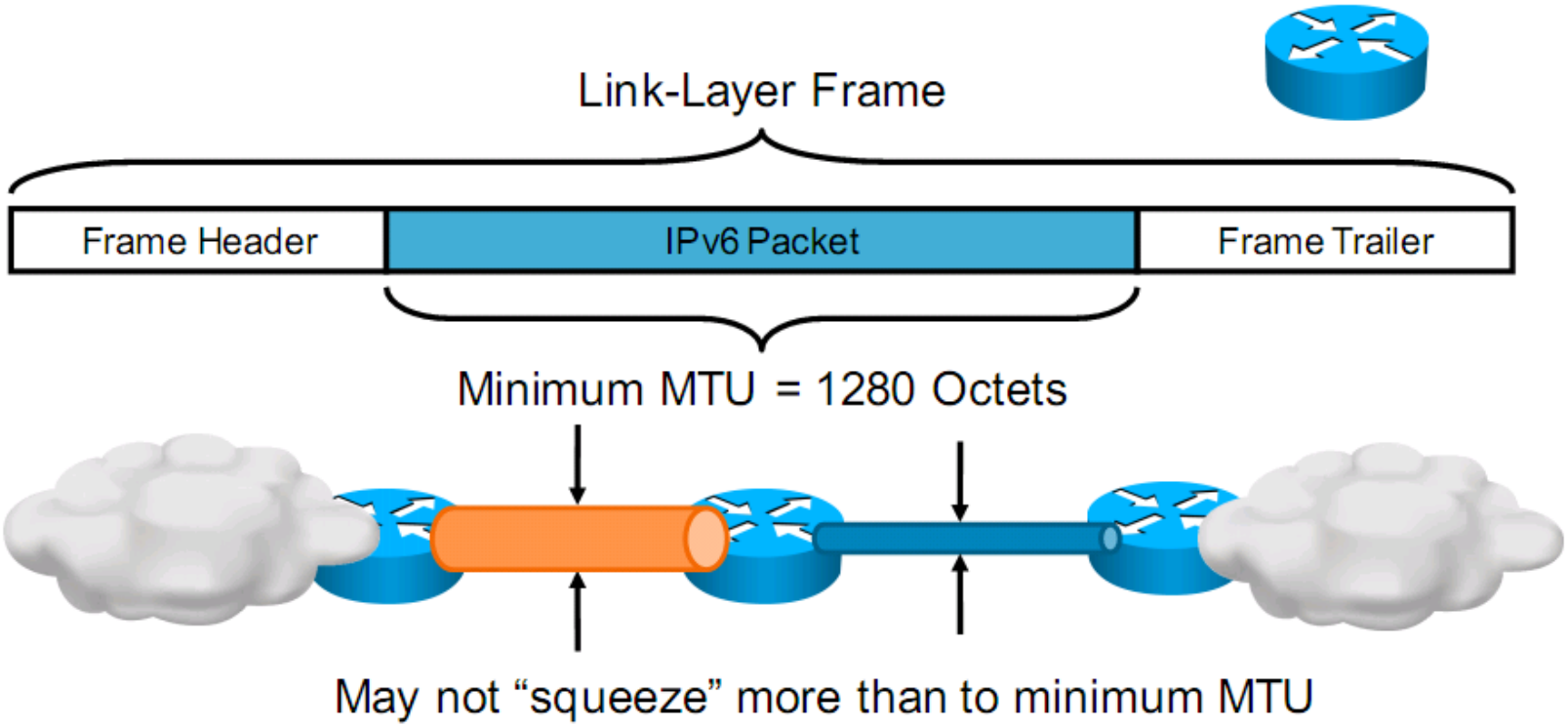
- Type 128: Echo Request
- Type 129: Echo Reply

ICMP Errors

ICMP Errors

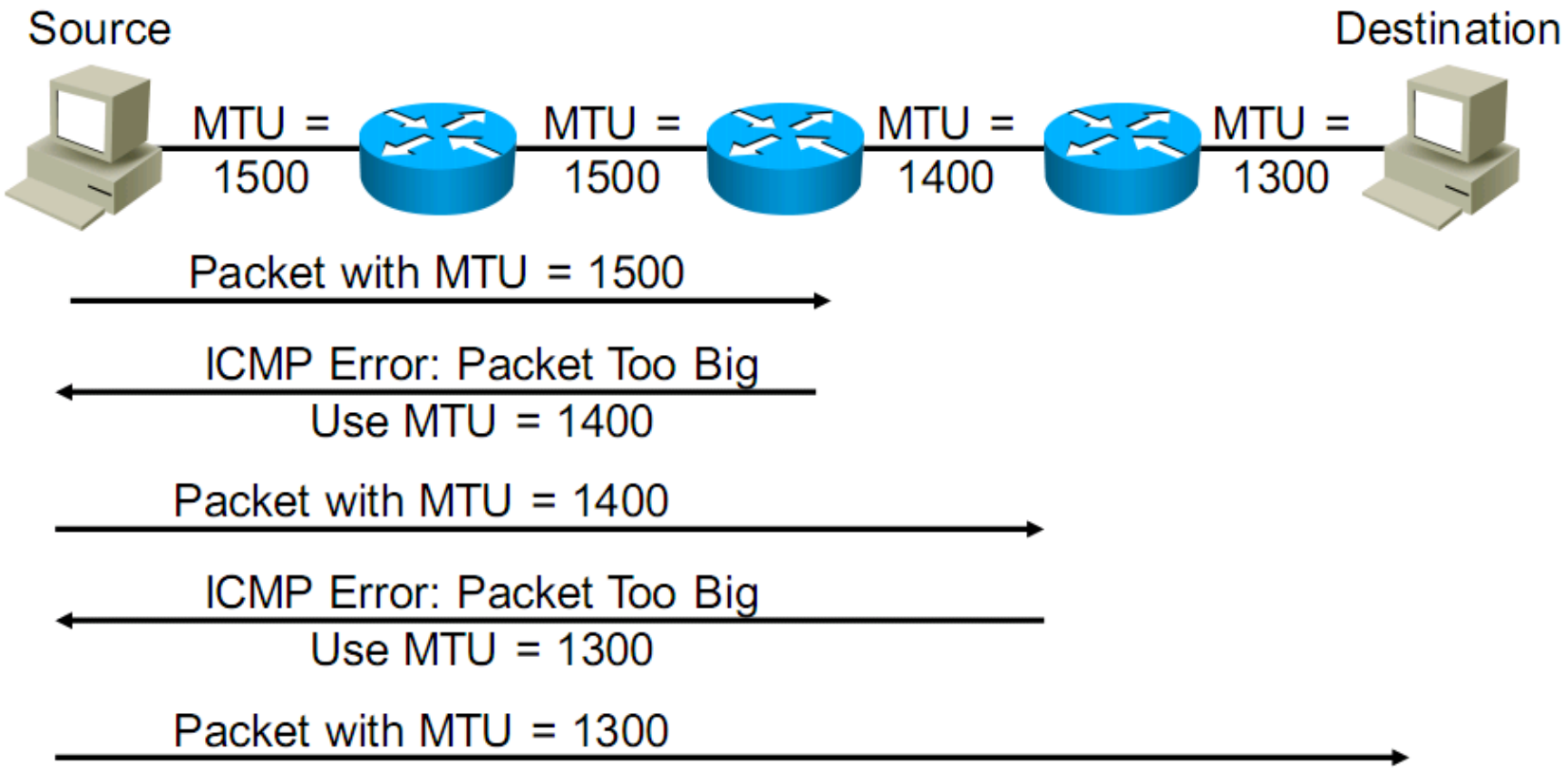
- Type 1: Destination Unreachable
- Type 2: Packet Too Big
- Type 3: Time Exceeded
  - Code 0: Hop Limit Exceeded
  - Code 1: Fragment Reassembly Time Exceeded
- Type 4: Parameter Problem

Maximum Transmission Unit



- IPv4
  - MTU >= 68 octets (576 octets)
- IPv6
  - MTU >= 1280 octets
  - Path MTU used

Path MTU Discovery



Path MTU = 1300

IPv6 over Data Link Layers

IPv6 over Data Link Layers

IPv6 is defined for most data link layers:

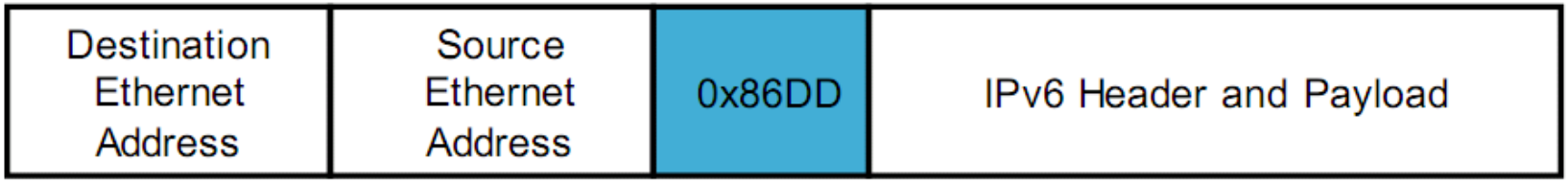
- Ethernet
- PPP
- FDDI
- Token Ring
- HDLC
- Nonbroadcast multiaccess
- ATM
- Frame Relay
- IEEE 1394

Neighbor Discovery

Neighbor Discovery

- Type 133: Router Solicitation
- Type 134: Router Advertisement
- Type 135: Neighbor Solicitation
- Type 136: Neighbor Advertisement
- Type 137: Redirect Message

IP over Ethernet



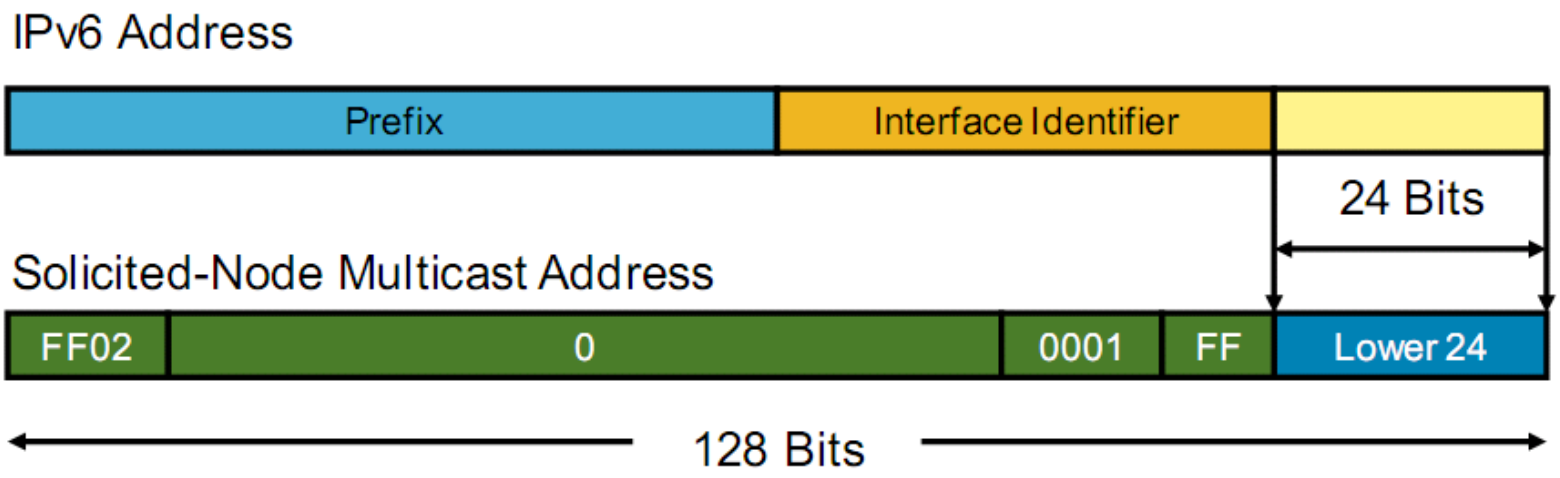
- Ethernet II has the 16-bit EtherType field to indicate payload protocol:
  - IPv4 uses EtherType value 0x0800.
  - ARP has EtherType value 0x0806.
  - IPv6 has a different EtherType value: 0x86DD.
- Most other link-layer protocols use the same value as EtherType to identify the carried protocol.

Neighbor Discovery

ARP is for IPv4 what neighbor discovery is for IPv6.

- How IP acquires Layer 2 address of a neighbor:
  - Known network layer address, unknown link layer address
  - IPv4 uses ARP
  - IPv6 uses neighbor discovery
- Neighbor discovery:
  - Queries for duplicate addresses
  - Determines the link layer address of a neighbor
  - Finds neighbor routers on link
  - Is achieved by using ICMPv6 with IPv6 multicast

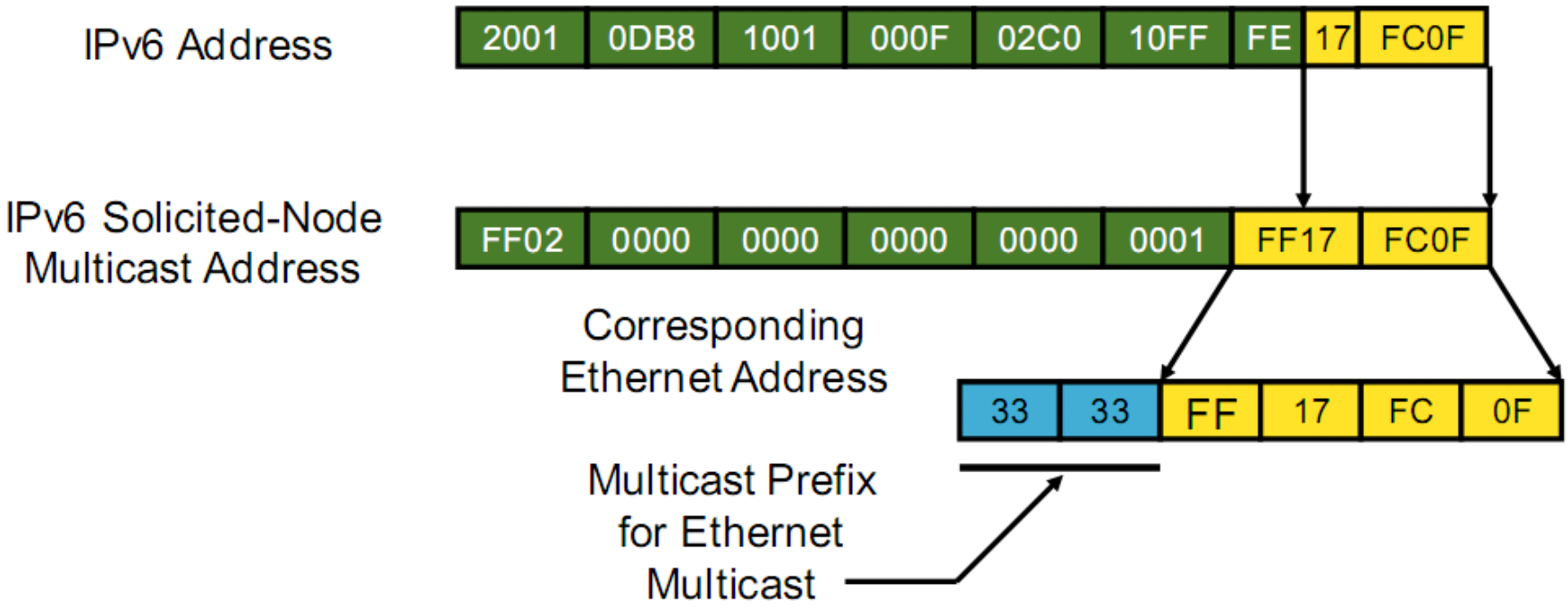
Solicited-Node Multicast Address



Solicited-node address:

- Multicast address with a link-local scope
- Formed by a prefix and the right-most 24 bits of every unicast and anycast address

Multicast Mapping over Ethernet



Multiple IPv6 multicast addresses are mapped into single Ethernet multicast address

Neighbor Discovery: Neighbor Solicitation

ICMP Type = 135
Src = A
Dst = Solicited-node Multicast of B
Data = Link Layer Address of A
Query = What Is Your Link Address?

ICMP Type = 136
Src = B
Dst = A
Data = Link Layer Address of B

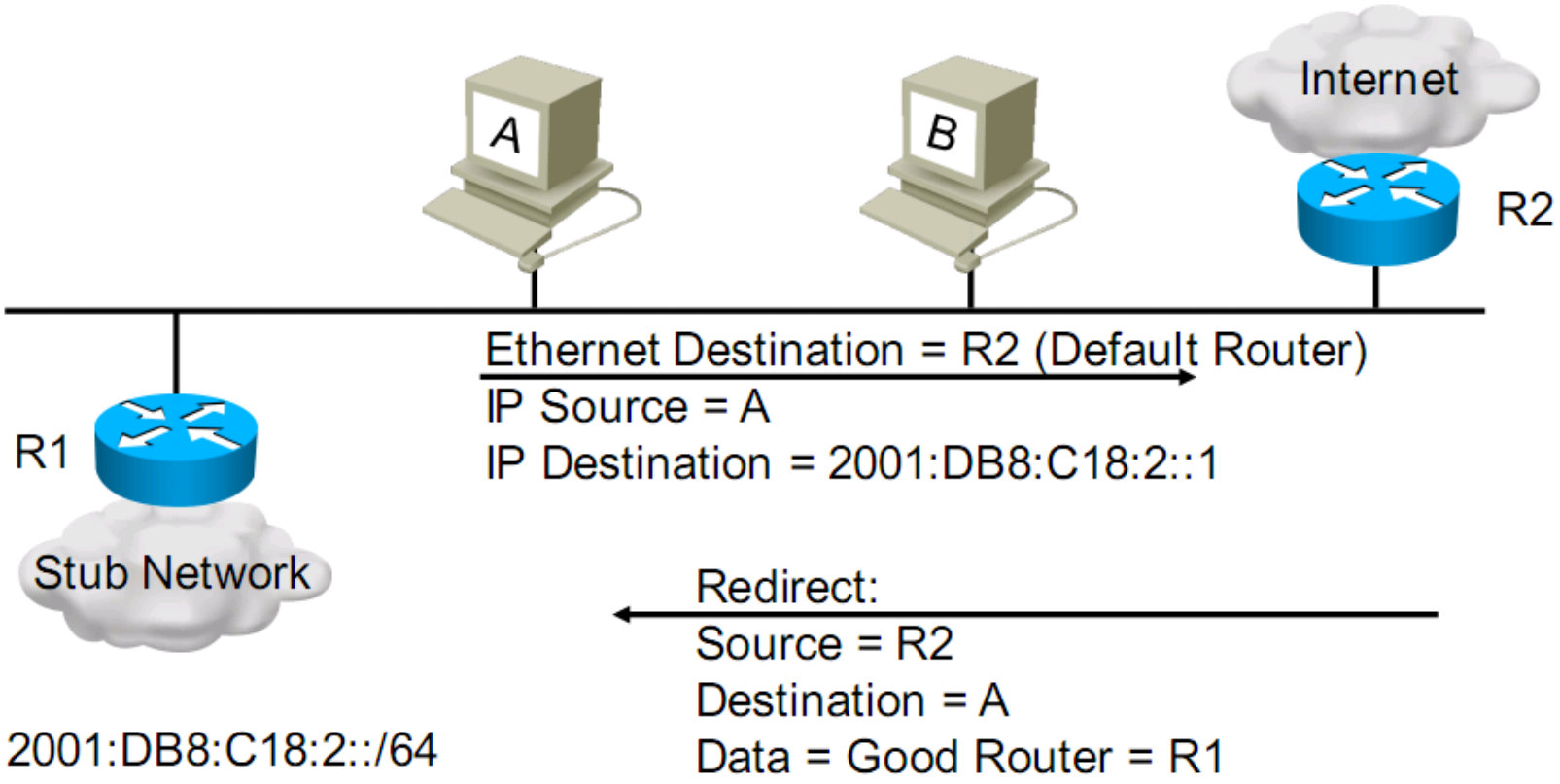
A and B can now exchange packets on this link.

Neighbor Discovery: Neighbor Solicitation (Cont.)

Neighbor advertisement message:

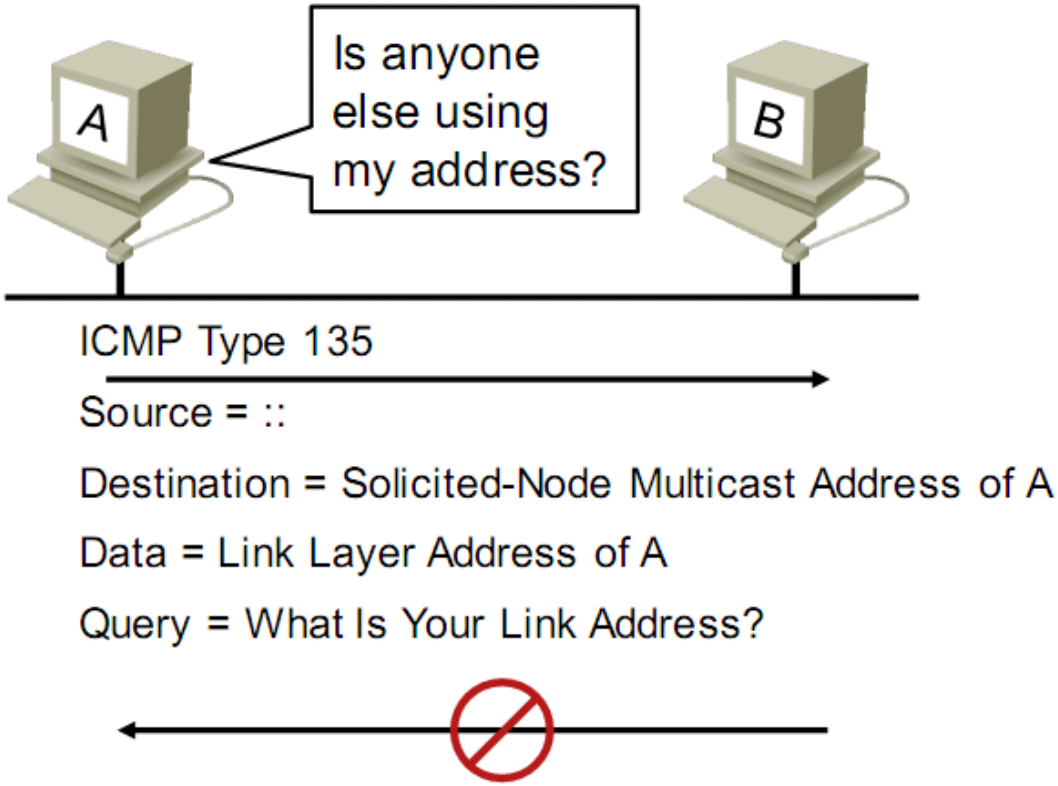
- **R:** Router flag, indicates sender is a router
- **S:** Solicited flag, indicates message is sent in response to a neighbor solicitation
- **O:** Override flag, indicates advertisement should override existing neighbor cache entry

Neighbor Discovery: Redirect



Routers use redirect to signal the rerouting of a packet to a better router.

Duplicate Address Detection



- DAD uses neighbor solicitation to verify the existence of an address to be configured.
- DAD is not used for anycast addresses.

Module Summary

- With a 128-bit address length, the IPv6 address space is significantly larger and more diverse than the IPv4 address space and thus is more complicated to manage.
- The header format for each IP packet carries crucial information for the routing and handling of each packet payload.
- Most major operating systems already support IPv6, but support in applications can vary from application to application.
- Cisco has provided support for IPv6 in Cisco IOS Software since 2002.
- IPv6 neighbor discovery is a process in which neighbors discover each other and autoconfigure addresses.
- After IPv6 has been enabled on a Cisco router, issues might arise and require troubleshooting of Cisco IOS Software configurations.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