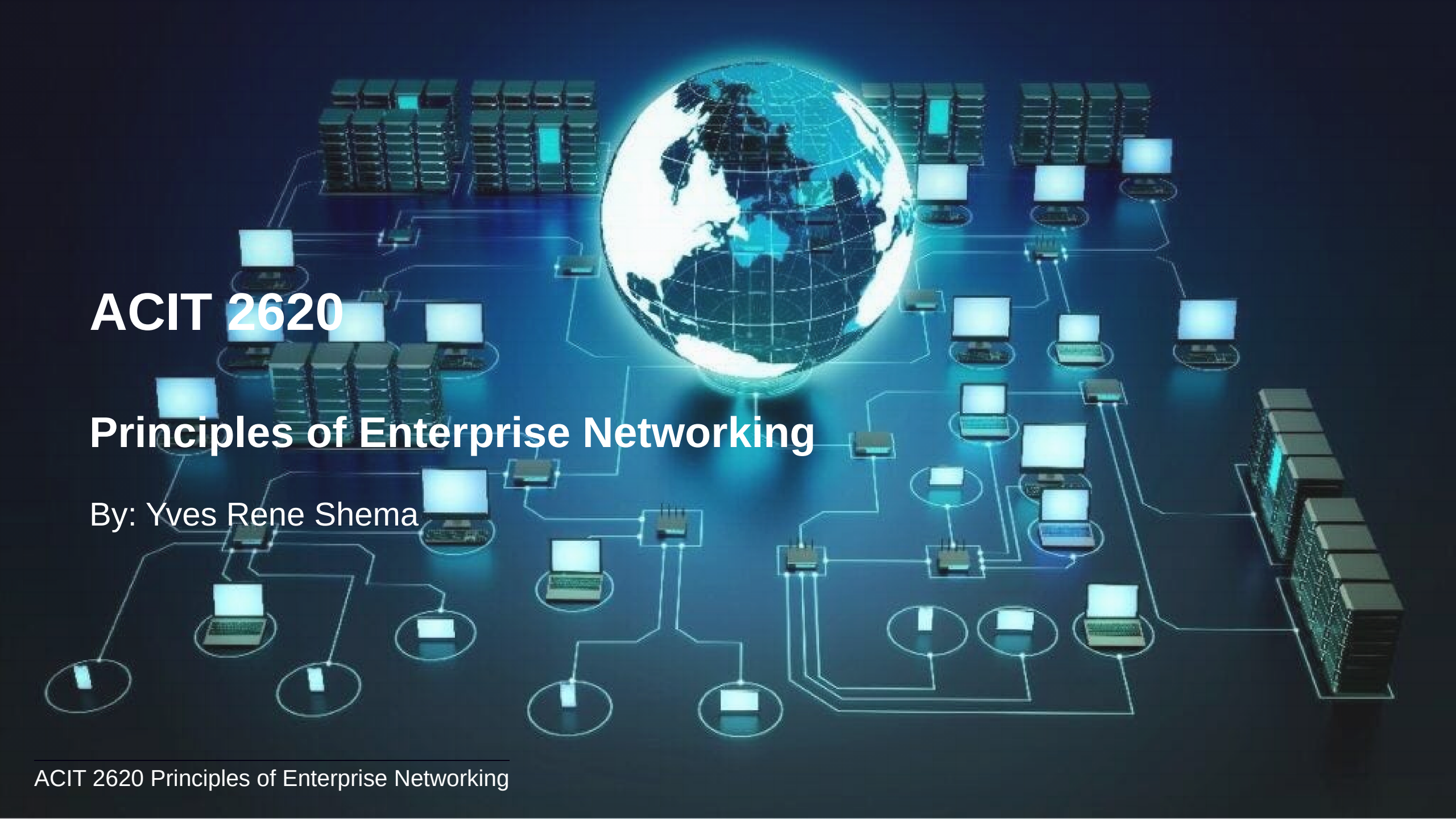


ACIT 2620

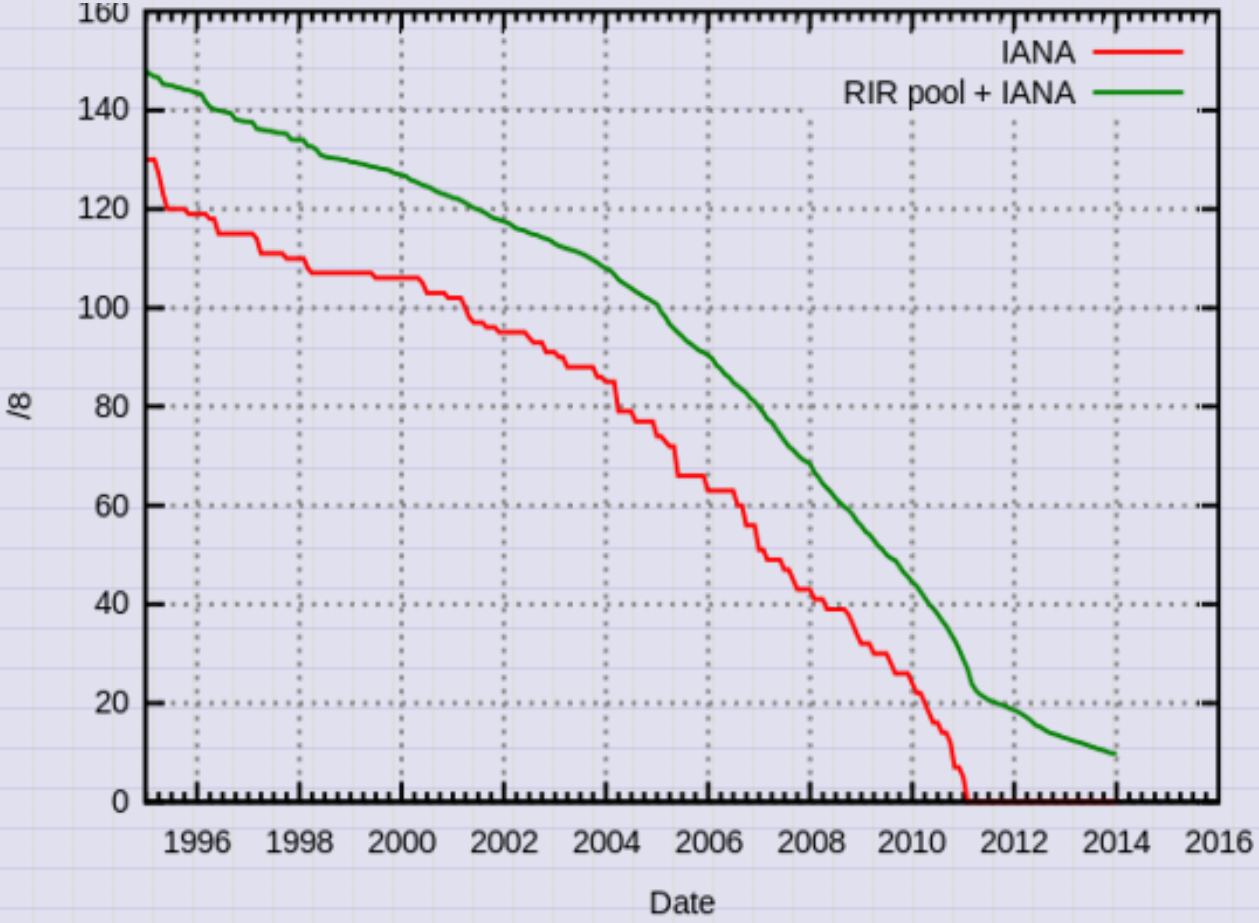
Principles of Enterprise Networking

By: Yves Rene Shema

Internet Protocol Version 6

The Motivation for Moving to IPv6

- The ability to scale networks for future demands requires a large supply of IP addresses and improved mobility.
  - IPv6 combines expanded addressing with a more efficient header.
  - IPv6 satisfies the complex requirements of hierarchical addressing.



IPv4 Address Depletion

- Though NAT, VLSM and CIDR were developed as workarounds and have helped to extend the life of IPv4, the address space is nearing exhaustion
- Below is a graph (05/2014) displaying the availability of /8 address Blocks

What Happened to IPv5?

- The Internet Stream Protocol (ST) was developed to experiment with voice, video and distributed simulation.
- Newer ST2 packets used IP version number 5 in the header.
- Although not officially know as IPv5, ST2 is considered to be the closest thing.
- The next Internet protocol became IPv6.

Features of IPv6

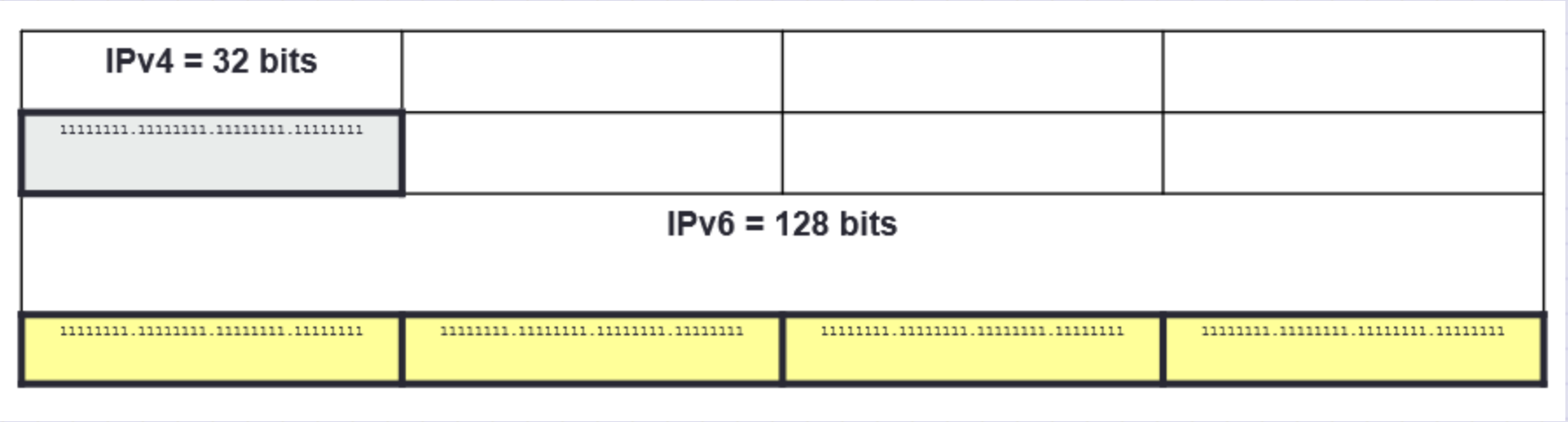
- Larger address space
- Elimination of public-to-private NAT
- Elimination of broadcast addresses
- Simplified header for improved router efficiency
- Support for mobility and security
- Many devices and applications already support IPv6
- Prefix renumbering simplified

Features of IPv6

- Multiple addresses per interface
- Address autoconfiguration
- No requirement for DHCP
- Link-local and globally routable addresses
- Multiple-level hierarchy by design
- More efficient route aggregation
- Transition mechanisms from IPV4 to IPV6

IPv6 Addressing Overview

- IPv6 increases the number of address bits by a factor of 4, from 32 to 128, providing a very large number of addressable nodes.



IPv6 Address Space

- 2 = 340,282,366,920,938,463,463,374,607,431,768,211,456
- Or about 3.4×10
- 340 **undecillion**
- How big is it?

> Two raised to the 128th power is an astronomical number. In decimal terms, it is roughly **340 billion billion billion billion**—or, as Martin Levy of Hurricane Electric likes to say, “more than four quadrillion addresses for every star in the observable universe.”
>
> — Astronomically inadequate - The Economist

IPv6 Address Specifics

- The 128-bit IPv6 address is written using 32 hexadecimal numbers.
- The format is `x:x:x:x:x:x:x:x`, where **x** is a 16-bit hexadecimal field, therefore each x represents four hexadecimal digits.
- Example address:
  - 2035:0001:2BC5:0000 : 0000:087C:0000:000A

Abbreviating IPv6 Addresses

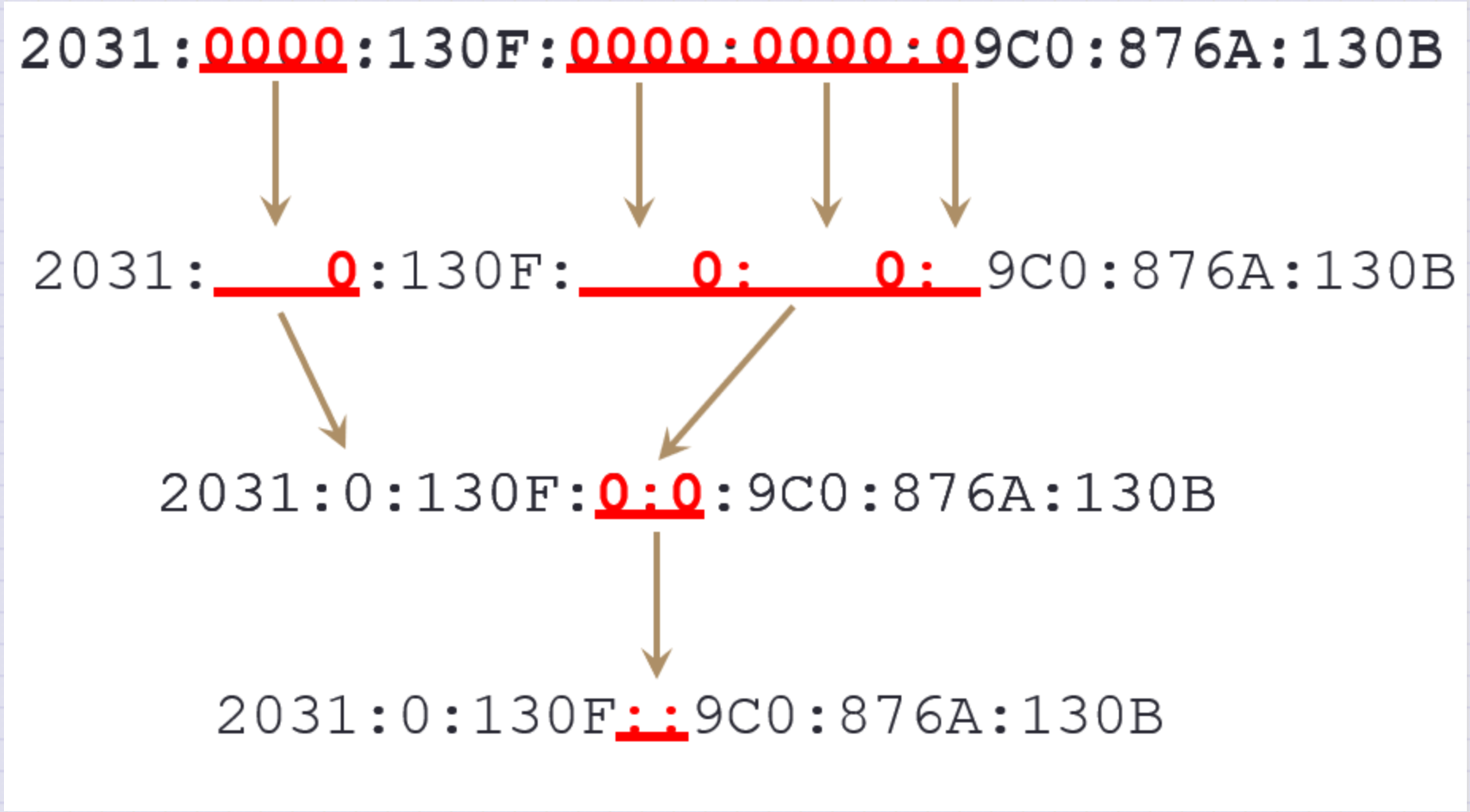
Leading 0s within each set of four hexadecimal digits can be omitted.

09C0 = 9C0

0000 = 0

A pair of colons (“::”) can be used, once within an address, to represent any number (“a bunch”) of successive zeros.

IPv6 Address Abbreviation Example



IPv6 Address Abbreviation Examples

```
  FF01:0000:0000:0000:0000:0000:0000:1
= FF01:0:0:0:0:0:0:1
= FF01::1
```

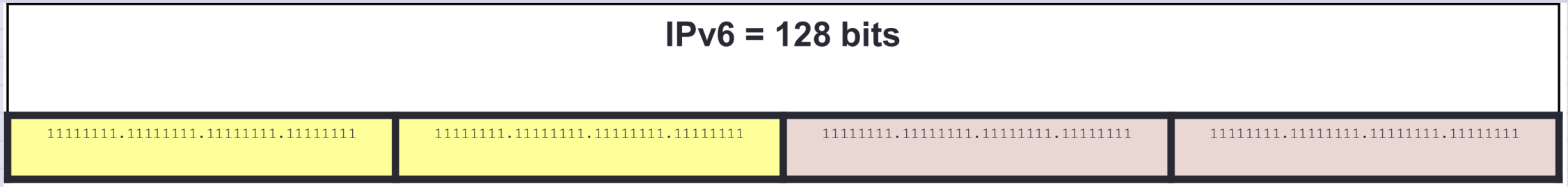
```
  E3D7:0000:0000:0000:51F4:00C8:C0A8:6420
= E3D7::51F4:C8:C0A8:6420
```

IPv6 Address Abbreviation Examples

```
   3FFE:0501:0008:0000:0260:97FF:FE40:EFAB
= 3FFE:501:8:0:260:97FF:FE40:EFAB
= 3FFE:501:8::260:97FF:FE40:EFAB
```

IPv6 Address Components

- An IPv6 address consists of two parts:
  - First 64 Bits: A subnet/network prefix
  - Last 64 Bits: An interface ID



Subnet Prefix

- IPv6 uses CIDR notation to denote the number of bits that represent the subnet.
- The prefix length is almost always /64.
  - However, IPv6 rules allow for either shorter or longer prefixes
- Deploying a /64 IPv6 prefix on a device recommended.
  - Allows Stateless Address Auto Configuration (SLAAC)

Subnet Prefix

Example

FC00:0:0:1::1234/64

is really

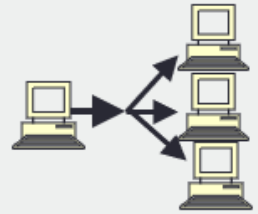
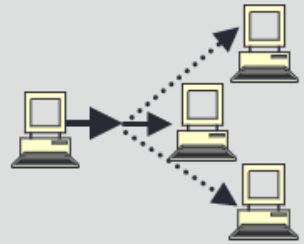
FC00:0000:0000:0001:0000:0000:0000:1234/64

- The first 64-bits (FC00:0000:0000:0001) forms the address prefix.
- The last 64-bits (0000:0000:0000:1234) forms the Interface ID.

Interface Identifiers

- IPv6 addresses on a link must be unique.
- Using the link prefix, IPv6 hosts can automatically create a unique IPv6 address.
- The following Layer 2 protocols can dynamically create the IPv6 address interface ID:
  - Ethernet
  - PPP
  - HDLC
  - NBMA, Frame Relay

IPv6 Address Types

Address Type	Description	Topology
Unicast	"***One to One***" • An address destined for a single interface. • A packet sent to a unicast address is delivered to the interface identified by that address.	
Multicast	"***One to Many***" • An address for a set of interfaces (typically belonging to different nodes). • A packet sent to a multicast address will be delivered to all interfaces identified by that address.	
Anycast	"***One to Nearest***" (Allocated from Unicast) • An address for a set of interfaces. • In most cases these interfaces belong to different nodes. • created "automatically" when a single unicast address is assigned to more than one interface. • A packet sent to an anycast address is delivered to the closest interface as determined by the IGP.	

IPv6 Unicast Address Scopes

- Address types have well-defined destination scopes:
  - **Link-local** address
  - **Unique-local** addresses (replaced Site-local address)
  - **Global** unicast address
- Determined by the leading digits of the subnet prefix

- Link-local addresses—only on single link, not routed
  - FE80::/10 prefix
- Unique-local addresses—routed within private network (aka private IPv4 addresses)
  - FC00::/7 (still reserved) and FD00 prefix
- Global unicast addresses—globally routable
  - 2001 prefix most common

Multiple IPv6 Addresses per Interface

- An interface can have multiple global IPv6 addresses.
- Typically, an interface is assigned a link-local and one (or more) global IPv6 address.
- For example, an Ethernet interface can have:
  - **Link-local address** (FE80::21B:D5FF:FE5B:A408)
  - **Global unicast address** (2001:8:85A3:4289:21B:D5FF:FE5B:A408)
- The Link-local address is used for local device communication.
- The Global address is used to provide Internet reachability.

IPv6 Addressing Space Overview

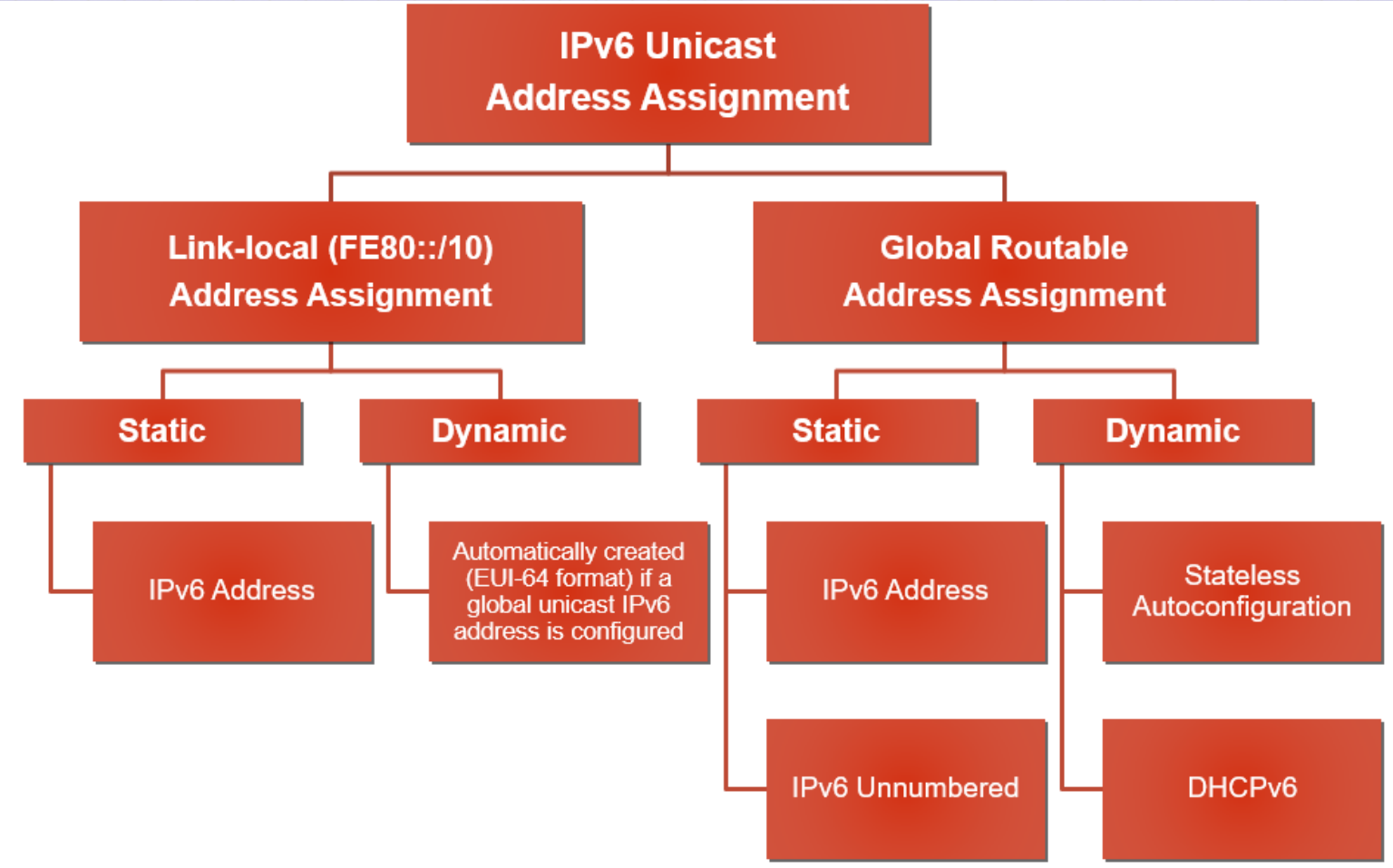
Note: IPv6 Internet uses **2001::/3** which is **< 2%** of IPv6 address space

16 Bit Prefix Hex Value	Use
0000 to 00FF	• **Unspecified** • **Loopback** • **IPv4-compatible**
0100 to 01FF	Unassigned (0.38 % of IPv6 space)
0200 to 03FF	NSAP (Network Service Access Provider)
0400 to 1FFF	Unassigned **(~11% of IPv6 space)**
2000 to 3FFF	**Aggregatable global unicast (12.5%)**
4000 to FE7F (Huge)	Unassigned **(~75% of IPv6 space)**
FE80 to FEBF	**Link-local**
FC00 to FCFF	**Unique-local**
FF00 to FFFF	**Multicast**

Special IPv6 Addresses

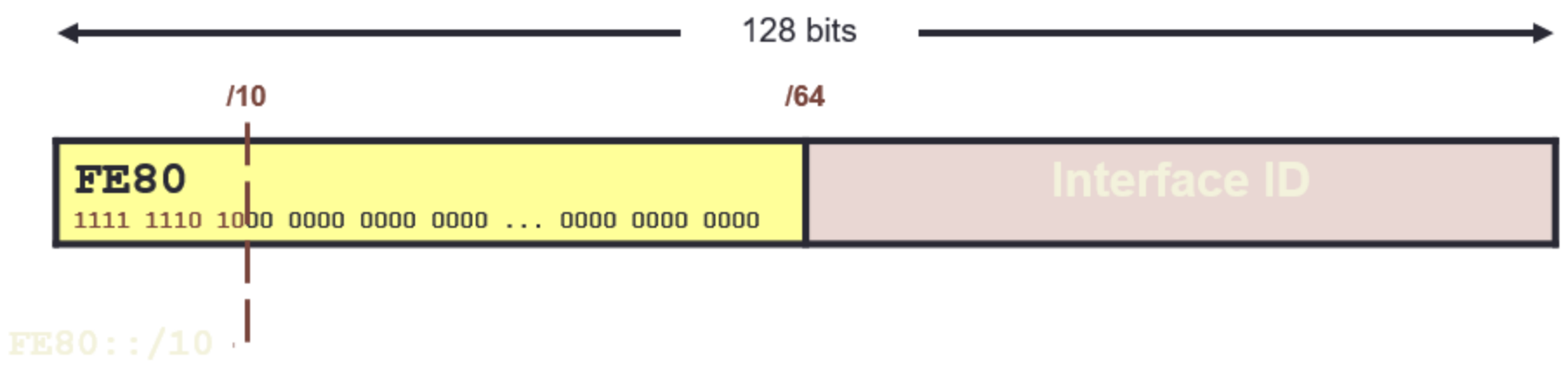
IPv6 Address	Description
::/0	• All networks and used when specifying a default static route. • It is equivalent to the IPv4 quad-zero (0.0.0.0)
::/128	• Unspecified address and is initially assigned to a host when it first resolves its local link address
::1/128	• Loopback address of local host • Equivalent to 127.0.0.1 in IPv4
FE80::/10	• Link-local unicast address • Similar to the Windows autoconfiguration IP address of 169.254.x.x
FF00::/8	• Multicast addresses
All other addresses	• Global unicast address

IPv6 Unicast Addresses



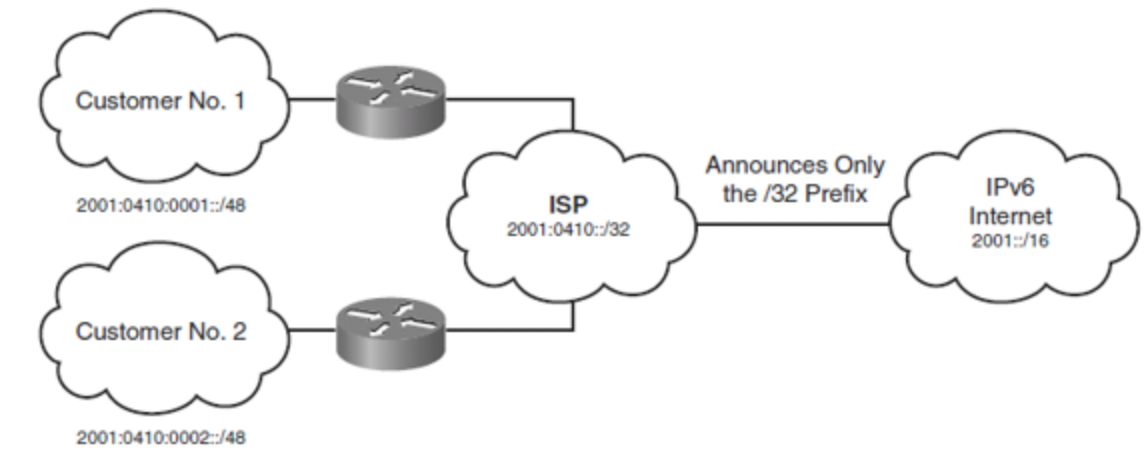
IPv6 Link-Local Unicast Address

- Link-local addresses play a crucial role in the operation of IPv6.
- They are dynamically created using a link-local prefix of **FE80::/10** and a 64-bit interface identifier.



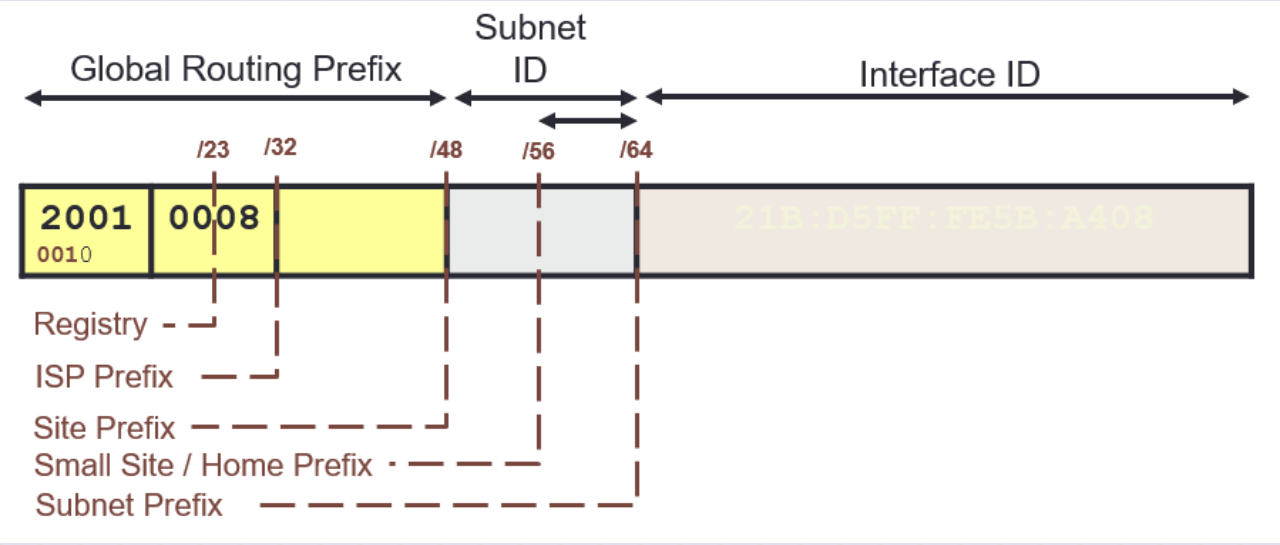
IPv6 Global Unicast Address

- A global unicast address is an IPv6 address from the global public unicast prefix (2001::/16).
- These addresses are routable on the global IPv6 Internet.
- Global unicast addresses are aggregated upward through organizations and eventually to the ISPs.



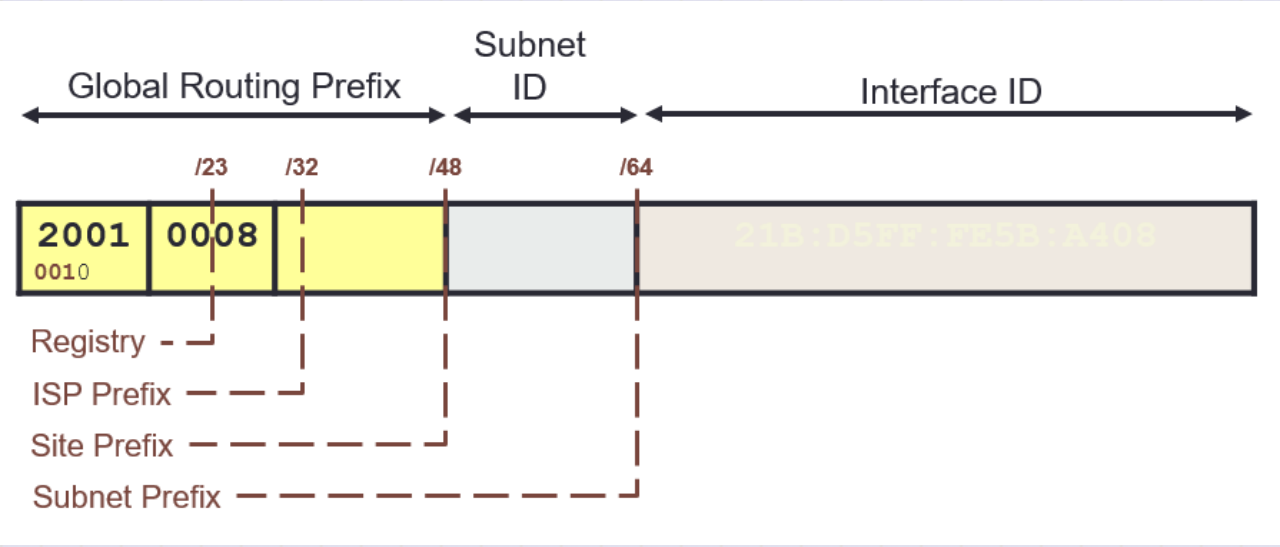
IPv6 Global Unicast Address

- The global unicast address consists of:
  - A 48-bit global routing prefix (or possibly a 56-bit global routing prefix see http://tools.ietf.org/html/rfc6177)
  - A 16-bit subnet ID (or 8 bit Subnet ID)
  - A 64-bit interface ID



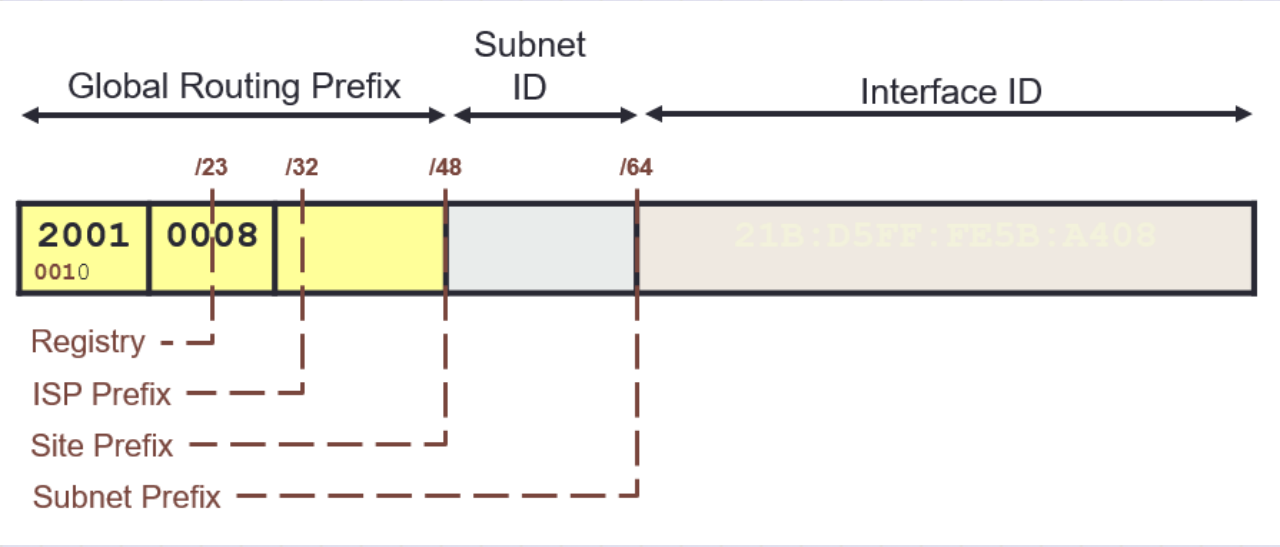
IPv6 Global Unicast Address

- The current IANA global routing prefix uses the range that starts with binary 0010 (2000::/3).

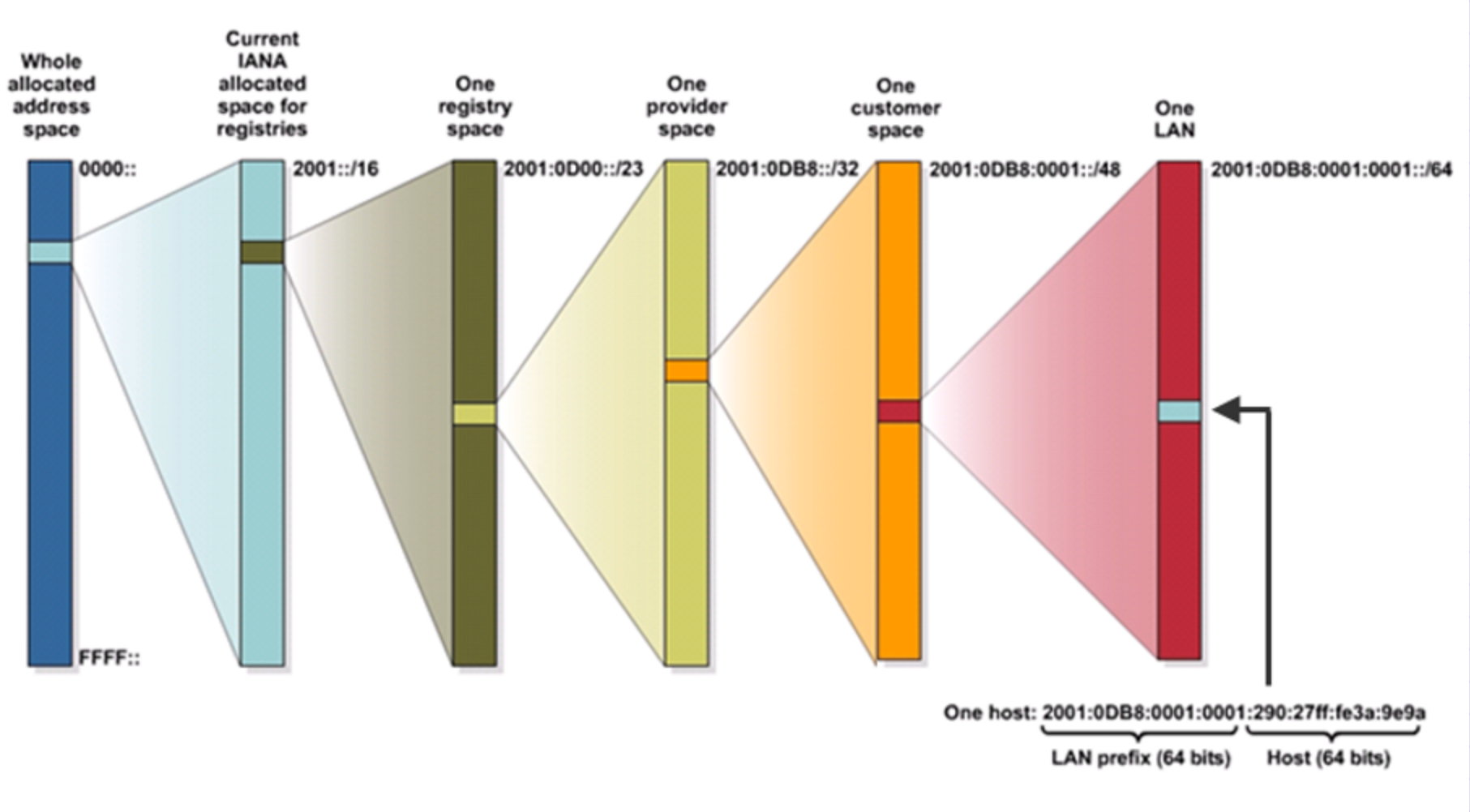


IPv6 Global Unicast Address

- The subnet ID can be used by an organization to create their own local addressing hierarchy.



IPv6 Address Allocation Process



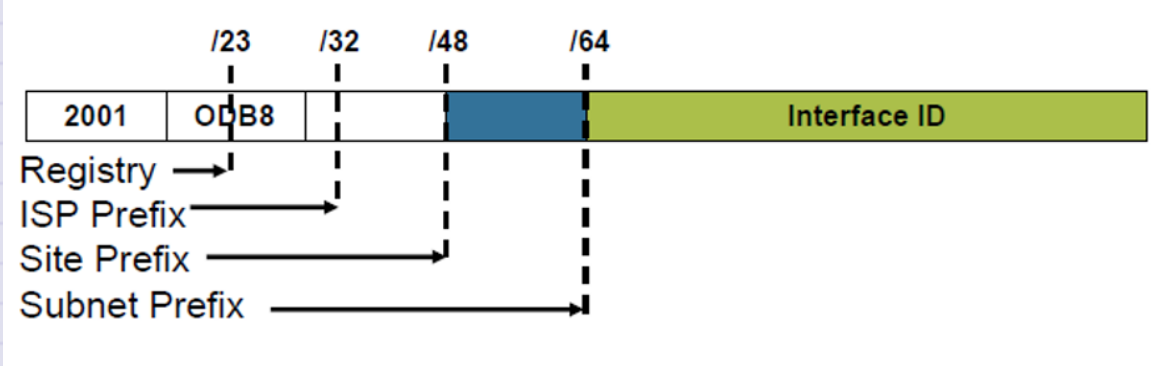
IPv6 Subnetting Overview

- CIDR notation is used
  - IPv6 address is in Hex
  - Network mask in decimal
- Number of subnet bits set to 1 define network prefix
- All other bits are for nodes
- There are no reserved addresses (network or broadcast)

2001:25:12:ab12:3456:dfb5:712:45FF/64

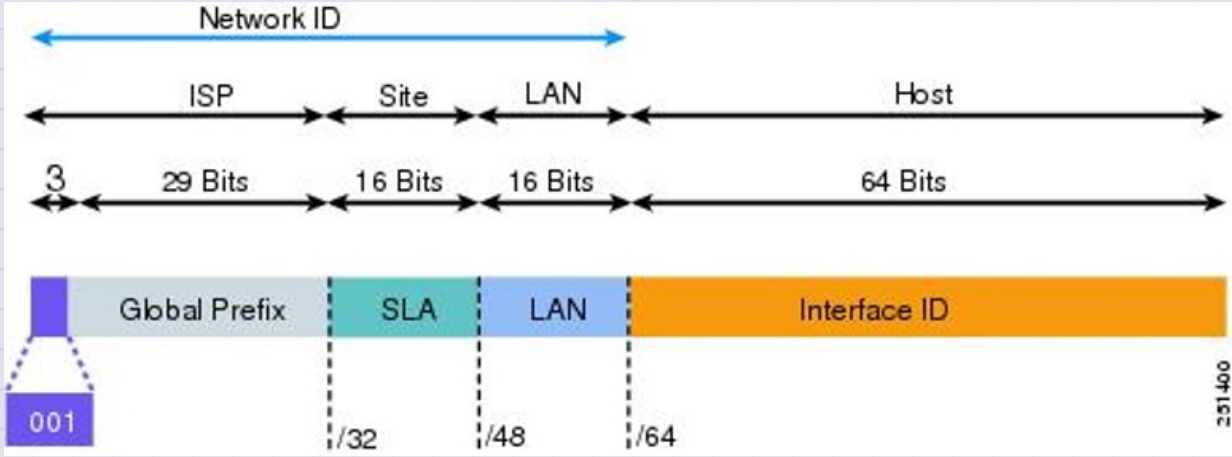
Prefix Length, Allocation of Bits

- Example:
  2001:DB8:0:2F00:2AA:FF:FE28:9C5A/64
- Prefix length (total number of network bits) is 64
- (Normally) 48 Bit Prefix (or 56 bit) is assigned by ISP
  - Allows for 16 subnet bits (or 8) allow 65,535 LANs
- (Generally) 64 bits are used for hosts in IPv6



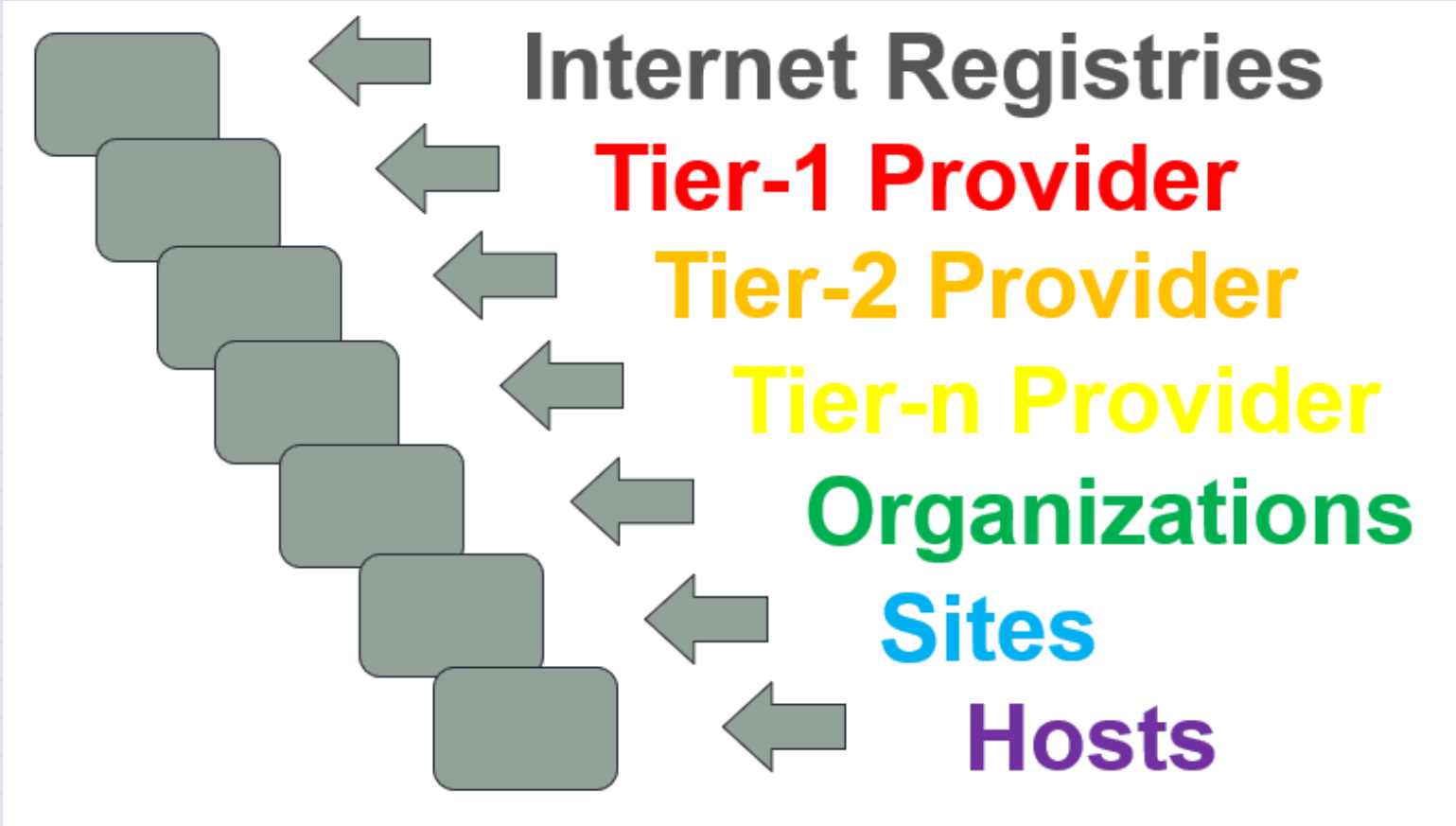
IPv6 Subnetting with Global Unicast Addresses

- The global routing prefix is assigned to a service provider by IANA (/32).
- The site level aggregator (SLA) is assigned by the ISP (/48).
- The LAN ID represents individual subnets within the customer site and is administered by the customer (/64).

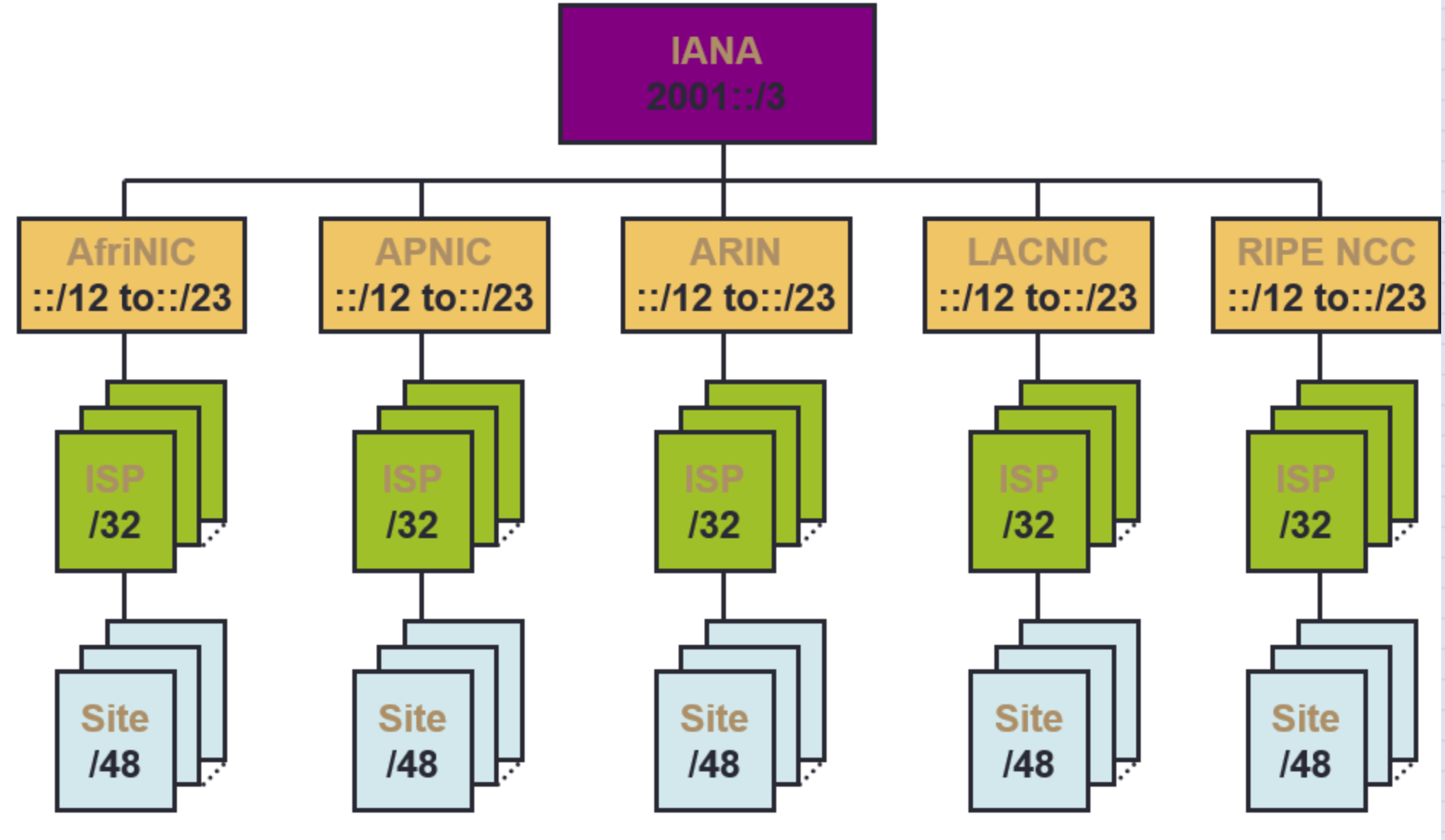


IPv6 Address Hierarchy

- Large address space
- Allows for multiple levels



IPv6 Prefix Allocation Hierarchy and Policy Example



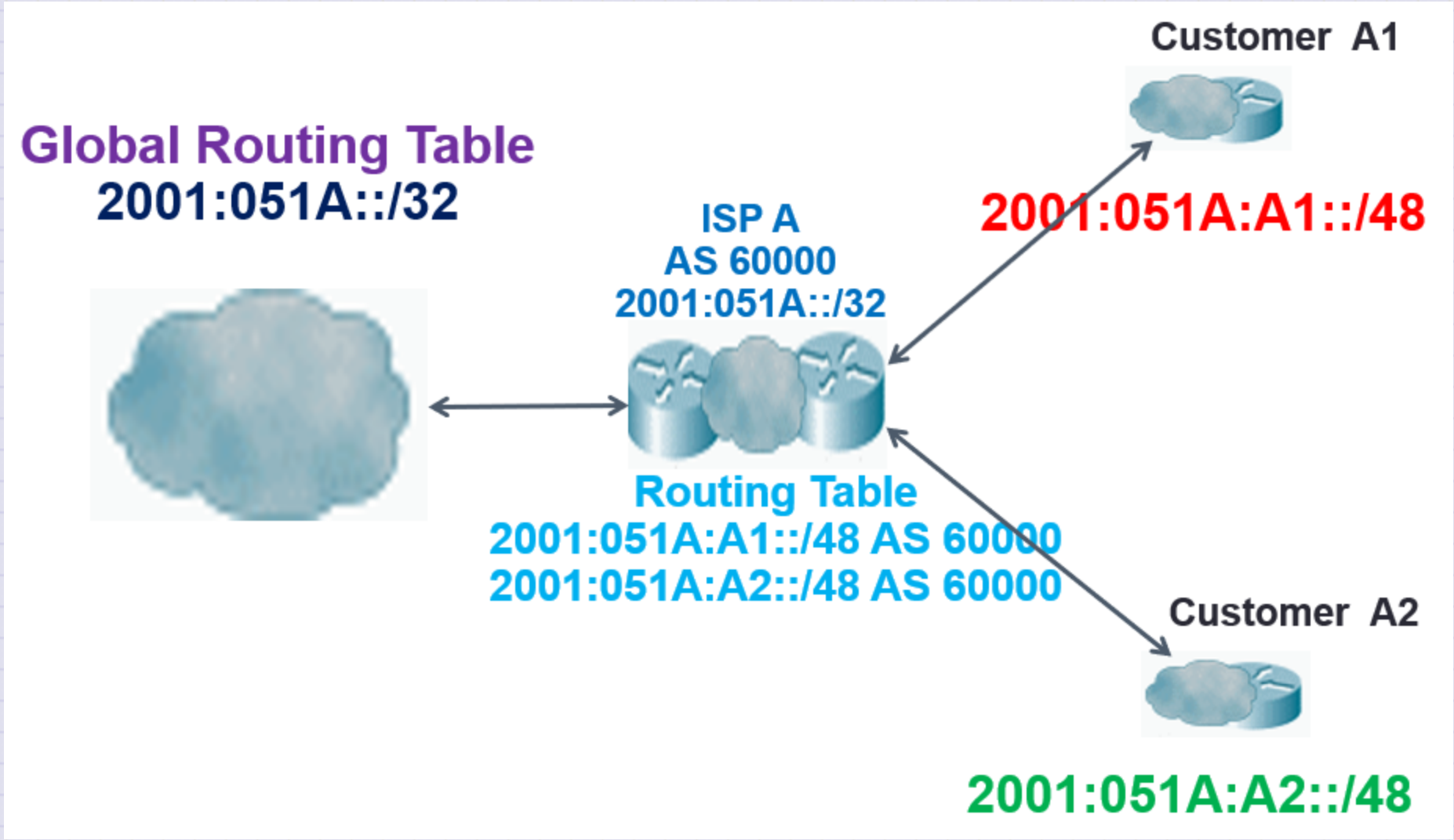
IP Address Space Allocated to American Registry For Internet Numbers

- IPv6 Allocation Blocks
  - 2001:0400::/23
  - 2001:1800::/23
  - 2001:4800::/23
  - 2600:0000::/12
  - 2610:0000::/23
  - 2620:0000::/23
- Information on all IP address blocks that IANA has assigned is available at: www.iana.org.

IPv6 Address Aggregation

- Large prefix for an organization
  - Can handle entire network
- ISPs summarize routes
  - All customer prefixes into one prefix
  - Make it available to the Internet
- Aggregation provides:
  - Efficient routing
  - Scalable routing
  - Fewer routes in global IPV6 routing table

Aggregation Example



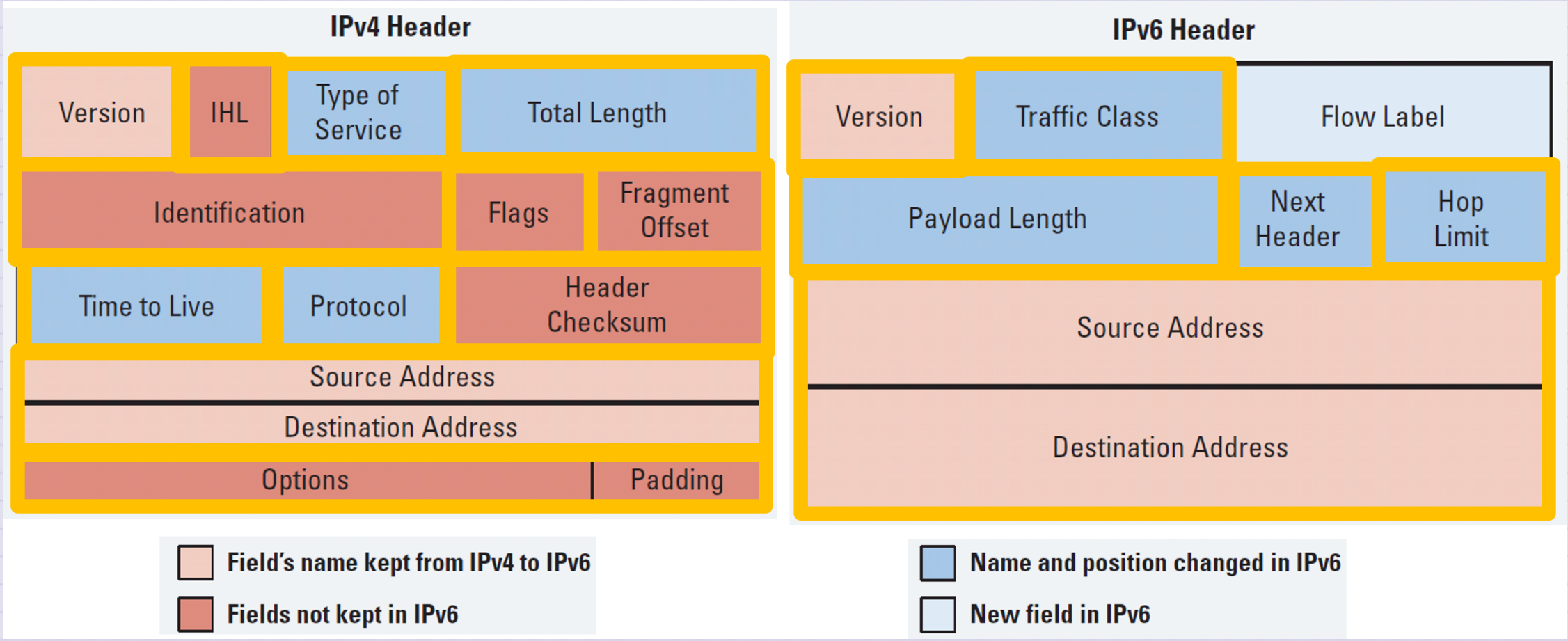
Good Practice in IPv6 Addressing

- Hosts should have globally routable addresses created with stateless autoconfiguration
  - Use 2001 prefix
  - Use /64 eui-64 to create them
- Serial links between routers should not use globally routable addresses
  - Use FC00 / FD00 prefix and static addressing
  - Use a prefix length /64
  - However, the prefix length could also be, for example, /112

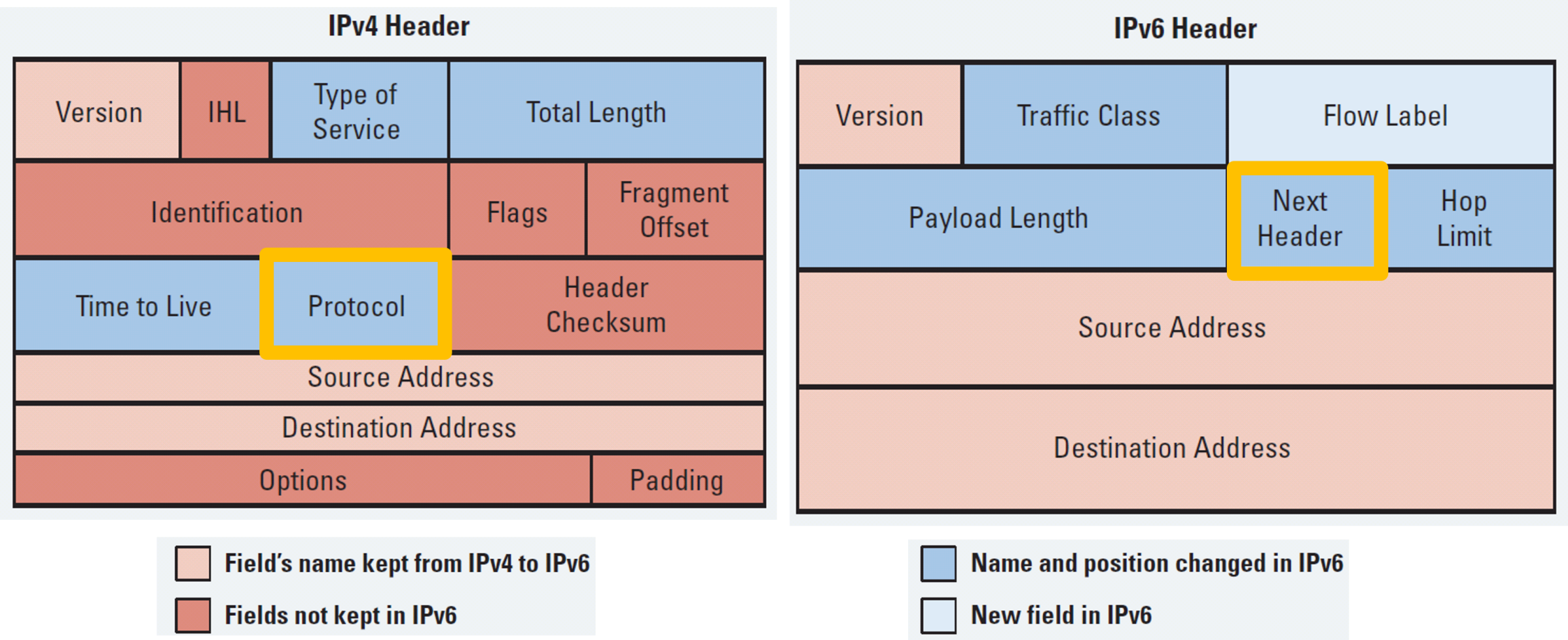
IPv6 Header Changes

- Improved routing efficiency
- No requirement for processing checksums
- Simpler and more efficient extension header mechanisms
- Flow labels for per-flow processing

IPv4 Header vs. IPv6 Header

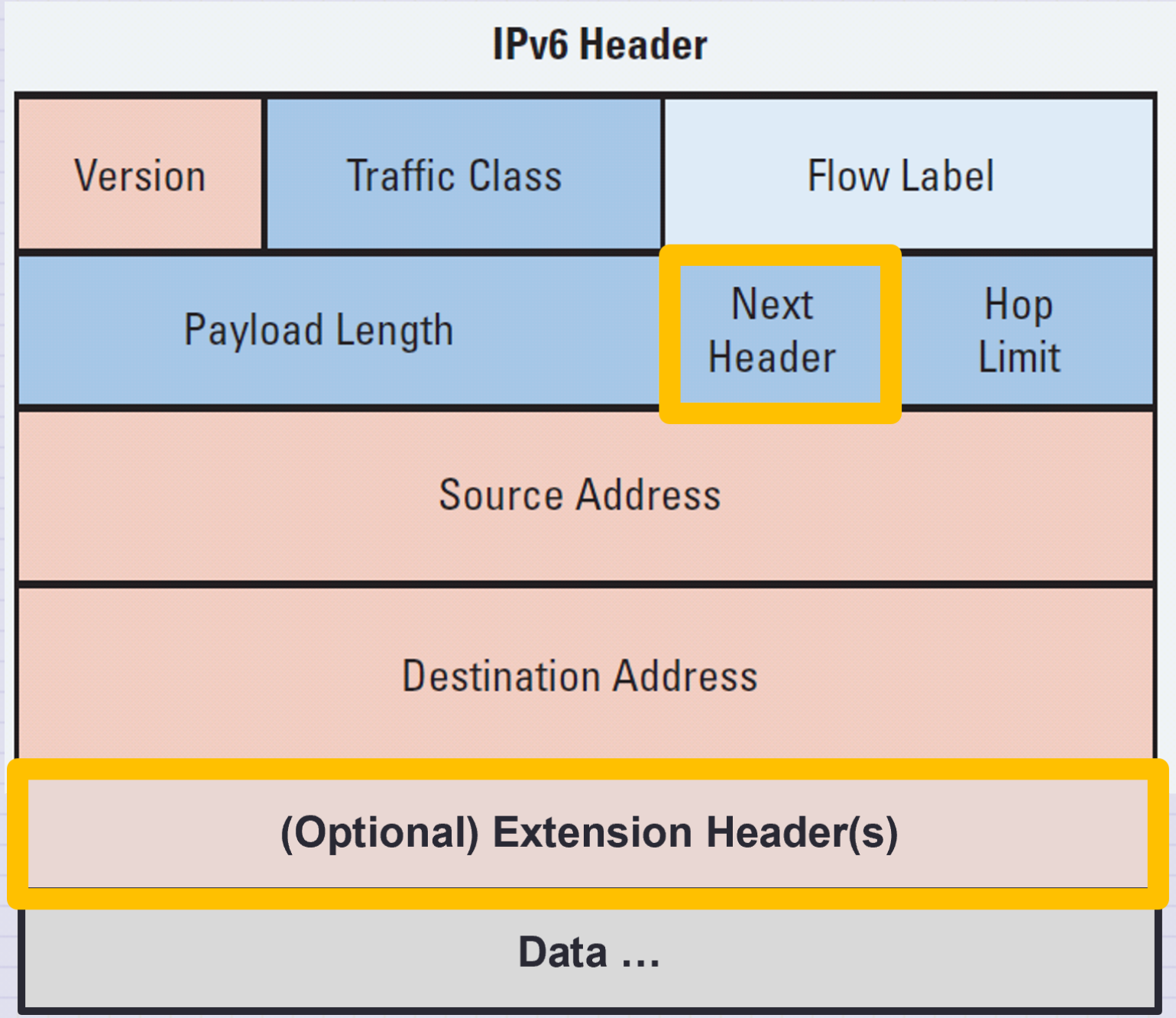


Protocol and Next Header Fields



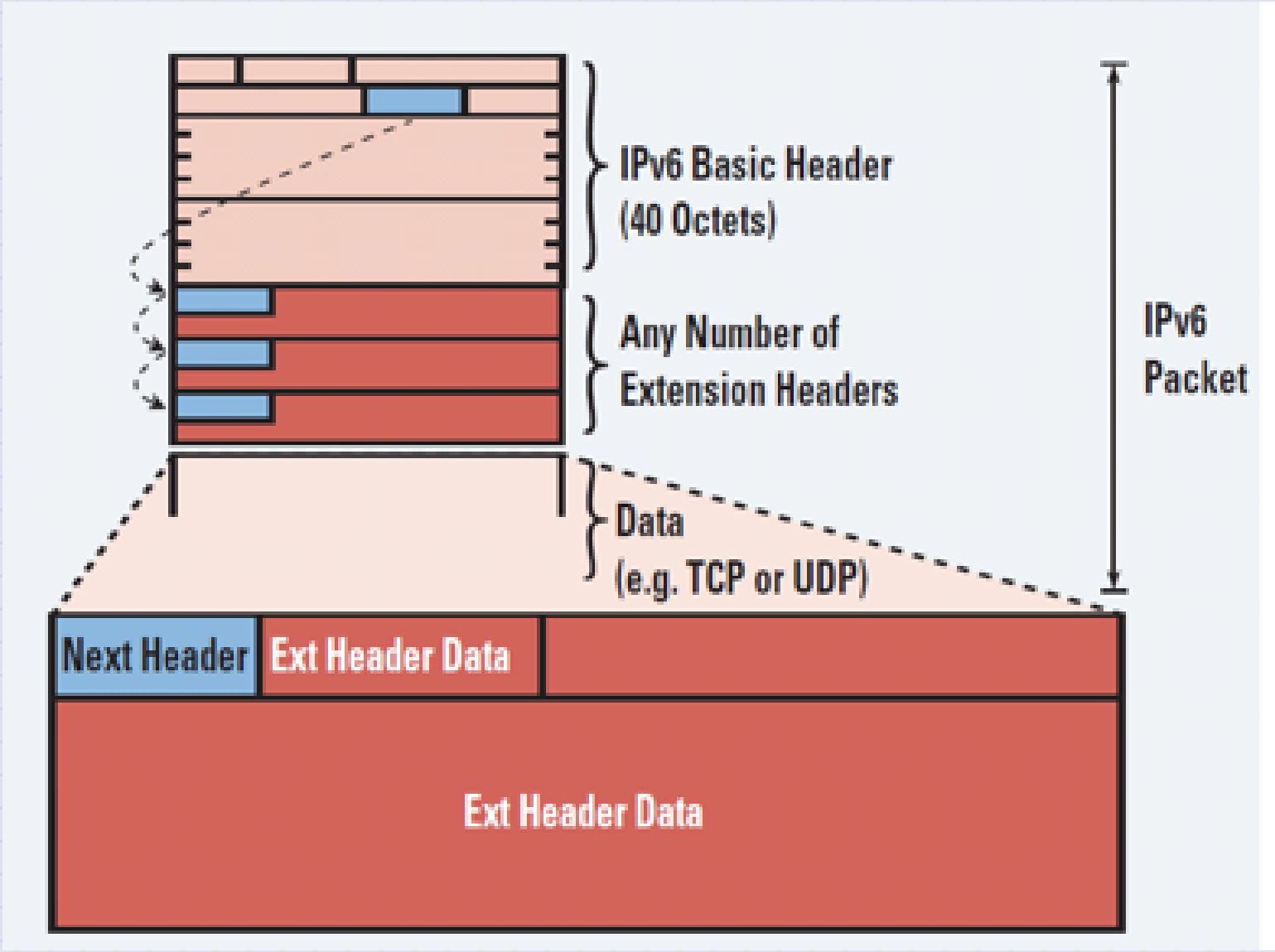
Extension Headers

- The Next Header field identifies what follows the Destination Address field:

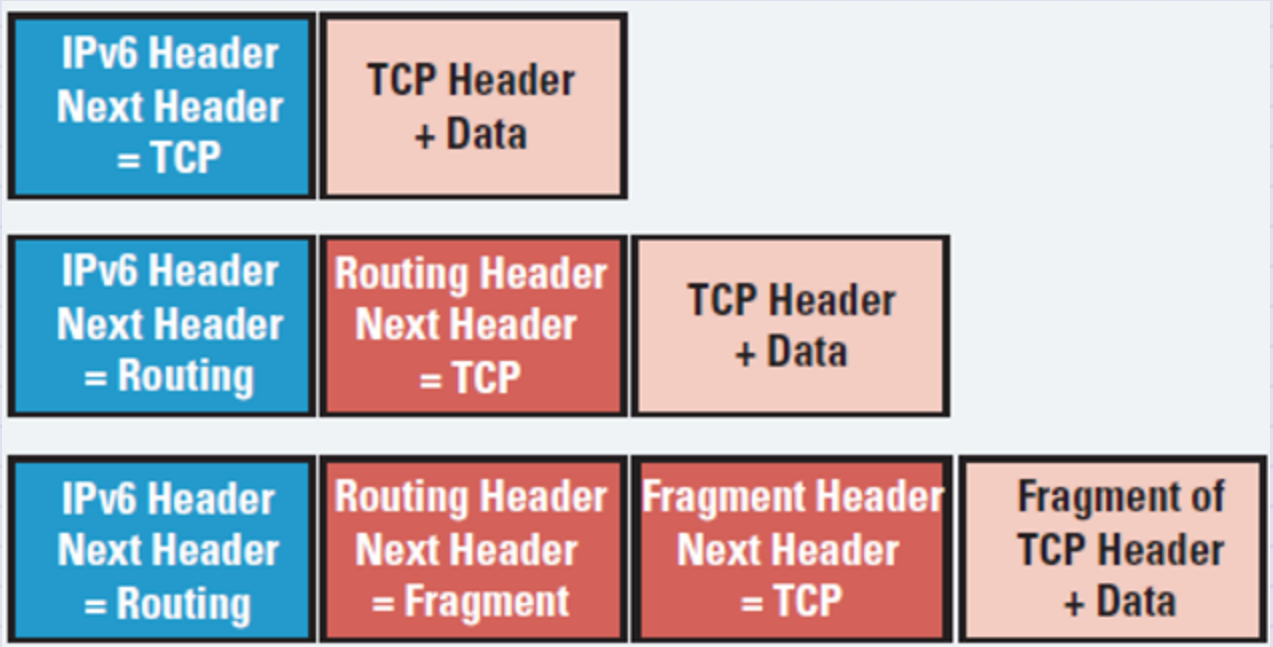


Extension Headers

- The destination node examines the first extension header (if any).



Extension Header Options

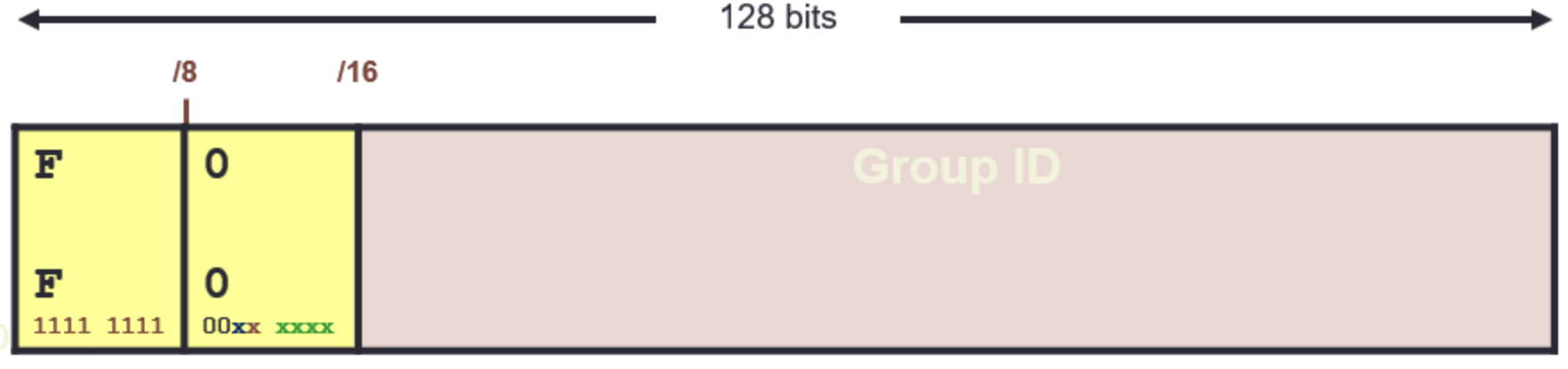


Extension Header Chain Order

Process Order	Extension Header	Next-header value (protocol #)
1	Hop-by-hop options header	0
2	Destination options header	60
3	Routing header	43
4	Fragment header	44
5	Authentication header (AH) and ESP header	ESP = 50 AH = 51
6	Upper-layer header: TCP UDP	TCP = 6 UDP = 17

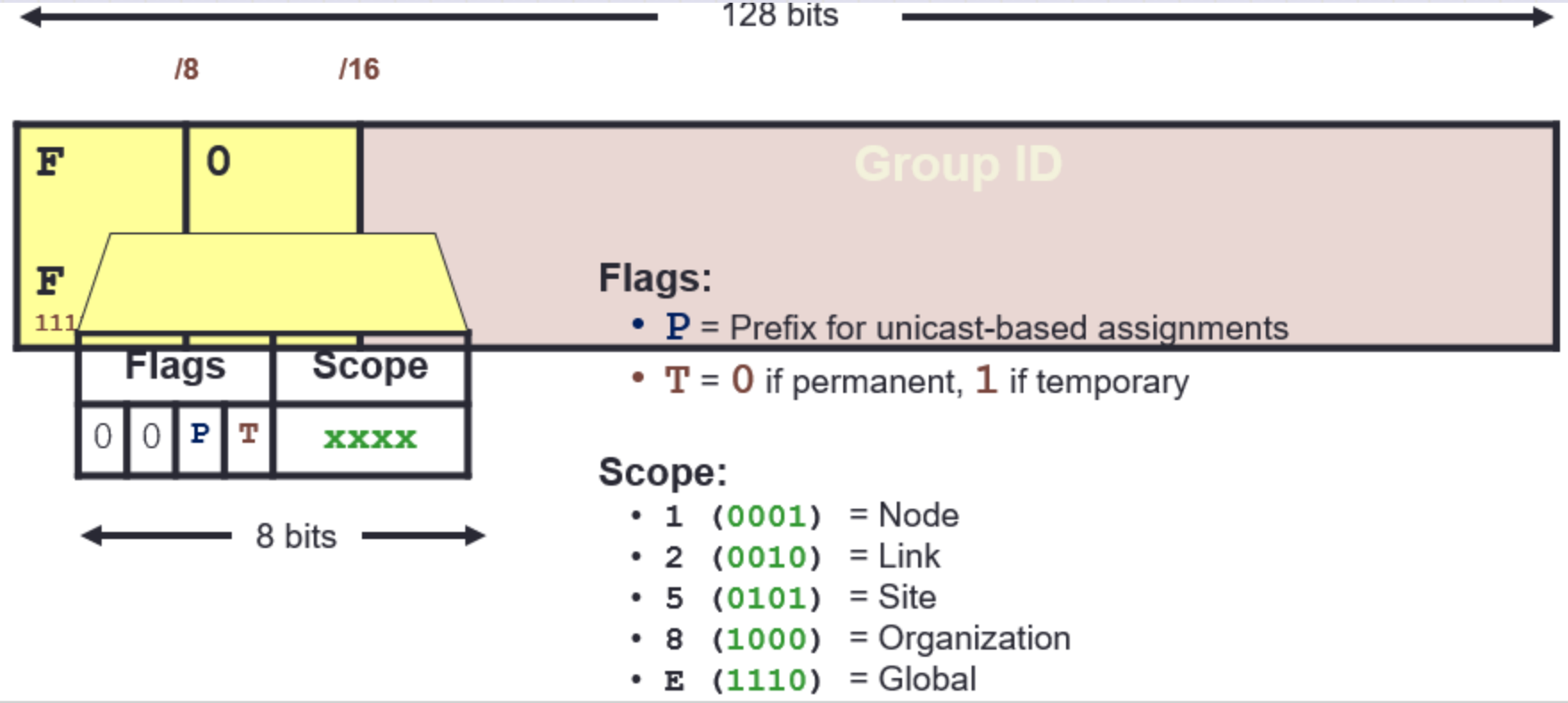
IPv6 Multicast Addresses

- Multicasting is at the core of many IPv6 functions and is a replacement for the broadcast address.
- They are defined by the prefix **FF00::/8**.



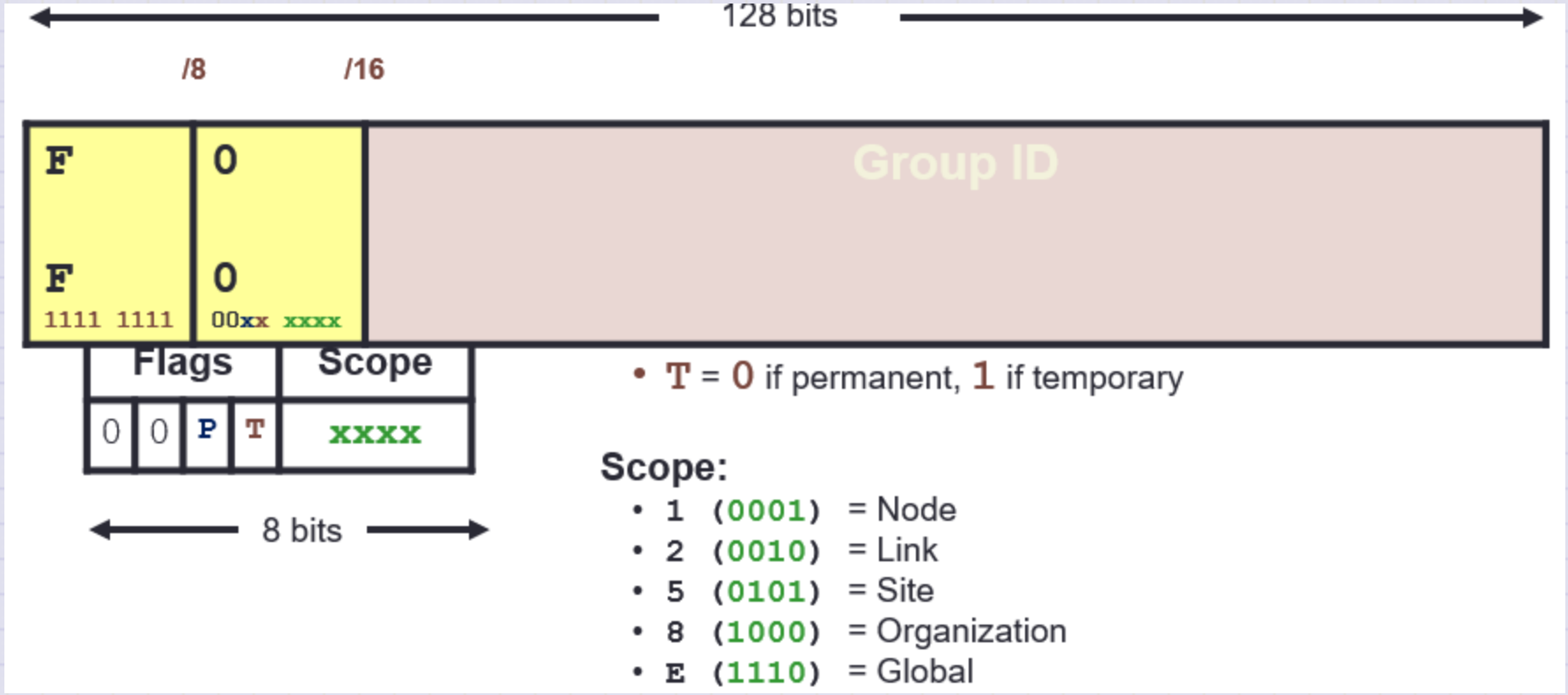
IPv6 Multicast Address

- The second octet of the address contains the prefix and transient (lifetime) flags, and the scope of the multicast address.



IPv6 Multicast Address

- The multicast addresses **FF00::** to **FF0F::** are permanent and reserved.

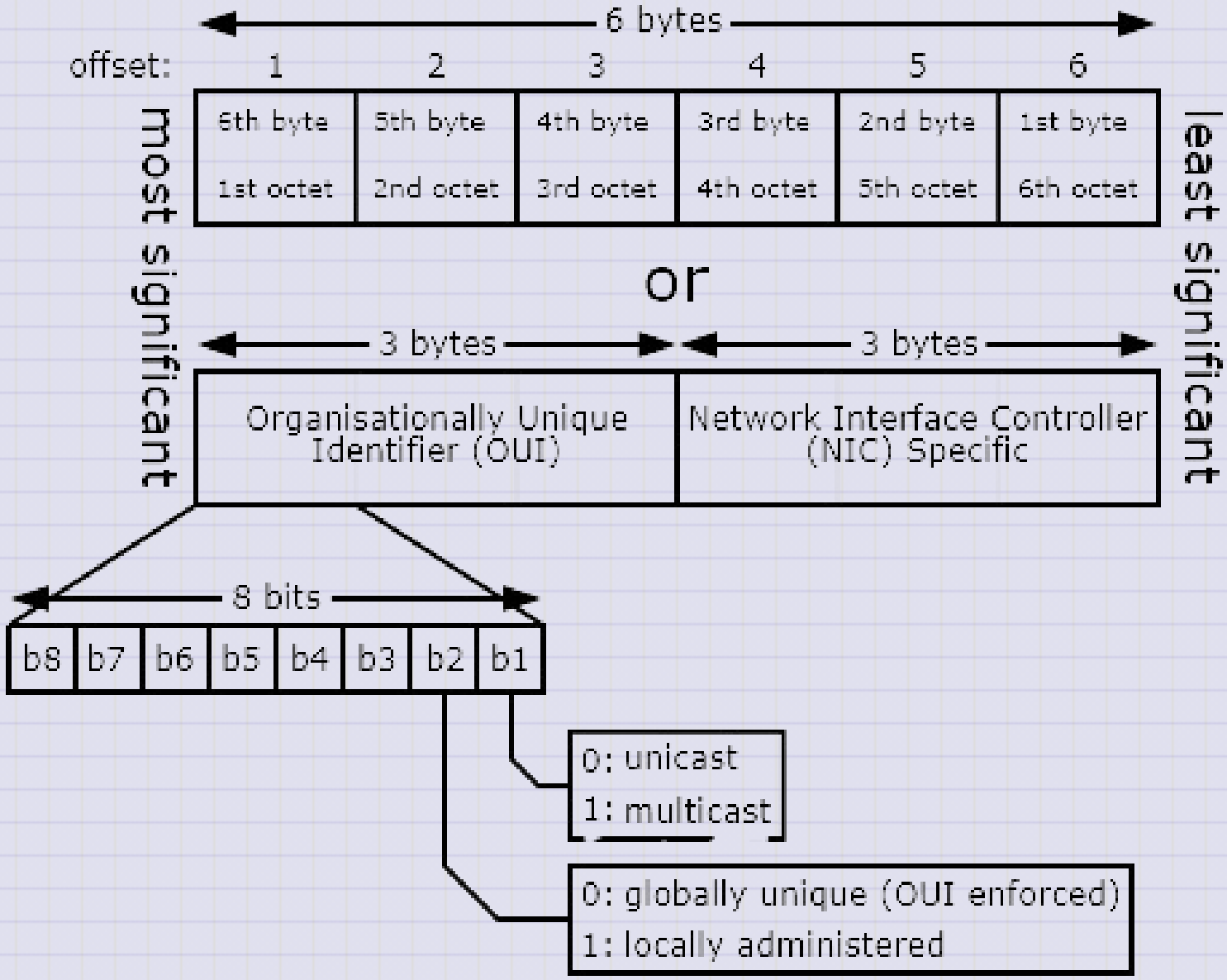


Reserved IPv6 Multicast Addresses

Reserved Multicast Address	Description
`FF02::1`	• All nodes on a link (link-local scope).
`FF02::2`	• All routers on a link.
`FF02::9`	• All routing information protocol (RIP) routers on a link.
`FF02::1:FFxx:xxxx`	• All solicited-node multicast addresses used for host autoconfiguration and neighbor discovery (similar to ARP in IPv4). • The xx:xxxx is the far right 24 bits of the corresponding unicast or anycast address of the node.
`FF05::101`	• All Network Time Protocol (NTP) servers.

Ethernet Multicast: MAC Revisited

- In the simplest of terms a host (router / pc) will listen for multiple addresses.
- These include specific multicast addresses that the hosts wishes to receive messages on.



IPv6 Neighbor Discovery

- Resolve the link-layer address of a neighboring node to which an IPv6 packet is being forwarded.
- Determine when the link-layer address of a neighboring node has changed.
- Determine whether a neighbor is still reachable.
- Discover neighboring routers.
- Auto configure addresses, address prefixes, routes, and other configuration parameters.
- Advertise router presence, host configuration parameters, routes, and on-link prefixes.
- Inform hosts of a better next-hop router address to forward packets for a specific destination.

Neighbor Discovery ICMPv6 Packet Types

- Neighbor Discovery uses five ICMPv6 packet types

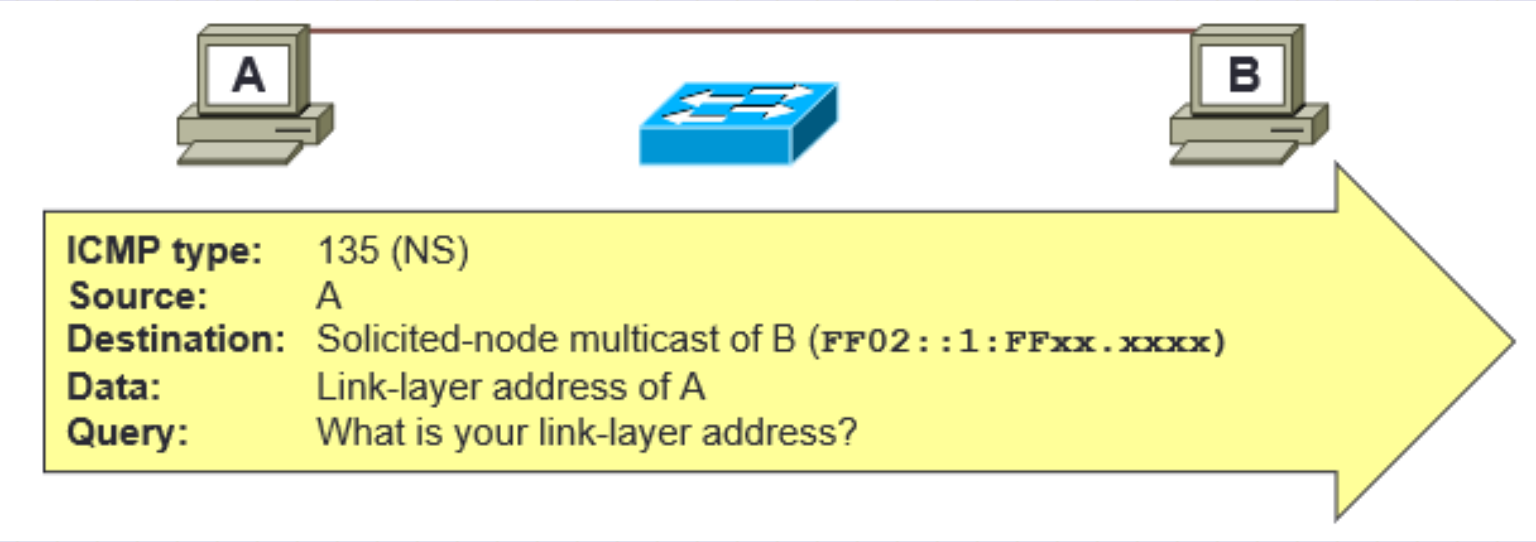
ICMPv6 Message	Type	Description
Neighbor Solicitation (NS)	135	• Sent by a host to determine the link-layer address of a neighbor. • Used to verify that a neighbor is still reachable. • An NS is also used for Duplicate Address Detection (DAD).
Neighbor Advertisement (NA)	136	• A response to a NS message. • A node may also send unsolicited NA to announce a link-layer address change.
Router Advertisement (RA)	134	• RAs contain prefixes that are used for on-link determination or address configuration, a suggested hop limit value and MTU value. • RAs are sent either periodically, or in response to a RS message.
Router Solicitation (RS)	133	• When a host is booting it sends out an RS requesting routers to immediately generate an RA rather than wait for their next scheduled time.
Redirect	137	

Solicited-Node Multicast Addresses

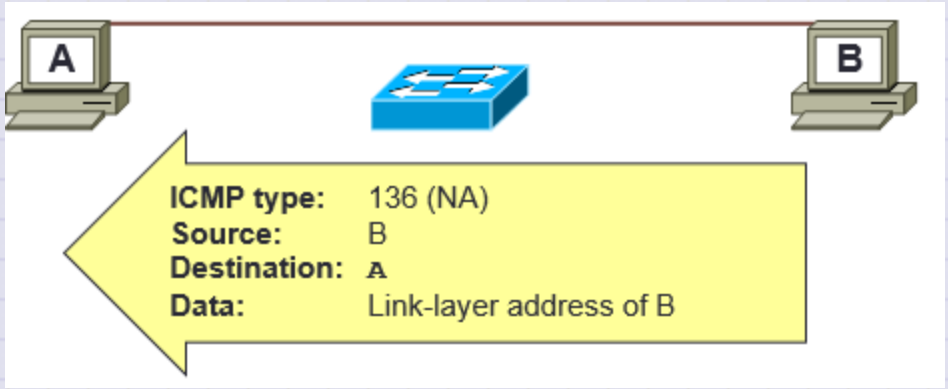
- The solicited-node multicast address (FF02::1:FF) is used for:
  - Neighbor discovery (ND) process
  - Stateless address autoconfiguration
- The Neighbor discovery (ND) process is used to:
  - Determine the local-link address of the neighbor
  - Determine the routers on the link and default route
  - Keep track of neighbor reachability
  - Send network information from routers to hosts

Neighbor Solicitation Example

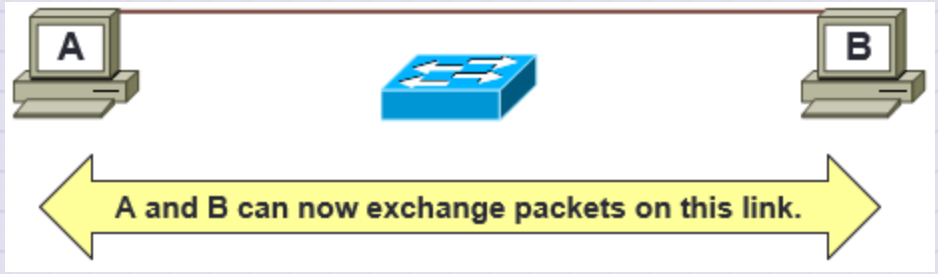
- ICMPv6 Neighbor Solicitation (NS) is similar to IPv4 ARP.
- For Host A to send a packet to Host B it needs the MAC address of Host B.



Neighbor Advertisement Example



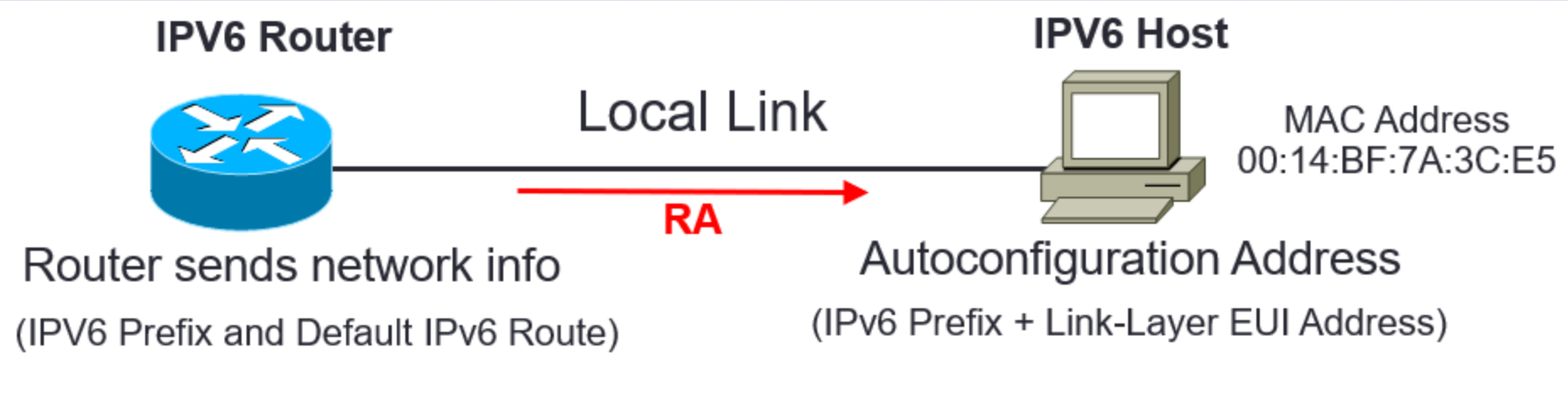
Each destination node that receives the NS responds with an ICMPv6 message type 136, NA, including Host B.



Stateless Address Autoconfiguration (SLAAC)

- Every IPv6 system (other than routers) is able to build its own unicast global address.
  - Enables new devices to easily connect to the Internet.
  - No configuration or DHCP servers is required.
- IPv6 Router - sends network-type info on local link.
  - IPv6 prefix
  - Default IPv6 route
- IPv6 Hosts - listen on local link and configure themselves.
  - IP Address (Extended Unique Identifier 64 bit)
  - Default route

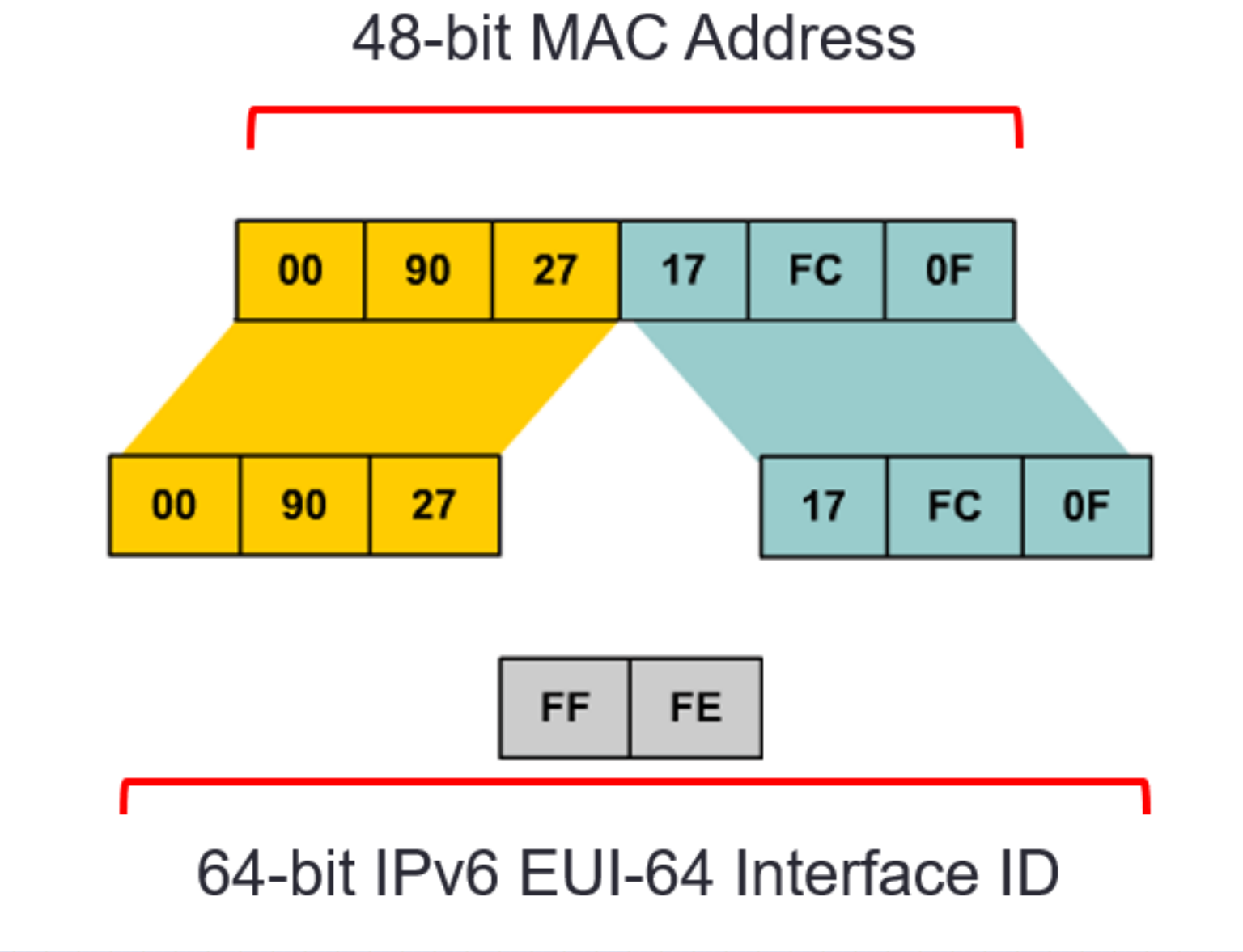
Stateless Address Autoconfiguration



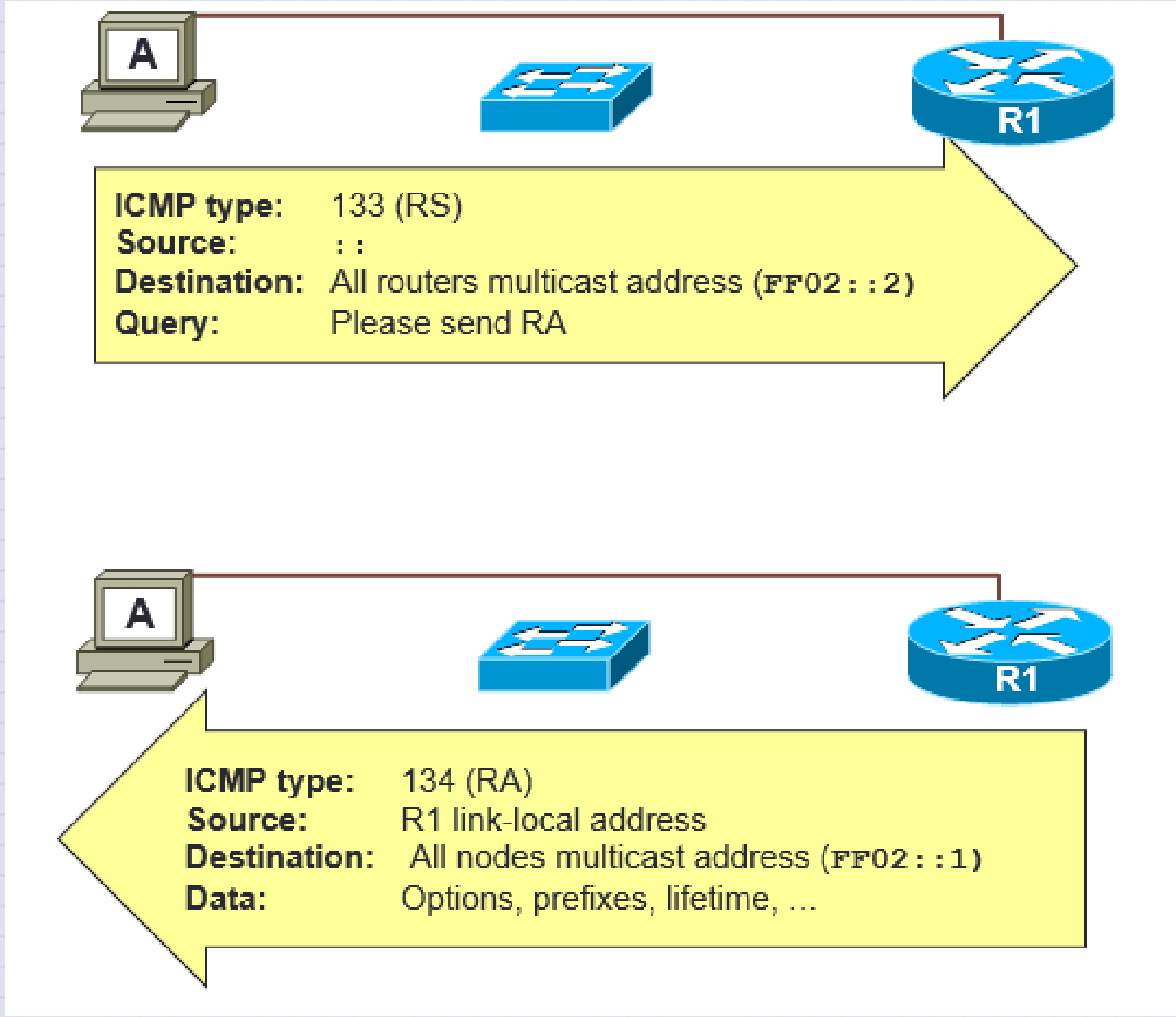
Ethernet EUI-64 IPv6 Addresses (RFC 4862)

- The first 64 bits are the network portion of the address and are specified or learned via SLAAC.
- The interface ID (second 64-bits) is the host portion of the address and is automatically generated by the router or host device.
- The interface ID on an Ethernet link is based on the 48-bit MAC address of the interface with an additional 16-bit **0xFFFE** inserted in the middle of the MAC address.
- The seventh bit of the First Byte is then inverted.
  - (This bit is called the universal/local bit, with a value of 0 meaning that the MAC is a universal burned-in address)
- The above can lead to privacy concerns, which RFC 4941 attempts to address (see also IPv6 on Windows).

EUI-64 IPv6 Interface Identifier

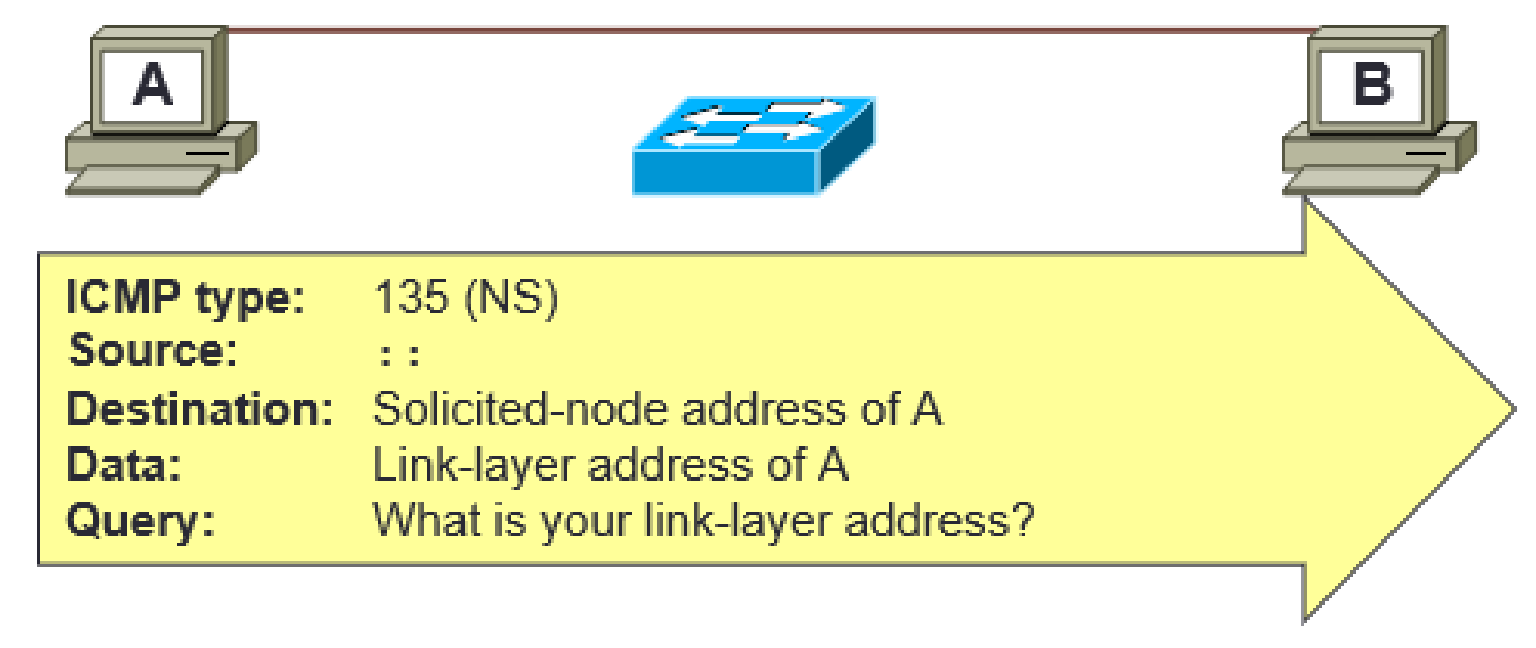


Stateless Autoconfiguration Process



Stateless Autoconfiguration Process

- Host A creates a link-local address and solicited-node address using the RA supplied by the router.
- Host A verifies that it's new IPv6 address is unique using DAD process.



Learn more

- IANA number resources
- North American IPv6 Rules

Reading List

- Introduction to DHCP (video)
- What is a Routing Protocol
- BIRD Internet Routing Daemon - Configuration