IPv6

Dr Kunwar Pal

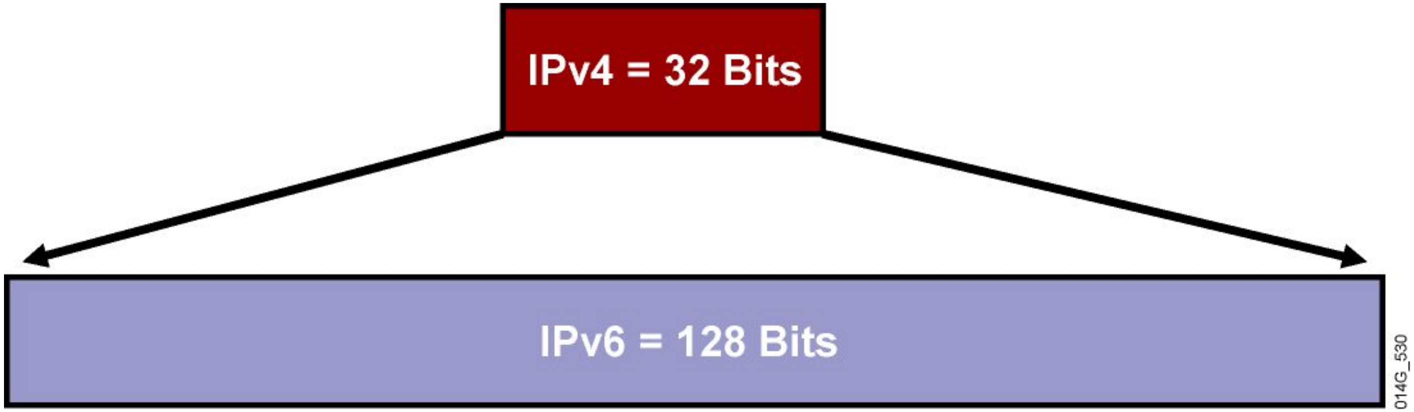
Computer Science & Engineering
National Institute of Technology Jalandhar, Punjab, INDIA

(Email : kunwarp@nitj.ac.in)

Why IPv6?

- Shortage of IPv4 addresses
  - Internet is expanding very rapidly in developing countries like India, China
  - New devices like phones need IP address
- End-to-End Reachability is not possible without IPv6
- New Features like Auto configuration, better support for QoS, Mobility and Security, Route Aggregation

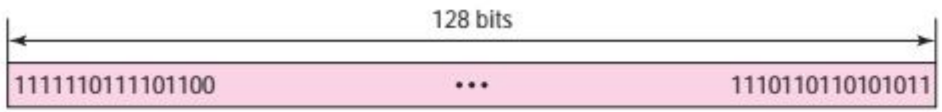
IPv6 Address



- IPv4: 32 bits or 4 bytes long
  - $4.2 * 10^9$ possible addressable nodes
  - 4,200,000,000
- IPv6: 128 bits or 16 bytes
  - $3.4 * 10^{38}$ possible addressable nodes
  - 340,282,366,920,938,463,374,607,432,768,211,456
  - $5 * 10^{28}$ addresses per person

- An IPv6 address is 128 bits or 16 bytes (octet) long as shown in Figure 26.1.
- The address length in IPv6 is four times of the length address in IPv4

Figure 26.1 *IPv6 address*



Notations

- ***Dotted-Decimal Notation***
  - 221.14.65.11.105.45.170.34.12.234.18.0.14.0.115.255
- ***Colon Hexadecimal Notation***

  FDEC:BA98:7654:3210:ADBF:BBFF:2922:FFFF

- **zero compression**

Figure 26.3 *Zero compression*

❑ *Mixed Representation*

FDEC:14AB:2311:BBFE:AAAA:BBBB:130.24.24.18

Figure 26.4 *CIDR address*

FDEC::BBFF:0:FFFF/60

IP Compression

- **Explain the compressed format for writing IPv6 addresses and write the following IPv6 addresses in their shortest compressed form:**

2001:0DB8:0000:1470:0000:0000:0000:0200

F380:0000:0000:0000:0123:4567:89AB:CDEF

A double colon (::) can replace any single, contiguous string of one or more 16-bit segments (hextets) consisting of all 0s, and can only be used once per IPv6 address. Any leading 0s (zeros) in any 16-bit section or hextet can be omitted.

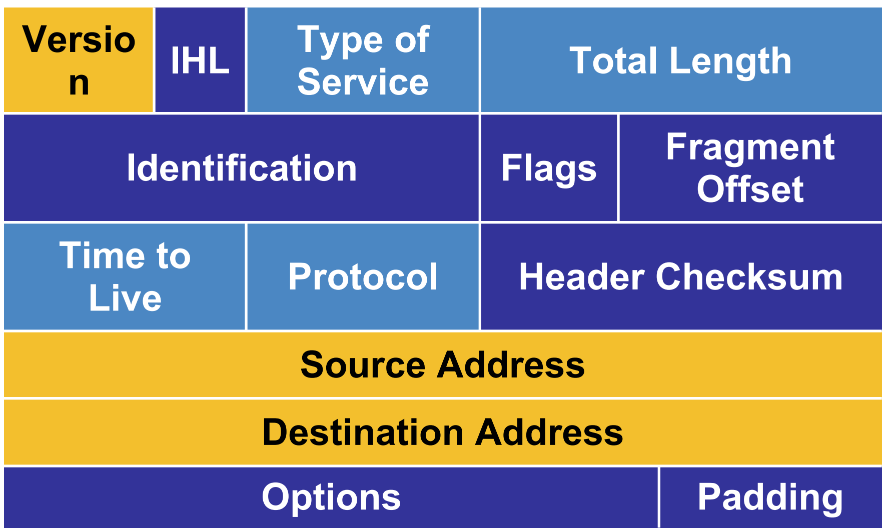
2001:DB8:0:1470::200

F380::123:4567:89AB:CDEF

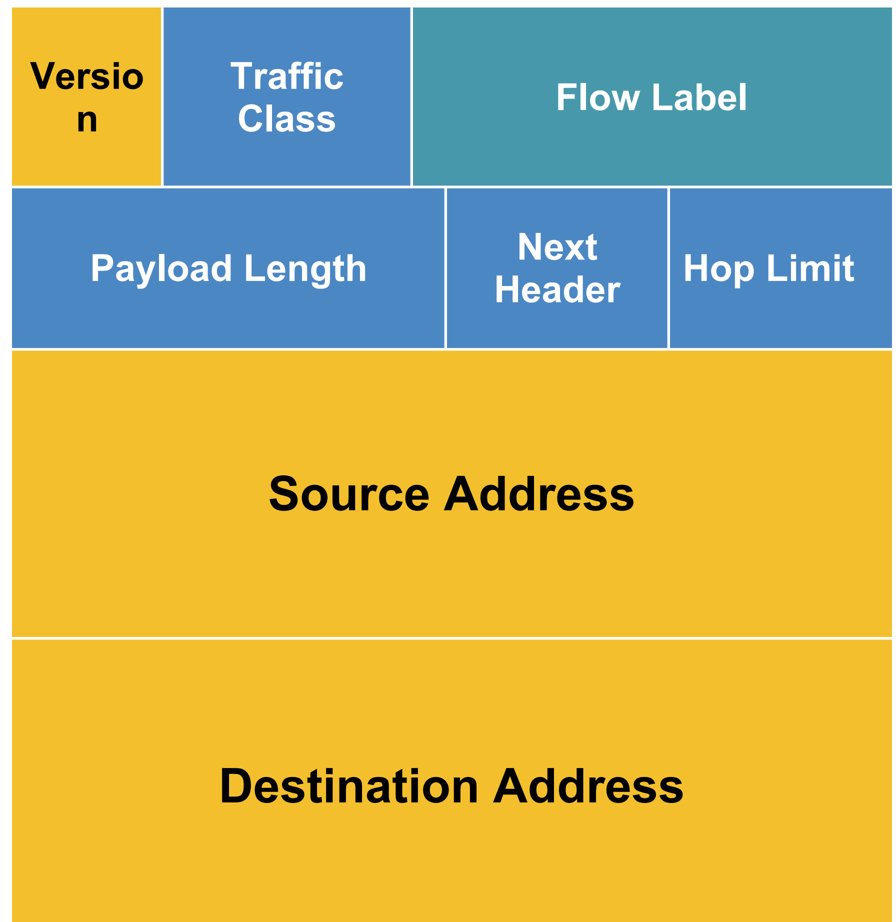
IPv6 Header Format

- IPv4: 20 Bytes + Options IPv6: 40 Bytes + Extension Header

IPv4 Header



IPv6 Header



IPv6

Fields of the IPv4 Header	Fields of the IPv6 Header	Comparison of IPv4 and IPv6 Headers
Version (4-bit)	Version (4-bit)	Same function but the IPv6 header contains a new value.
Header length (4-bit)	—	Removed in IPv6. The basic IPv6 header always has 40 octets.
Type of service (8-bit)	Traffic class (8-bit)	Same function for both headers.
—	Flow label (20-bit)	New field added to tag a flow for IPv6 packets.
Total length (16-bit)	Payload length (16-bit)	Same function for both headers.
Identification (16-bit)	—	Removed in IPv6 because fragmentation is handled differently in IPv6.
Flags (3-bit)	—	Removed in IPv6 because fragmentation is handled differently in IPv6.
Fragment offset (13-bit)	—	Removed in IPv6 because fragmentation is handled differently in IPv6.
Time to live (8-bit)	Hop limit (8-bit)	Same function for both headers.
Protocol number (8-bit)	Next header (8-bit)	Same function for both headers.
Header checksum (16-bit)	—	Removed in IPv6. Link-layer technologies and upper-layer protocols handle checksum and error control.
Source address (32-bit)	Source address (128-bit)	Source address is expanded in IPv6.
Destination address (32-bit)	Destination address (128-bit)	Destination address is expanded in IPv6.
Options (variable)	—	Removed in IPv6. The way to handle this option is different in IPv4.
Padding (variable)	—	Removed in IPv6. The way to handle this option is different in IPv4.
—	Extension headers	New way in IPv6 to handle Options fields, fragmentation, security, mobility, Loose Source Routing, Record Route, and so on. The following section presents IPv6's extension headers.

IPv6 Address Types

- Unicast
  - Address is for a single interface.
  - IPv6 has several types (for example, global and IPv4 mapped).
- Multicast
  - One-to-many
  - Enables more efficient use of the network
  - Uses a larger address range
- Anycast
  - One-to-nearest (allocated from unicast address space).
  - Multiple devices share the same address.
  - All anycast nodes should provide uniform service.
  - Source devices send packets to anycast address.
  - Routers decide on closest device to reach that destination.
  - Suitable for load balancing and content delivery services.

IPv6 Unicast Address Scope

- Link-local: The scope is the local link (nodes on the same subnet)
  - Default IPv6 address on every IPv6 enabled interface
- Unique-local: The scope is the organization (private site addressing)
  - Private IP
- Global: The scope is global (IPv6 Internet addresses)
  - Public IP

IPv6 Address Representation

- ***x*:*x*:*x*:*x*:*x*:*x*:*x*:*x*, where *x* is a 16-bit hexadecimal field**
- **Leading zeros in a field are optional:**
  - **2031:0:130F:0:0:9C0:876A:130B**
- **Successive fields of 0 can be represented as ::, but only once per address.**

Examples:

2031:0000:130F:0000:0000:09C0:876A:130B

2031:0:130f::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 Representation: Link Local

- Hosts on the same link (the same subnet) use these automatically configured addresses to communicate with each other.

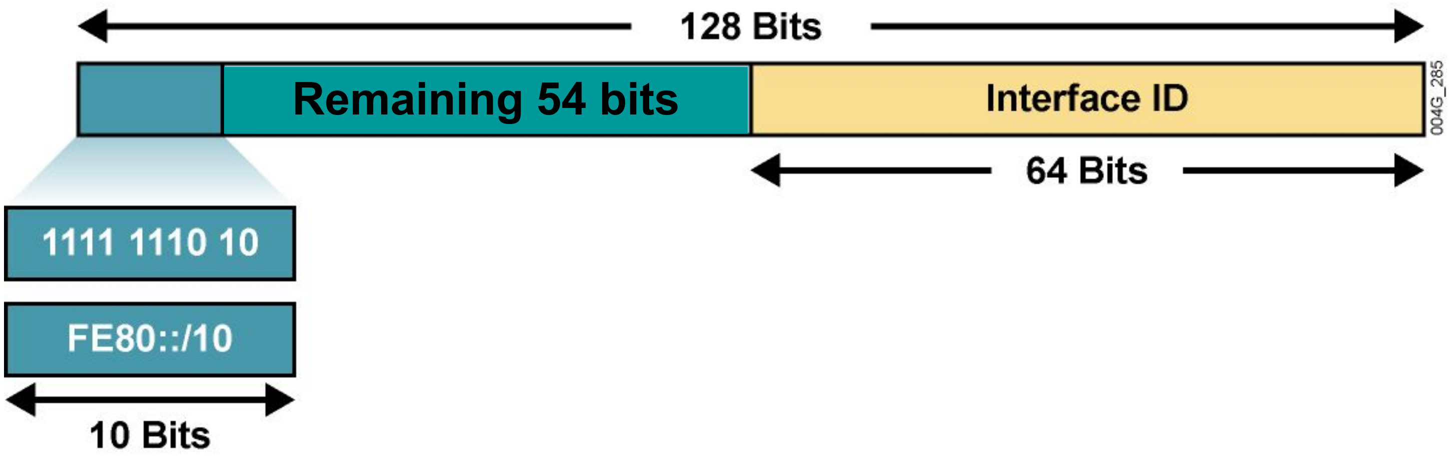
- Neighbor Discovery provides address resolution.

- The prefix for link-local addresses is FE80::/10.

- The following illustration shows the structure of a link-local address.

1111 1110 10 (10 bits)	000 . . . 000 (54 bits)	Interface ID (64 bits)

IPv6 Address Representation: Link Local



- Mandatory address for communication between two IPv6 devices
- Automatically assigned by router as soon as IPv6 is enabled

IPv6 Address Representation: Unique Local

- IPv6 unicast unique-local addresses are similar to IPv4 private addresses.

- The scope of a unique-local address is the internetwork of an organization's site. (You can use both global addresses and unique-local addresses in your network)

- The prefix for unique-local addresses is **FC00::/7**.

IPv6 Address Representation: Global Unicast

Figure 26.14 *Global unicast address*

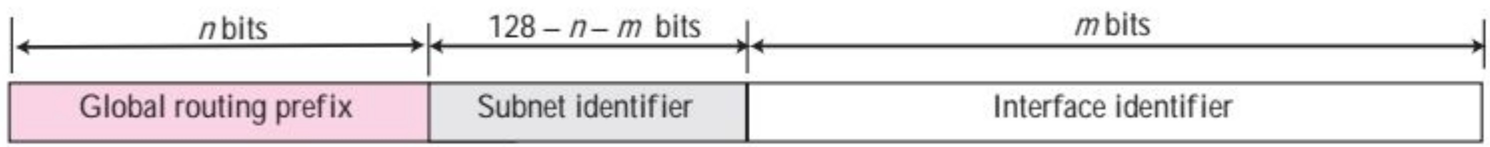


Table 26.2 *Recommended Length of Different Parts in Unicast Addressing*

Block Assignment	*Length*
Global routing prefix (n)	48 bits
Subnet identifier ($128 - n - m$)	16 bits
Interface identifier (m)	64 bits

Global Routing Prefix

- The first 48 bits of a global unicast address are called global routing prefix.
- These 48 bits are used to route the packet through the Internet to the organization site such as ISP that owns the block.
- Since the first three bits in this part is fixed (001), the rest of the 45 bits can defined up to 245 sites (a private organization or an ISP).
- The global routers in the Internet route a packet to its destination site based on the value of *n*.

Subnet Identifier

- The next 16 bits defines a subnet in an organization.
- This means that an organization can have up to 2^16 subnets, which is more than enough.

Interface Identifier

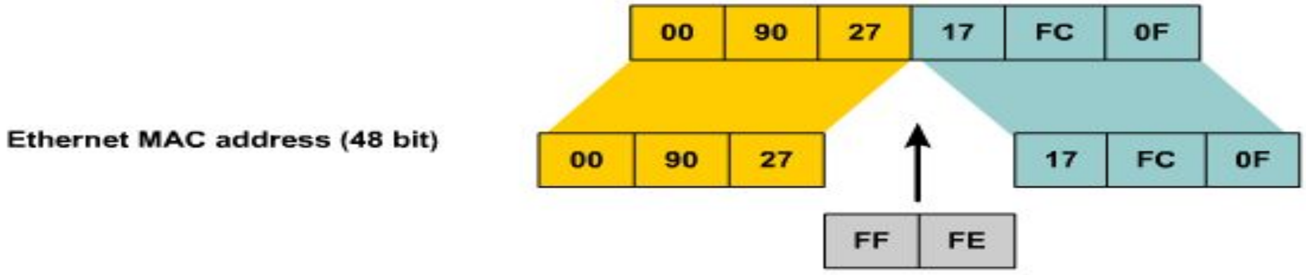
- The last 64 bits define the interface identifier.
- The interface identifier is similar to hosted in IPv4 addressing.
- If the host is moved from one interface to another, its IP address needs to be changed.

Mapping Ethernet MAC Address

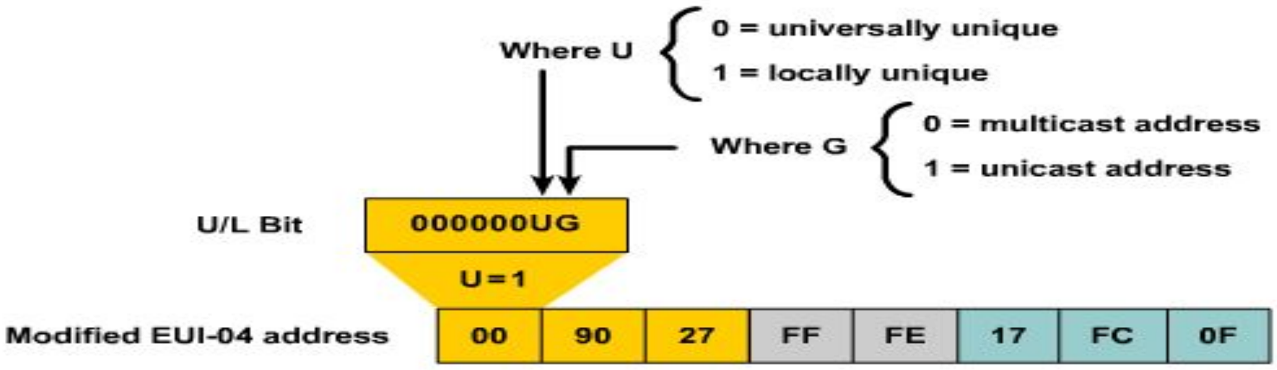
- In IPv4 addressing, there is not a specific relation between the hostid (at the IP level) and physical or MAC address (at the data link layer) because the physical address is normally much longer than the hostid.
- For example, using the Ethernet technology, the physical address is 48 bits while the hostid is less than 32 bits.
- The IPv6 addressing allows this opportunity.
- A physical address whose length is less than 64 bits can be imbedded as the whole or part of the interface identifier, eliminating the mapping process.
- Two common physical addressing scheme can be considered for this purpose: the 64-bit extended unique identifier (EUI-64) defined by IEEE and the 48-bit physical address defined by Ethernet

IPv6 Address Representation EUI 64

- IPv6 uses the extended universal identifier (EUI)-64 format to do autoconfiguration.
- 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 universal/local (U/L bit) is set to 1 for global scope (0 for local scope).



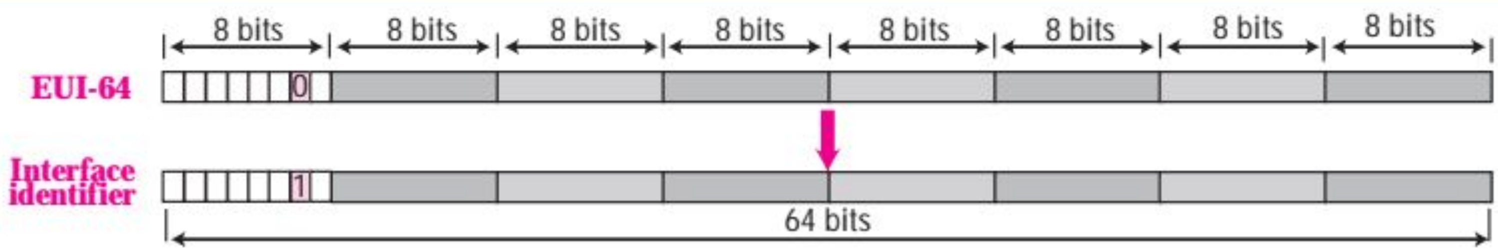
IPv6 Address Representation EUI 64



Mapping EUI-64

- To map a 64-bit physical address, the global/local bit of this format needs to be changed from 0 to 1 (local to global) to define an interface address, as shown in Figure 26.15

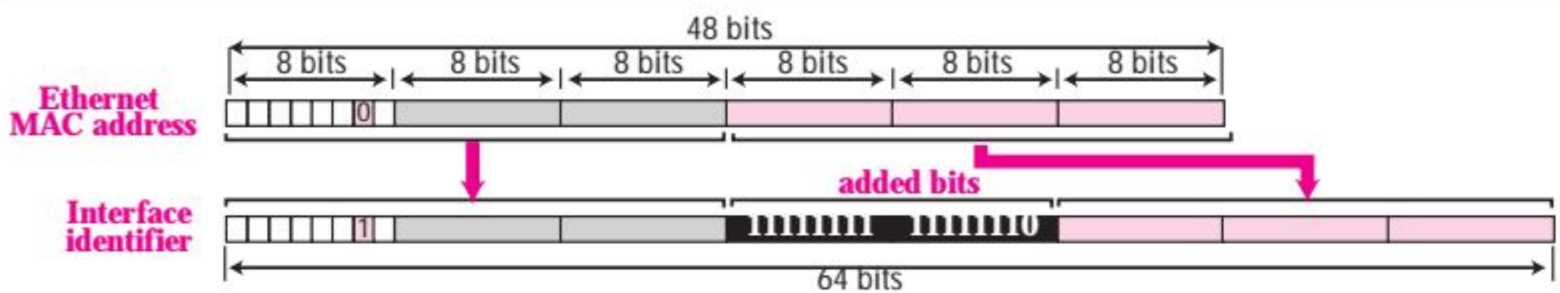
Figure 26.15 *Mapping for EUI-64*



Mapping Ethernet MAC Address

- Mapping a 48-bit Ethernet address into a 64-bit interface identifier is more involved.
- We need to change the local/global bit to 1 and insert an additional 16 bits.
- The additional 16 bits are defined as 15 ones followed by one zero, or FFFE16. Figure 26.16 shows the mapping.

Figure 26.16 *Mapping for Ethernet MAC*



Example

- Find the interface identifier if the physical address in the EUI is (**F5-A9-23-EF-07-14-7A-D2**)16 using the format we defined for Ethernet addresses.

Solution

- We only need to change the seventh bit of the first octet from 0 to 1 and change the format to colon hex notation. The result is **F7A9:23EF:0714:7AD2**.

Example 2

- Find the interface identifier if the Ethernet physical address is (**F5-A9-23-14-7A-D2**)16 using the format we defined for Ethernet addresses.

Solution

- We only need to change the seventh bit of the first octet from 0 to 1, insert two octet FFFE16 and change the format to colon hex notation. The result is **F7A9:23FF:FE14:7AD2** in colon hex.

Example 3

- An organization is assigned the block 2000:1456:2474/48. What is the IPv6 address of an interface in the third subnet if the IEEE physical address of the computer is (**F5-A9-23-14-7A-D2**)16

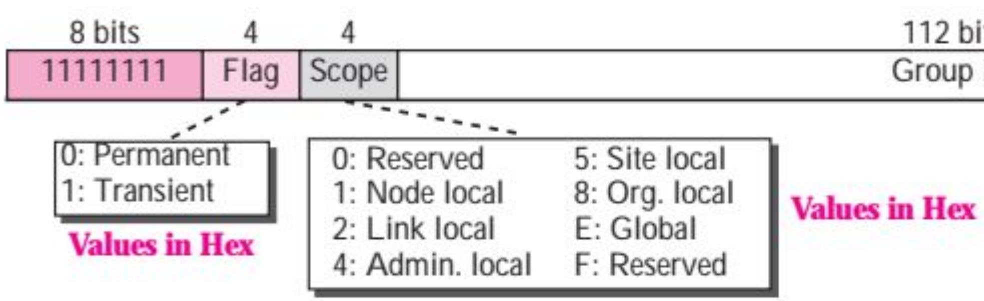
Solution

- The interface identifier for this interface is **F7A9:23FF:FE14:7AD2** (see Example 26.12). If we this identifier to the global prefix and the subnet identifier, we get:
- **2000:1456:2474:0003:F7A9:23FF:FE14:7AD2/128**

IPv6 Address

- **IPv6 Multicast Addressing:**
  - An **IPv6 multicast address** is an **IPv6 address** that has a prefix of FF00::/8 (1111 1111).

Figure 26.13 *Multicast address*



- The second field is a flag that defines the group address as either permanent or transient.
- A permanent group address is defined by the Internet authorities and can be accessed at all times.
- A transient group address, on the other hand, is used only temporarily. Systems engaged in a teleconference, for example, can use a transient group address.
- The third field defines the scope of the group address

AUTOCONFIGURATION

- One of the interesting features of IPv6 addressing is the **autoconfiguration** of hosts.
- In IPv4, the host and routers are originally configured manually by the network manager.
- However, the Dynamic Host Configuration Protocol, DHCP, can be used to allocate an IPv4 address to a host that joins the network.
- In IPv6, DHCP protocol can still be used to allocate an IPv6 address to a host, but a host can also configure itself.

- The host first creates a link local address for itself.
  - This is by taking the 10-bit link local prefix (1111 1110 10), adding 54 zeros, and adding the 64-bit interface identifier, which any host knows how to generate it from its interface card. The result is a 128-bit link local address.
- The host then tests to see if this link local address is unique and not used by other hosts.
  - Since the 64-bit interface identifier is supposed to be unique, the link local address generated is unique with a high probability. However, to be sure, the host sends a *neighbor solicitation message* and waits for *neighbor advertisement message.* If any host in the subnet is using this link local address, the process fails and the host cannot autoconfigure itself; it needs to use other means such as DHCP protocol for this purpose.

- If the uniqueness of the link local address is passed, the host stores this address as its link-local address (for private communication), but it still needs a global unicast address.
- The host then sends a *router solicitation message* to a local router.
- If there is a router running on the network, the host receives a *router advertisement message* that includes the global unicast prefix and the subnet prefix that the host needs to add to its interface identifier to generate its global unicast address.
- If the router cannot help the host with the configuration, it informs the host in the *router advertisement message*. The host then needs to use other means for configuration

Example

- Assume a host with Ethernet address (**F5-A9-23-11-9B-E2**)16 has joined the network. What would be its global unicast address if the global unicast prefix of the organization is 3A21:1216:2165 and the subnet identifier is A245:1232

Solution

- The host first creates its interface identifier as **F7A9:23FF:FE11:9BE2** using the Ethernet address read from its card. The host then creates its link-local address as **FE80::F7A9:23FF:FE11:9BE2**

- Assuming that this address is unique, the host sends a router solicitation message and receives the router advertisement message that announces the combination of global unicast prefix and the subnet identifier as 3A21:1216:2165:A245:1232. The host then appends its interface identifier to this prefix to find and store its global unicast address as: **3A21:1216:2165:A245:1232:F7A9:23FF:FE11:9BE2**

Figure 27.1 *IPv6 datagram*

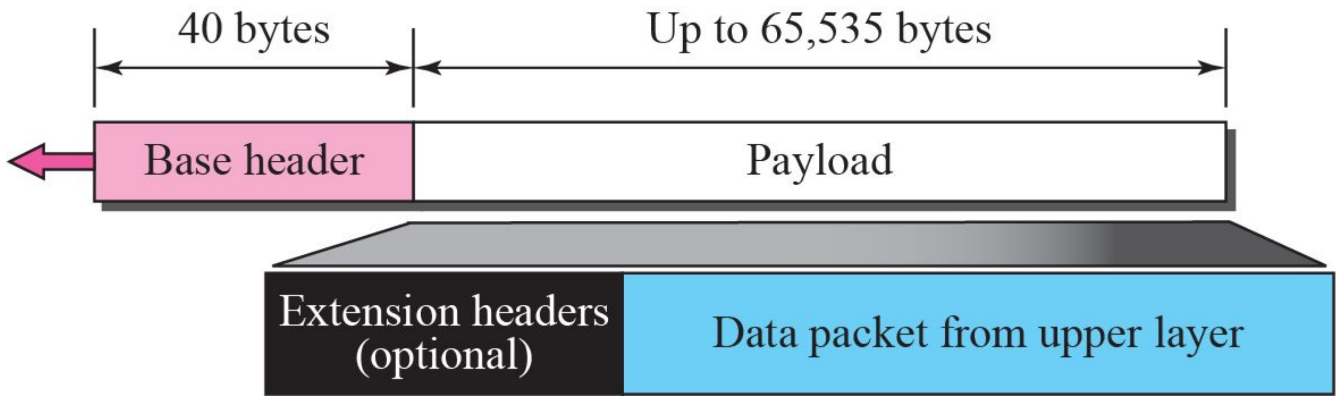


Figure 27.2 *Format of the base header*

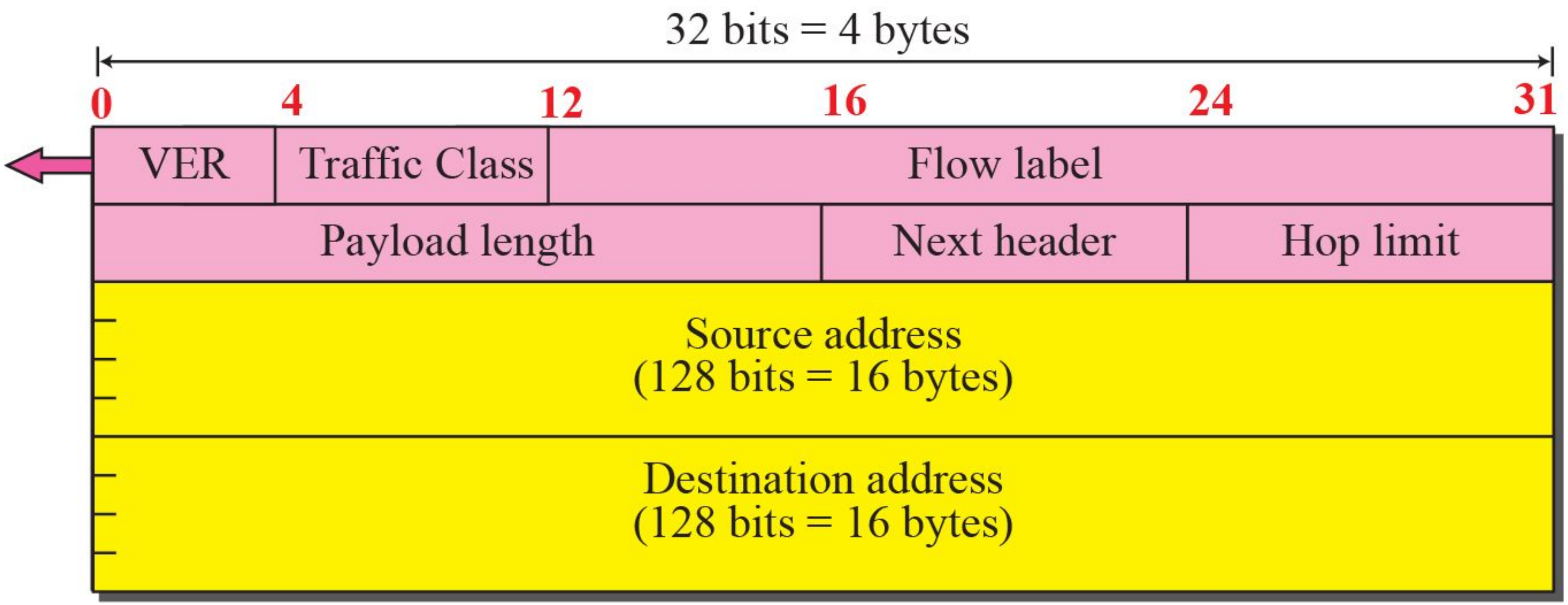


Table 27.1 *Next Header Codes*

Code	*Next Header*	*Code*	*Next Header*
0	Hop-by-hop option	44	Fragmentation
2	ICMP	50	Encrypted security payload
6	TCP	51	Authentication
17	UDP	59	Null (No next header)
43	Source routing	60	Destination option

Figure 27.3 *Extension header format*

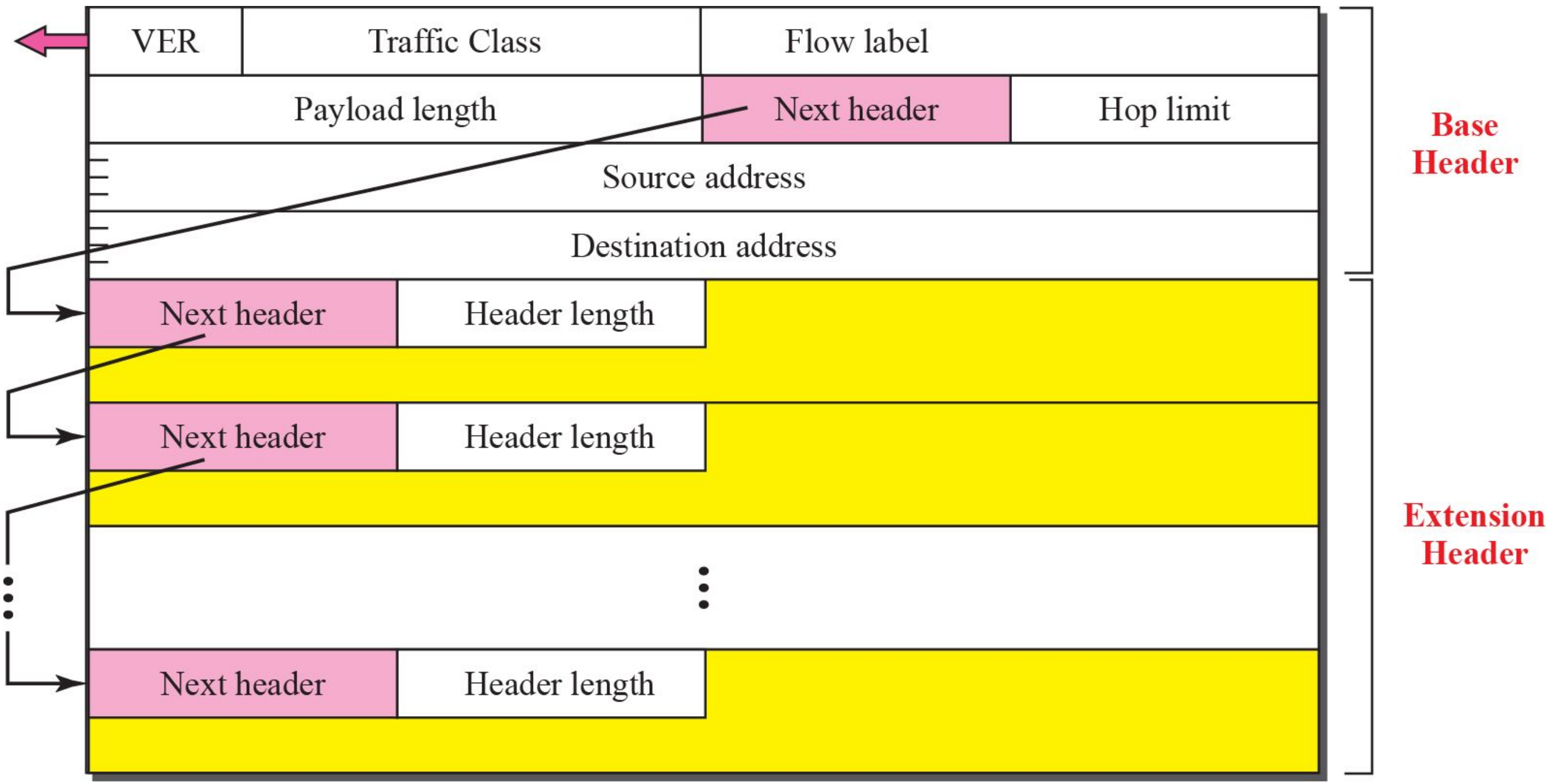


Figure 27.4 *Extension header types*

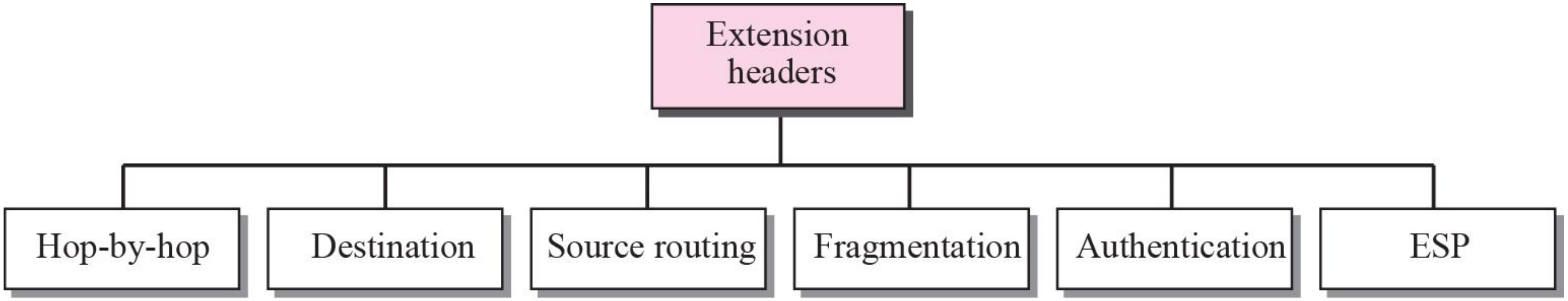


Figure 27.5 *Hop-by-hop option header format*

Figure 27.6 *The format of the option in a hop-by-hop option header*

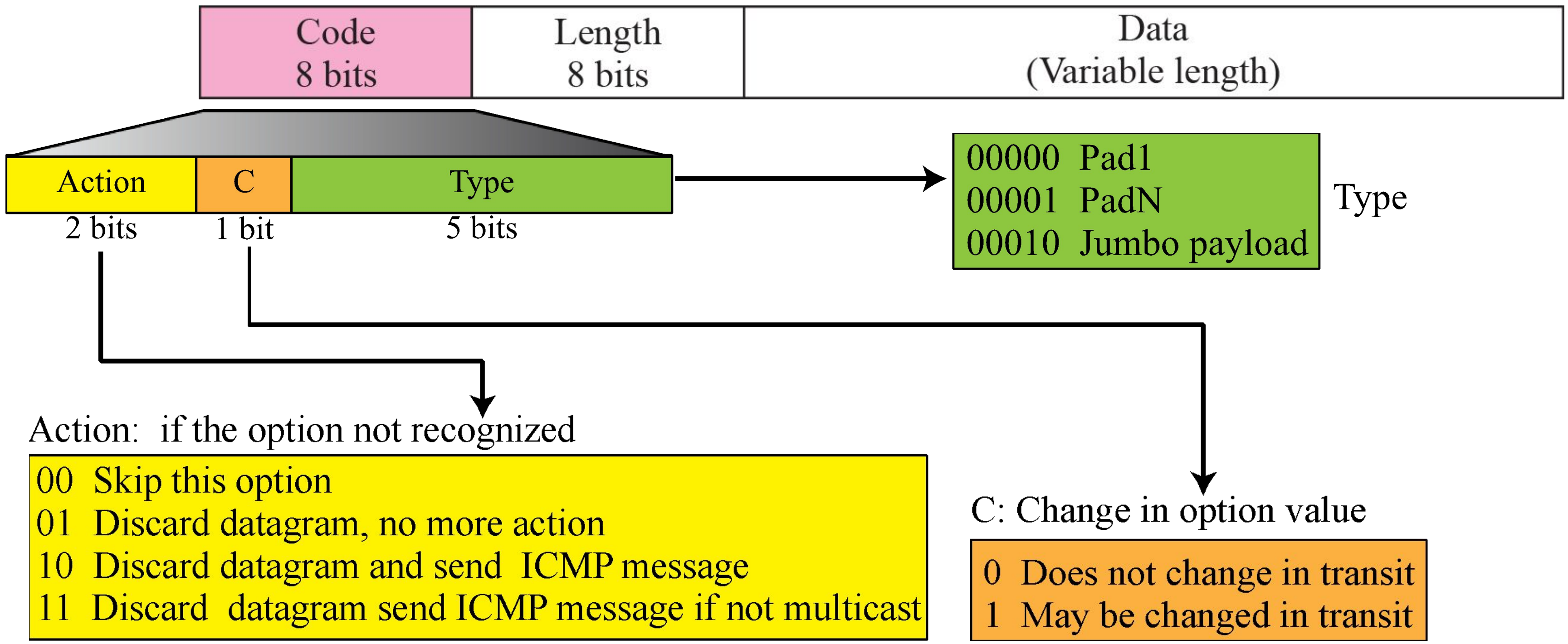


Figure 27.7 *Pad1*

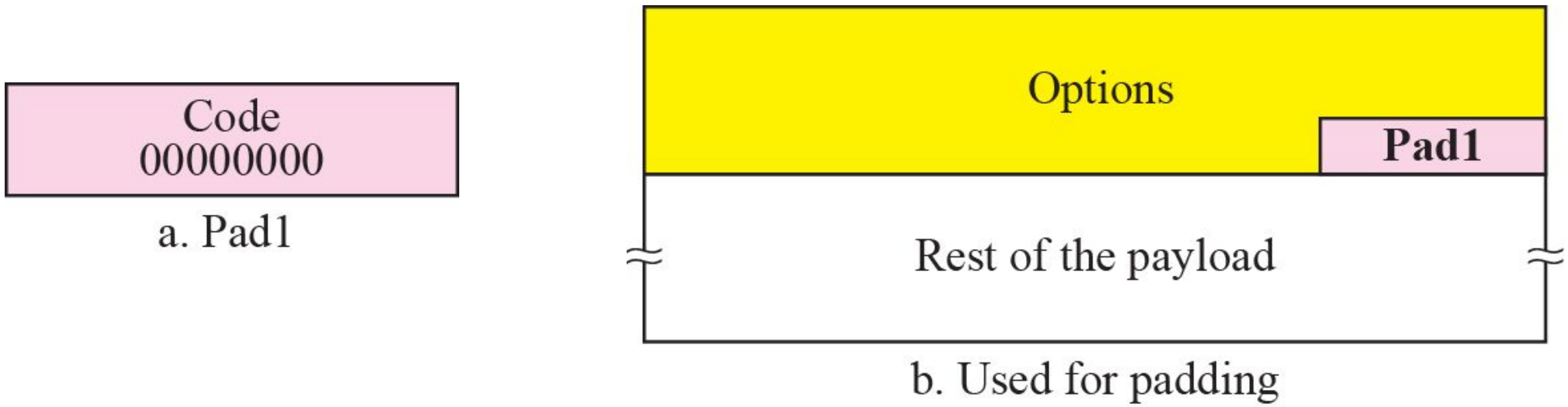


Figure 27.8 *PadN*

Figure 27.9 *Jumbo payload*

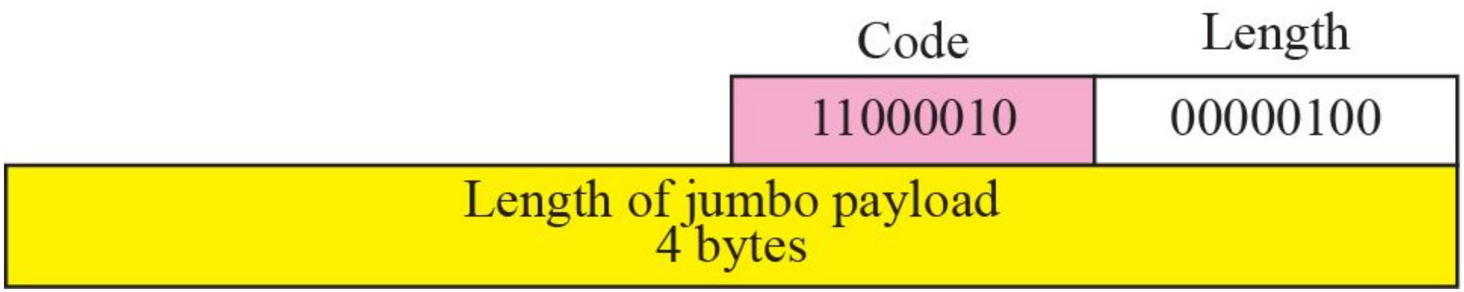


Figure 27.10 *Source routing*

Next header	Header length	Type	Addresses left
Reserved	Strict/loose mask		
First address			
Second address			
⋮			
Last address			

Figure 27.11 *Source routing example*

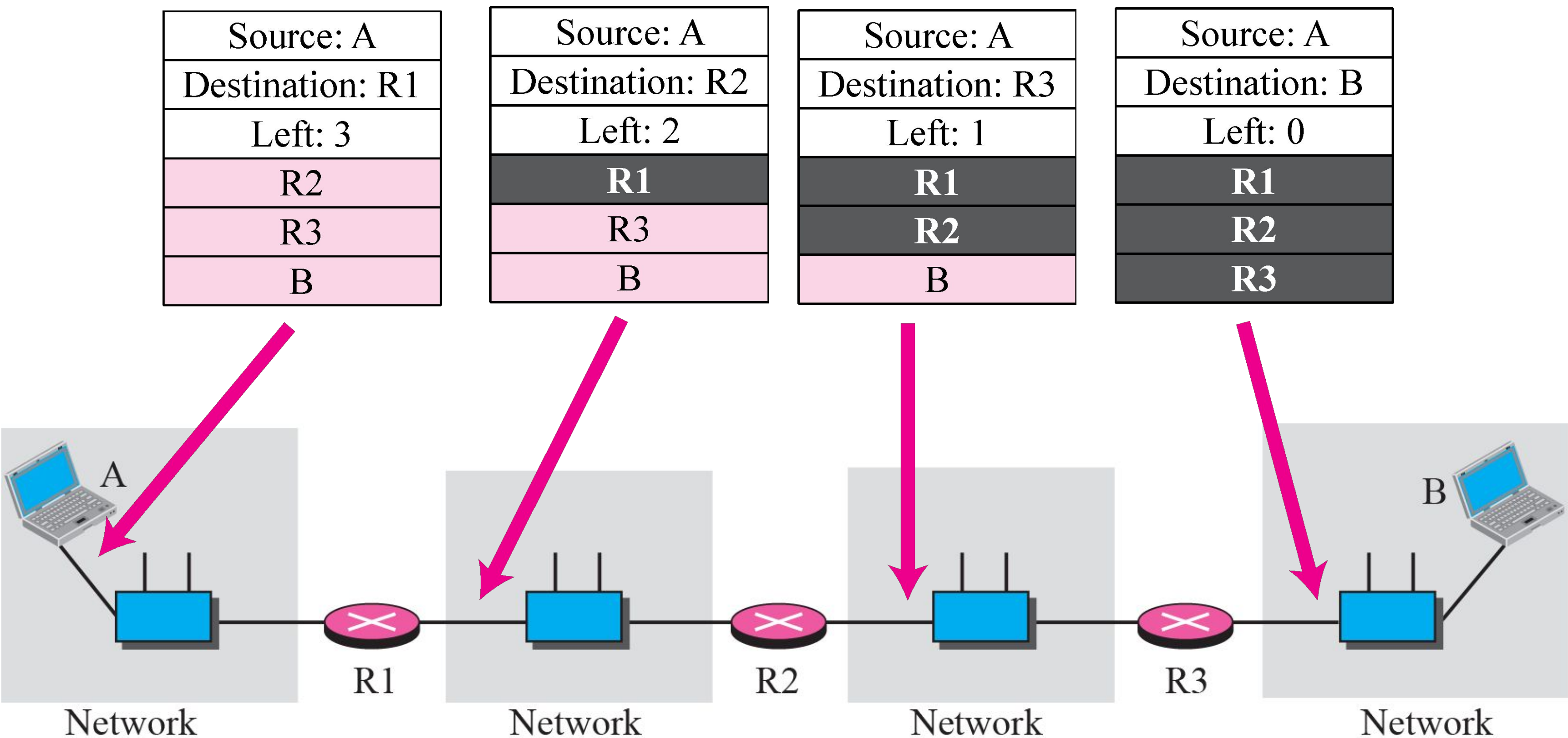


Figure 27.12 *Fragmentation*

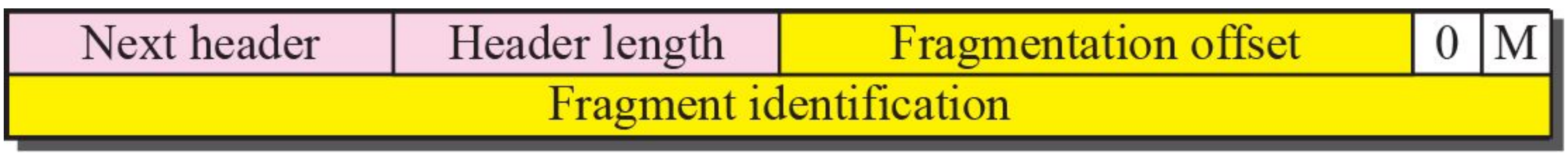


Figure 27.13 *Authentication*

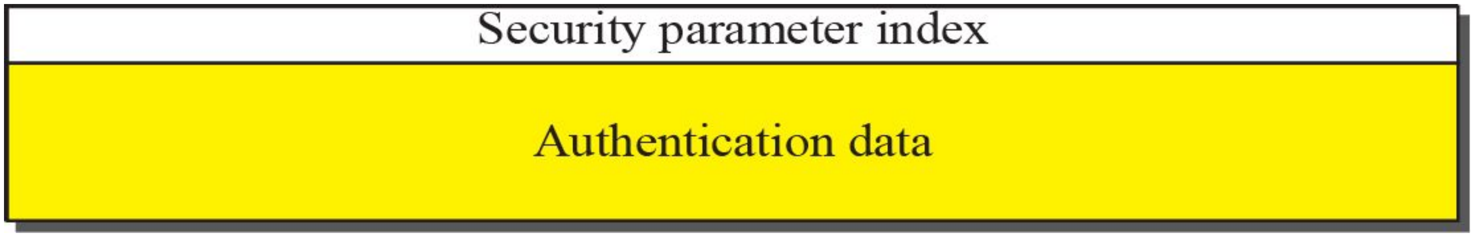


Figure 27.14 *Calculation of authentication data*

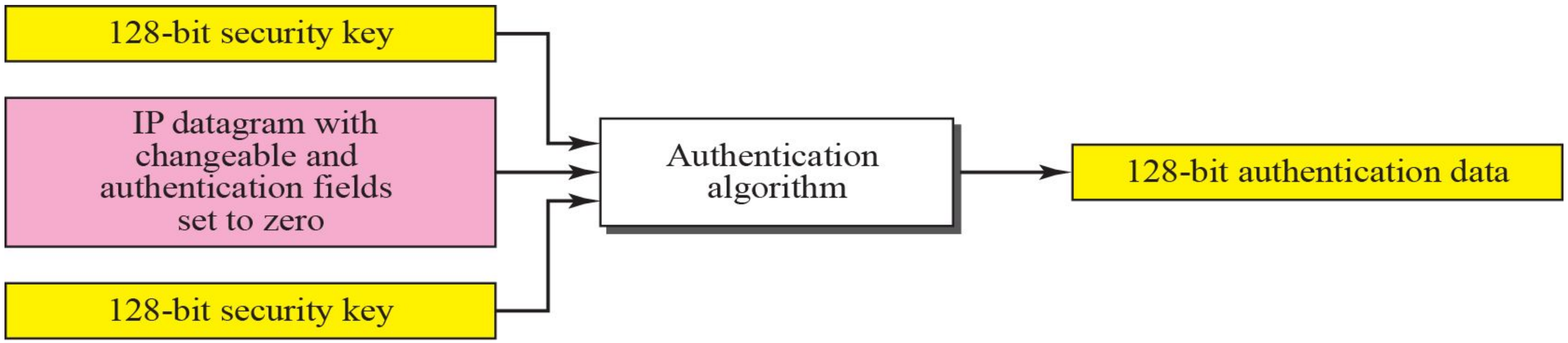
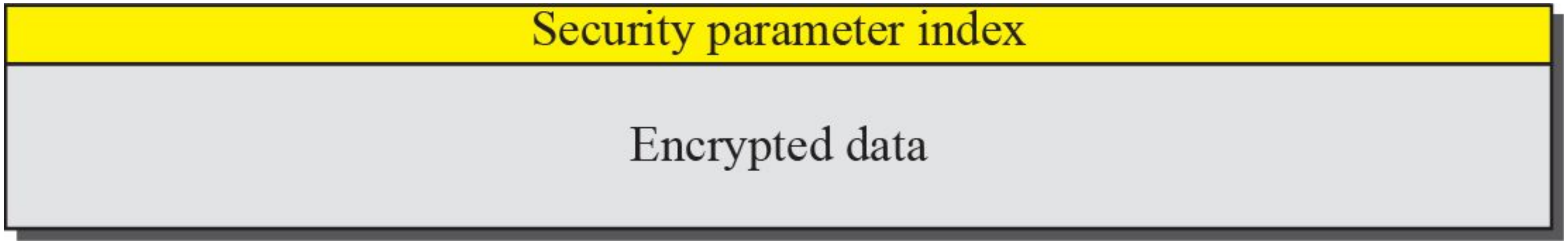


Figure 27.15 *Encrypted security payload*



Fields Related to Fragmentation

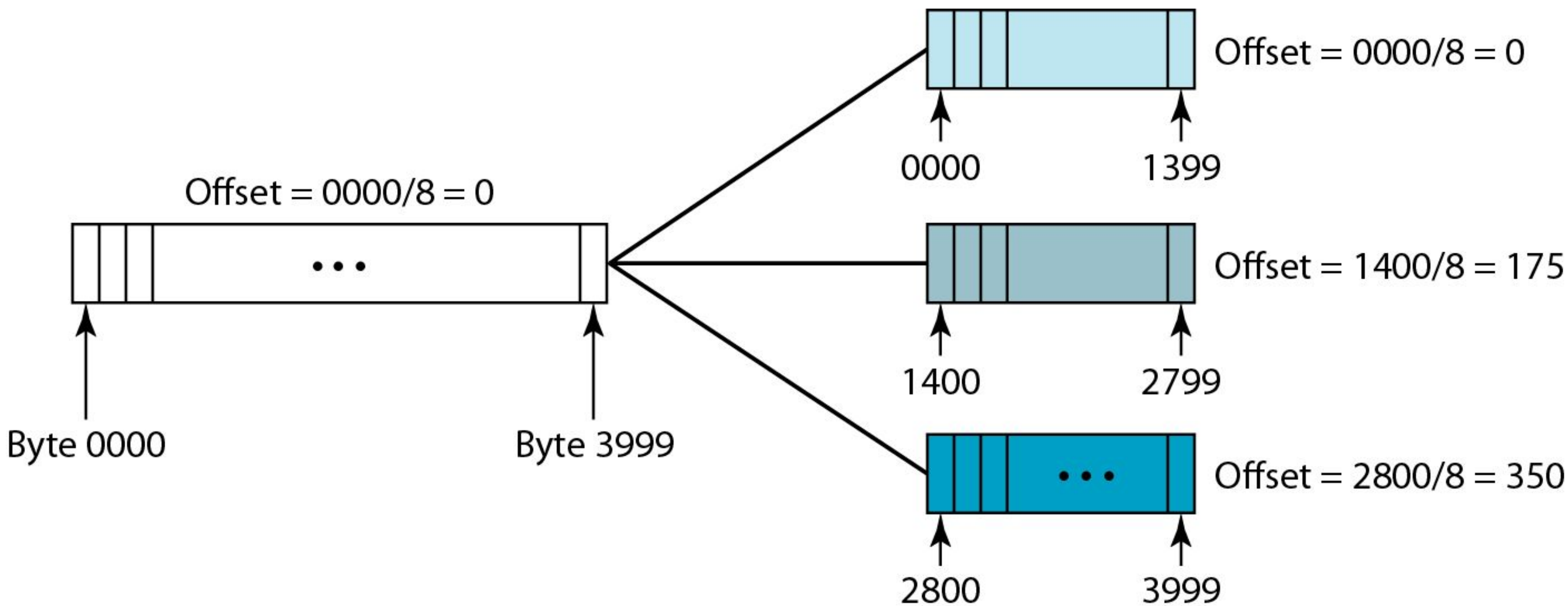
- **Identification:** identifies a datagram originating from the source host. A combination of the identification and source address must uniquely define a datagram as it leaves the source node.
- **Flags:** see next slide.
- **Fragmentation offset:** is the offset of the data in the original datagram measured in <u>units of 8 bytes</u>.

Figure 20.10 *Flags (3 bits) used in fragmentation*

- first bit: reserved (not used)
- second bit: = 1 requires the packet not to be fragmented
  drops the packet if it is > MTU

- third bit: =1 more fragmented packets later
  =0 the last fragmented packet

Figure 20.11 *Fragmentation example*



IP Fragmentation and Reassembly

Example

- 4000 byte datagram
- MTU = 1500 bytes

	length	ID	fragflag	offset	
	=4000	=x	=0	=0	

One large datagram becomes several smaller datagrams

	length	ID	fragflag	offset	
	=1500	=x	=1	=0	

1480 bytes in data field

	length	ID	fragflag	offset	
	=1500	=x	=1	=185	

offset = 1480/8

	length	ID	fragflag	offset	
	=1040 **1060**	=x	=0	=370	

27-3 TRANSITION FROM IPv4 TO IPv6

Because of the huge number of systems on the Internet, the transition from IPv4 to IPv6 cannot happen suddenly. It will take a considerable amount of time before every system in the Internet can move from IPv4 to IPv6. The transition must be smooth to prevent any problems between IPv4 and IPv6 systems. Three strategies have been devised by the IETF to help the transition (see Figure 27.16).

Figure 27.16 *Three transition strategies*

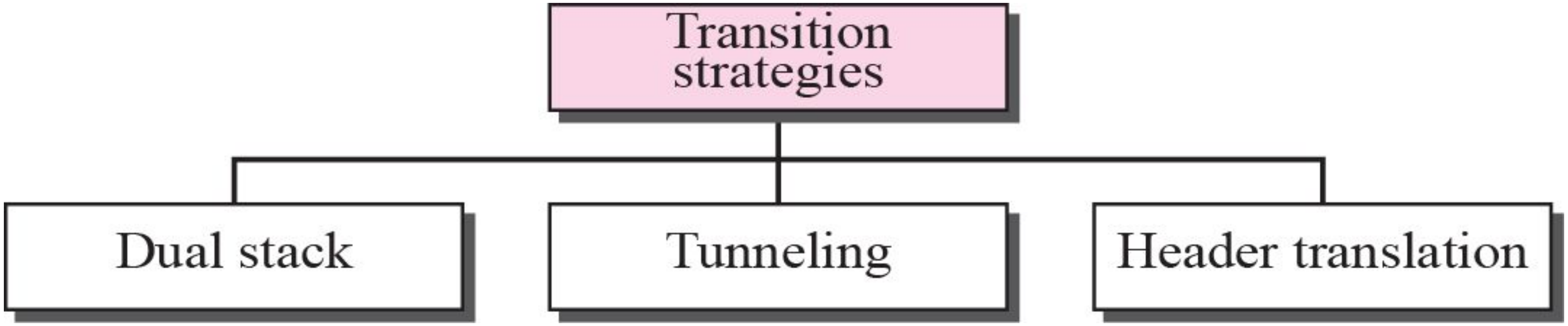


Figure 27.17 *Dual stack*

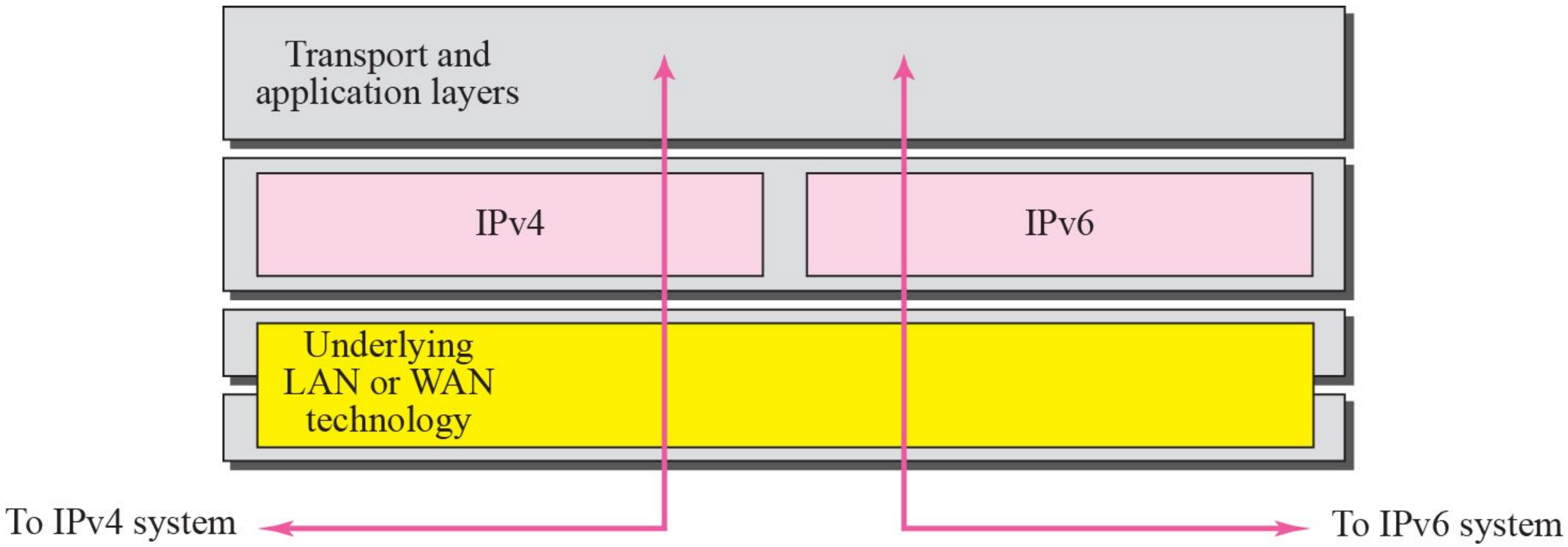


Figure 27.18 *Tunneling strategy*

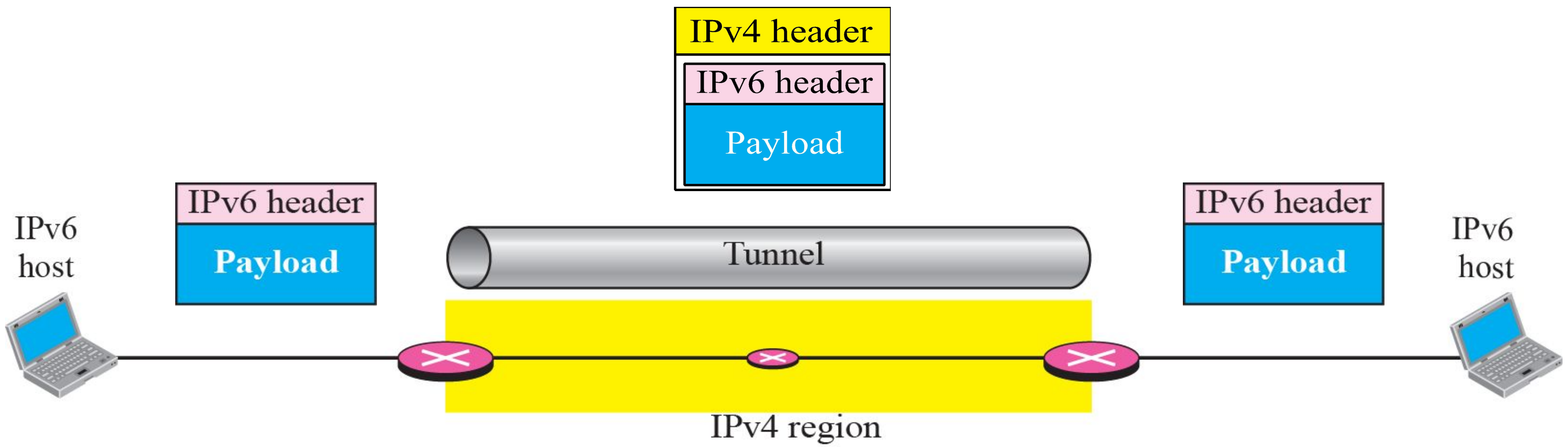
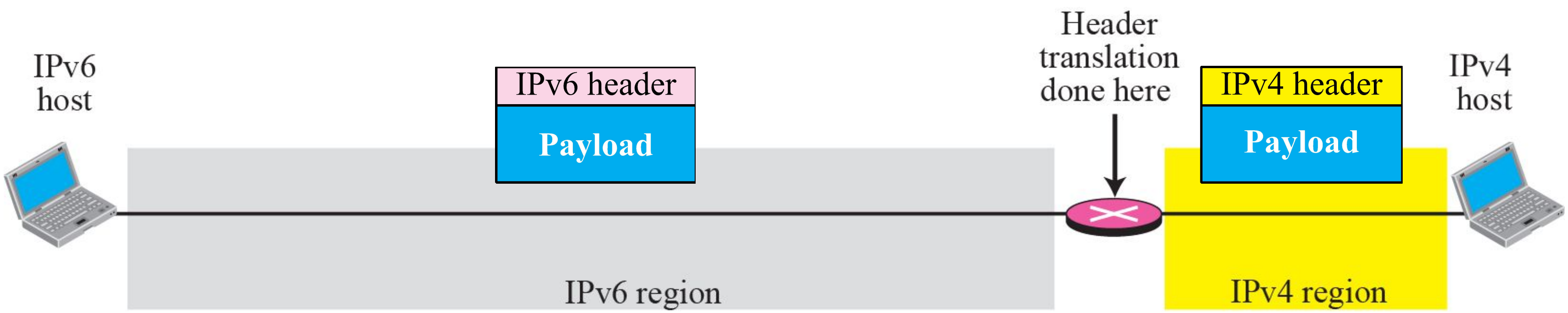


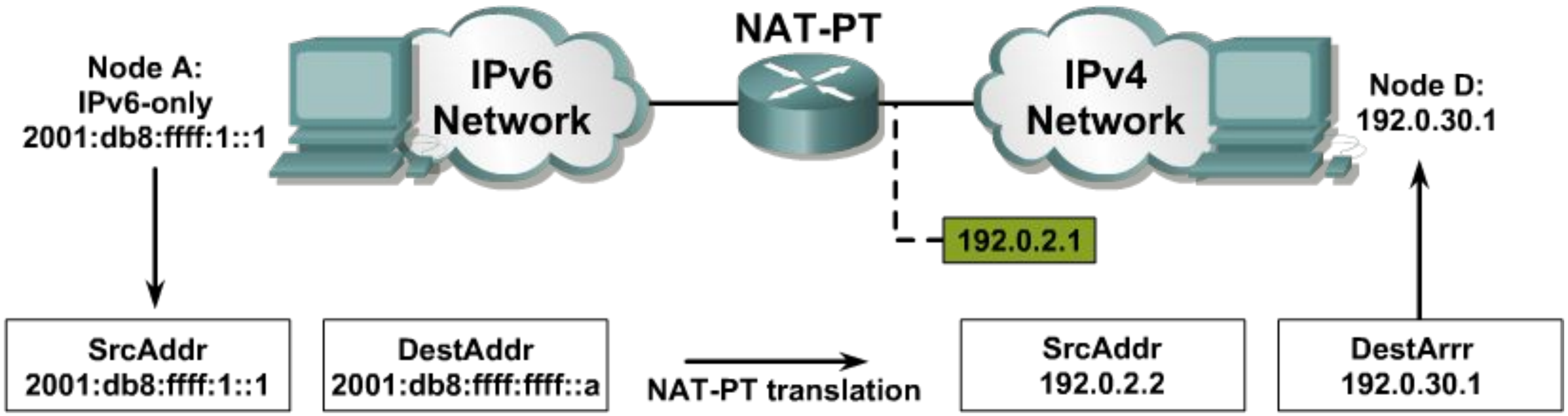
Figure 27.19 *Header translation strategy*



- The IPv6 mapped address is changed to an IPv4 address by extracting the rightmost 32 bits.
- The type of service field in IPv4 is set to zero.
- The checksum for IPv4 is calculated and inserted in the corresponding field.
- The IPv6 flow label is ignored.
- Compatible extension headers are converted to options and inserted in the IPv4 header. Some may have to be dropped.
- The length of IPv4 header is calculated and inserted into the corresponding field.
- The total length of the IPv4 packet is calculated and inserted in the corresponding field.

IP6-IP4 Translation

- This allows communication between IPv4 only and IPv6 only end stations.



- The job of the translator is to translate IPv6 packets into IPv4 packets by doing address and port translation and vice versa.

IPv4-IPv6 Translation

- An IPv4 address : example 192.168.99.1
  - Each Octet (8 bits) "between the dot-things" denote 1 byte
- An IPv6 address : example 2001:0db8:85a3:0000:0000:8a2e:0370:7334
  - Two Tuples (1 Tuple = 4 bits = 1 Hex character) denotes 1 byte

Lets take the following IPv4 address : 192.168.99.1 and convert it to Hex.

IPv4-IPv6 Translation

- An IPv4 address : example 192.168.99.1
- Step1 > Divide the first octet (192) by 16 (since Hex is a Base-16)
  - 192/16 = 12 times exactly with 0 left over
  - 12 in Hex is represented as C
  - 0 (zero) in Hex is, you guessed it, 0
  - Thus 192 in HEX is C0
- Step2 > Repeat step 1 with the second octet (168),
  - 168/16 = 10 times with 8 left over because 10*6 = 160,
  - 10 in HEX is A
  - 8 in HEX is 8
  - Thus 168 in HEX is A8

IPv4-IPv6 Translation

- Step3 > Repetition rules!!! Third octet (99)
  - 99/16 = 6 times with 3 left over
  - 6 in HEX is 6
  - 3 in HEX is 3
  - Thus 99 in HEX is 63
- Step4 > Last octet
  - 1/16 = 0 times with 1 left over
  - 0 in HEX is, yeah it is 0
  - 1 in HEX is 1
  - Thus 1 in HEX is 01
- So the IPv4 address of 192.168.99.1, represented in the IPv6 address portion would be C0A8:6301.

IPv6-IPv4 Translation

- To convert the same portion of the IPv6 address 2002:C0A8:6301::1 back to IPv4, the reverse method would apply.
- Taking the portion C0A8:6301, first divide the address into 2 Tuple-groupings (2 Hex Characters) = C0 A8 63 01
- Step1 > Take C0 and multiply the first character ‘C’ by 16 and the second character ‘0’ by 1.
  - Add the two decimal values together to get the IPv4 decimal value
  - ((C=12)*16) + (0*1) = 192

IPv6-IPv4 Translation

- Step2 > Repeat the same process with A8,
  - ((A=10)*16) + (8*1) = 168
- Step3 > Repeat the same process with 63,
  - (6*16) + (3*1) = 99
- Step4 > Repeat the same process with 01,
  - (0*16) + (1*1) = 1
- This will give you an IPv4 address of 192.168.99.1