Data Communications and Networking Fourth Edition

Forouzan

Chapter 19

Network Layer: Logical Addressing

19-1 IPv4 ADDRESSES

An IPv4 address is a 32-bit address that uniquely and universally defines the connection of a device (for example, a computer or a router) to the Internet.

Topics discussed in this section:

Address Space
Notations
Classful Addressing
Classless Addressing
Network Address Translation (NAT)

Note

An IPv4 address is 32 bits long.

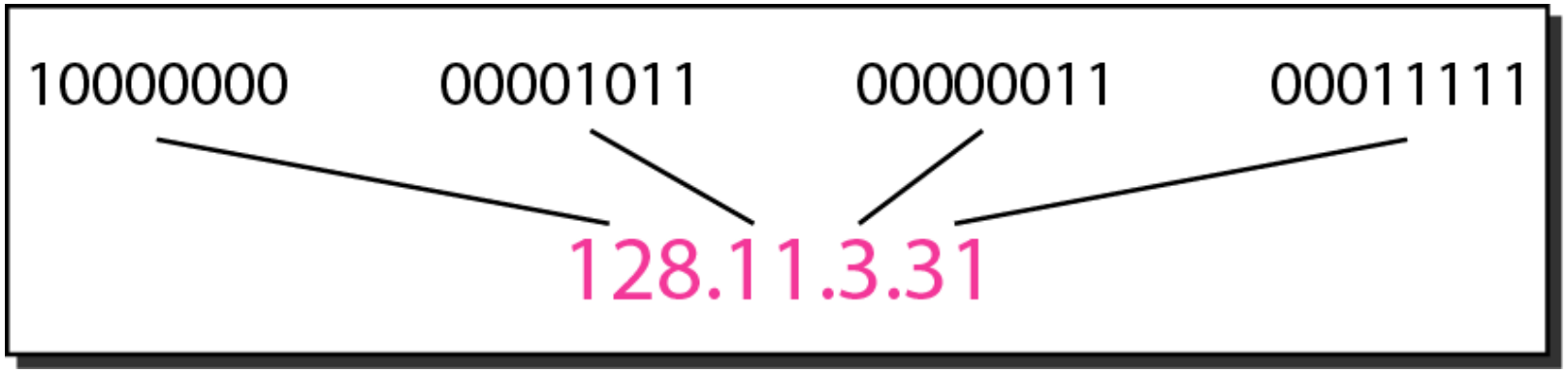
Note

The IPv4 addresses are unique and universal.

Note

The address space of IPv4 is 2^{32} or 4,294,967,296.

Figure 19.1 *Dotted-decimal notation and binary notation for an IPv4 address*



Example 19.1

Change the following IPv4 addresses from binary notation to dotted-decimal notation.

a. 10000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

Solution

We replace each group of 8 bits with its equivalent decimal number (see Appendix B) and add dots for separation.

a. 129.11.11.239

b. 193.131.27.255

Example 19.2

Change the following IPv4 addresses from dotted-decimal notation to binary notation.

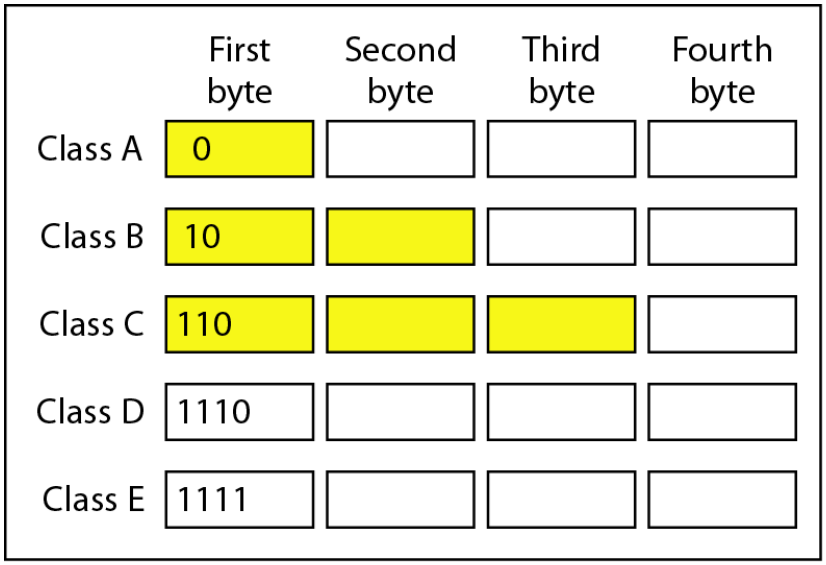
Solution

We replace each decimal number with its binary equivalent (see Appendix B).

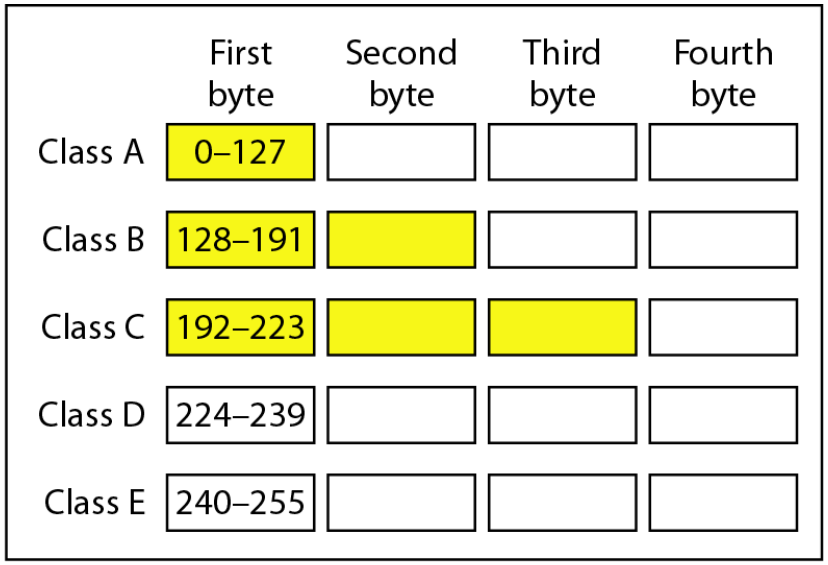
Note

In classful addressing, the address space is divided into five classes: A, B, C, D, and E.

Figure 19.2 *Finding the classes in binary and dotted-decimal notation*



a. Binary notation



b. Dotted-decimal notation

Example 19.4

Find the class of each address.

a. 0**0000001 00001011 00001011 11101111**

b. 1**10**00001 10000011 00011011 11111111

c. 1**4**.23.120.8

d. 2**52**.5.15.111

Solution

a. The first bit is 0. This is a class A address.

b. The first 2 bits are 1; the third bit is 0. This is a class C address.

c. The first byte is 14; the class is A.

d. The first byte is 252; the class is E.

Table 19.1 *Number of blocks and block size in classful IPv4 addressing*

Class	*Number of Blocks*	*Block Size*	*Application*
A	128	16,777,216	Unicast
B	16,384	65,536	Unicast
C	2,097,152	256	Unicast
D	1	268,435,456	Multicast
E	1	268,435,456	Reserved

Note

In classful addressing, a large part of the available addresses were wasted.

Table 19.2 *Default masks for classful addressing*

Class	*Binary*	*Dotted-Decimal*	*CIDR*
A	**11111111** 00000000 00000000 00000000	**255**.0.0.0	/8
B	**11111111 11111111** 00000000 00000000	**255.255**.0.0	/16
C	**11111111 11111111 11111111** 00000000	**255.255.255**.0	/24

Note

Classful addressing, which is almost obsolete, is replaced with classless addressing.

Note

In IPv4 addressing, a block of addresses can be defined as x.y.z.t /*n* in which x.y.z.t defines one of the addresses and the /*n* defines the mask.

Note

The first address in the block can be found by setting the rightmost $32 - n$ bits to 0s.

Example 19.6

A block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.39/28. What is the first address in the block?

Solution

The binary representation of the given address is

11001101 00010000 00100101 00100111

If we set 32−28 rightmost bits to 0, we get

11001101 00010000 00100101 0010000

or

205.16.37.32.

This is actually the block shown in Figure 19.3.

Note

The last address in the block can be found by setting the rightmost 32 − n bits to 1s.

Example 19.7

Find the last address for the block in Example 19.6.

Solution

The binary representation of the given address is

11001101 00010000 00100101 00100111

If we set 32 − 28 rightmost bits to 1, we get

11001101 00010000 00100101 00101111

or

205.16.37.47

This is actually the block shown in Figure 19.3.

Note

The number of addresses in the block can be found by using the formula 2^{32-n}.

Example 19.8

Find the number of addresses in Example 19.6.

Solution

The value of n is 28, which means that number of addresses is 2^{32-28} *or 16.*

Example 19.9

Another way to find the first address, the last address, and the number of addresses is to represent the mask as a 32-bit binary (or 8-digit hexadecimal) number. This is particularly useful when we are writing a program to find these pieces of information. In Example 19.5 the /28 can be represented as

11111111 11111111 11111111 11110000

(twenty-eight 1s and four 0s).

Find

a. The first address

b. The last address

c. The number of addresses.

Example 19.9 (continued)

Solution

a. ***The first address can be found by ANDing the given addresses with the mask. ANDing here is done bit by bit. The result of ANDing 2 bits is 1 if both bits are 1s; the result is 0 otherwise.***

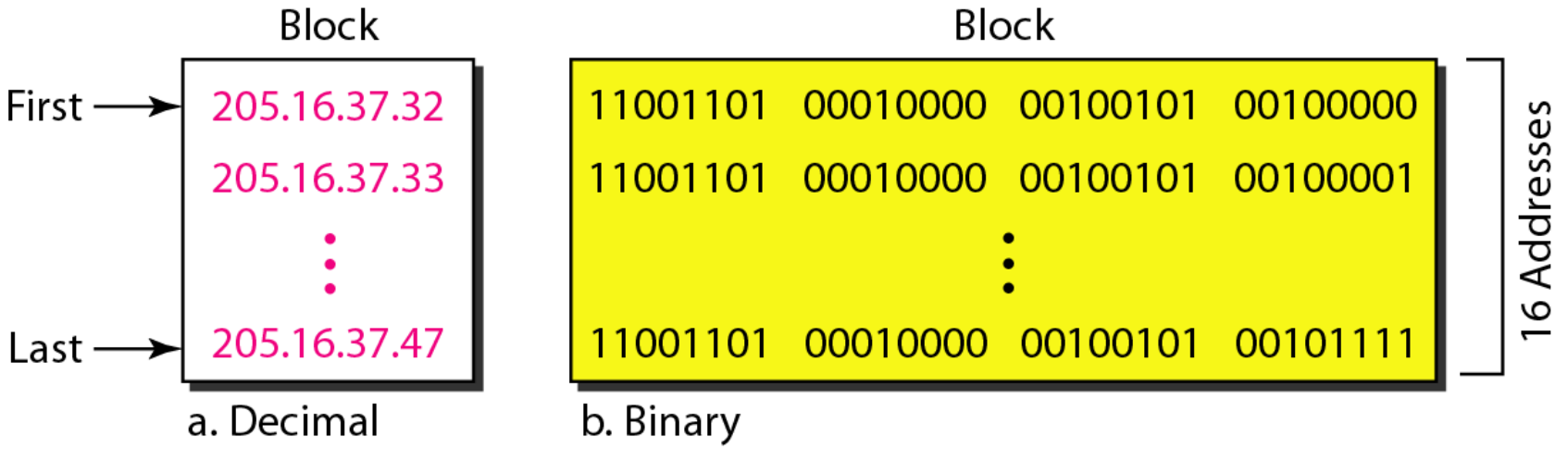
Address:	11001101	00010000	00100101	00100111
Mask:	**11111111**	**11111111**	**11111111**	**11110000**
First address:	11001101	00010000	00100101	00100000

Example 19.9 (continued)

b. ***The last address can be found by ORing the given addresses with the complement of the mask. ORing here is done bit by bit. The result of ORing 2 bits is 0 if both bits are 0s; the result is 1 otherwise. The complement of a number is found by changing each 1 to 0 and each 0 to 1.***

Address:	11001101	00010000	00100101	00100111
Mask complement:	**00000000**	**00000000**	**00000000**	**00001111**
Last address:	11001101	00010000	00100101	00101111

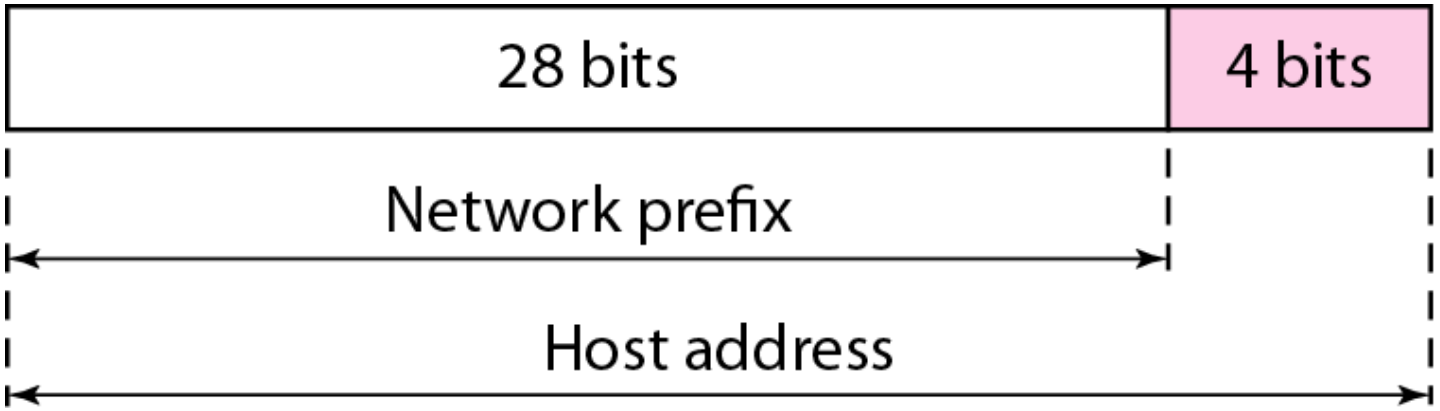
Figure 19.4 *A network configuration for the block 205.16.37.32/28*



Note

The first address in a block is normally not assigned to any device; it is used as the network address that represents the organization to the rest of the world.

Figure 19.6 *A frame in a character-oriented protocol*



Note

Each address in the block can be considered as a two-level hierarchical structure: the leftmost *n* bits (prefix) define the network; the rightmost 32 − n bits define the host.

Figure 19.7 *Configuration and addresses in a subnetted network*

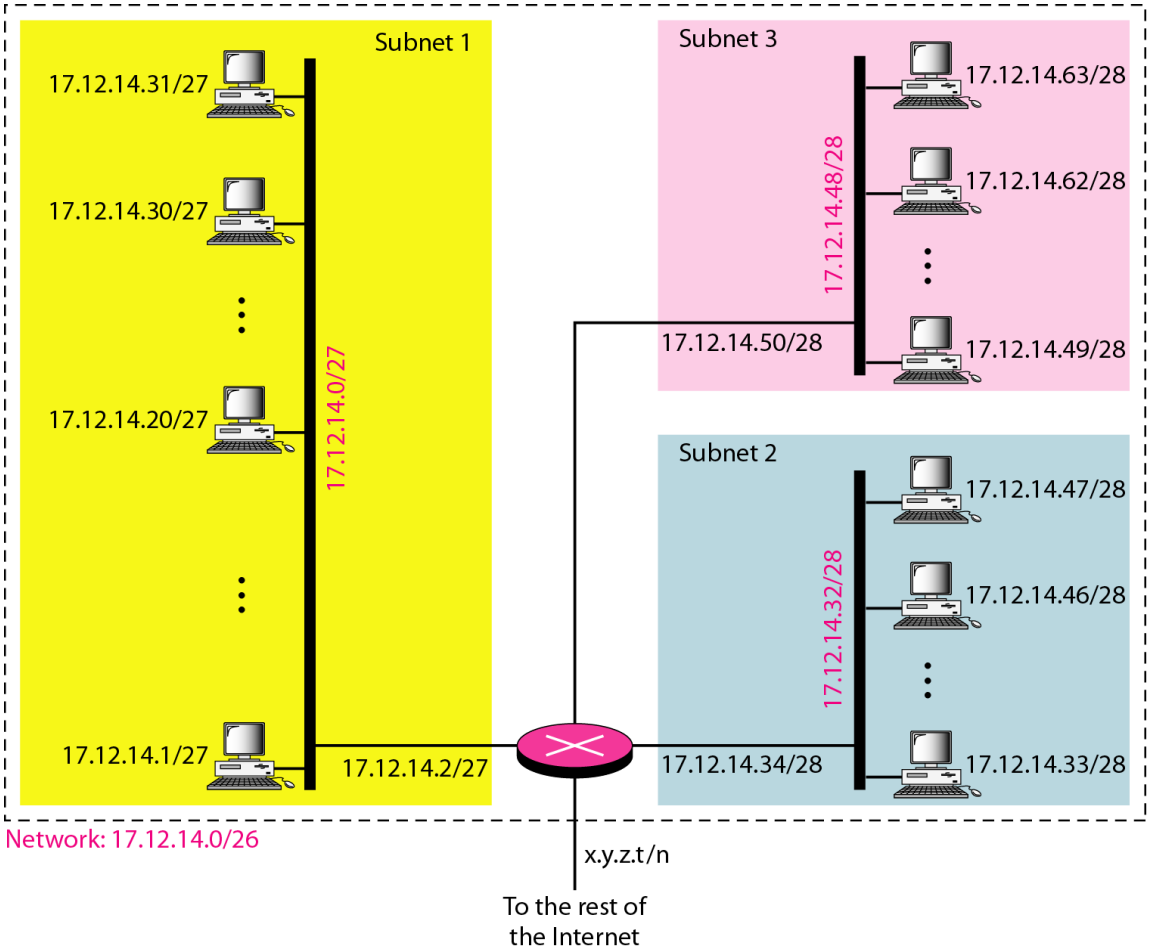
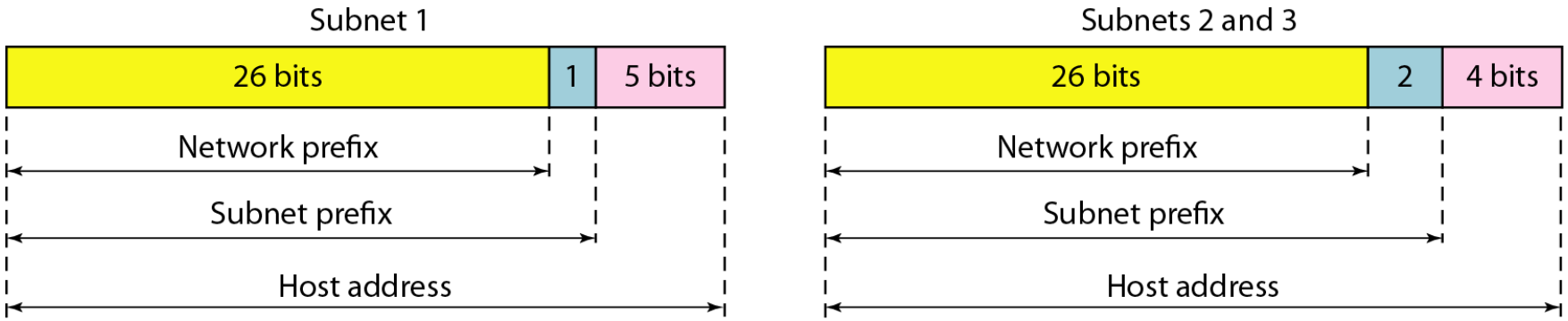


Figure 19.8 *Three-level hierarchy in an IPv4 address*



Example 19.10

An ISP is granted a block of addresses starting with 190.100.0.0/16 (65,536 addresses). The ISP needs to distribute these addresses to three groups of customers as follows:

a. The first group has 64 customers; each needs 256 addresses.

b. The second group has 128 customers; each needs 128 addresses.

c. The third group has 128 customers; each needs 64 addresses.

Design the subblocks and find out how many addresses are still available after these allocations.

Example 19.10 (continued)

Solution

Figure 19.9 shows the situation.

Group 1

For this group, each customer needs 256 addresses. This means that 8 (log2 256) bits are needed to define each host. The prefix length is then 32 − 8 = 24. The addresses are

Example 19.10 (continued)

Group 2

For this group, each customer needs 128 addresses. This means that 7 (log2 128) bits are needed to define each host. The prefix length is then 32 − 7 = 25. The addresses are

1st Customer:	*190.100.64.0/25*	*190.100.64.127/25*
2nd Customer:	*190.100.64.128/25*	*190.100.64.255/25*
. . .		
128th Customer:	*190.100.127.128/25*	*190.100.127.255/25*
Total = 128 × 128 = 16,384		

Example 19.10 (continued)

Group 3

For this group, each customer needs 64 addresses. This means that 6 ($log_2 64$) bits are needed to each host. The prefix length is then 32 − 6 = 26. The addresses are

1st Customer:	*190.100.128.0/26*	*190.100.128.63/26*
2nd Customer:	*190.100.128.64/26*	*190.100.128.127/26*
. . .		
128th Customer:	*190.100.159.192/26*	*190.100.159.255/26*

Total = 128 × 64 = 8192

Number of granted addresses to the ISP: 65,536
Number of allocated addresses by the ISP: 40,960
Number of available addresses: 24,576

Figure 19.10 *A NAT implementation*

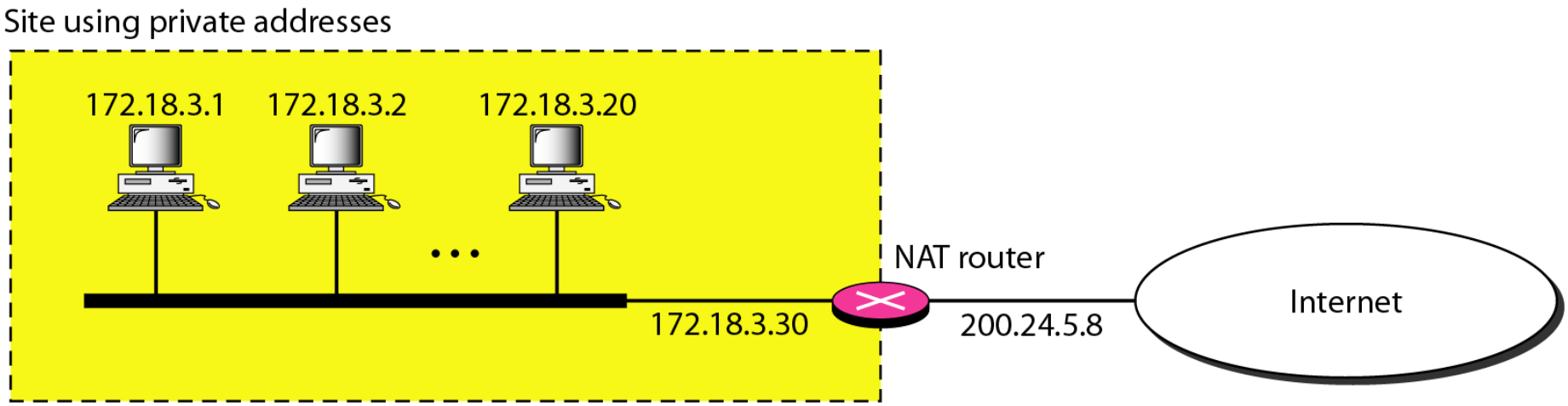


Figure 19.11 *Addresses in a NAT*

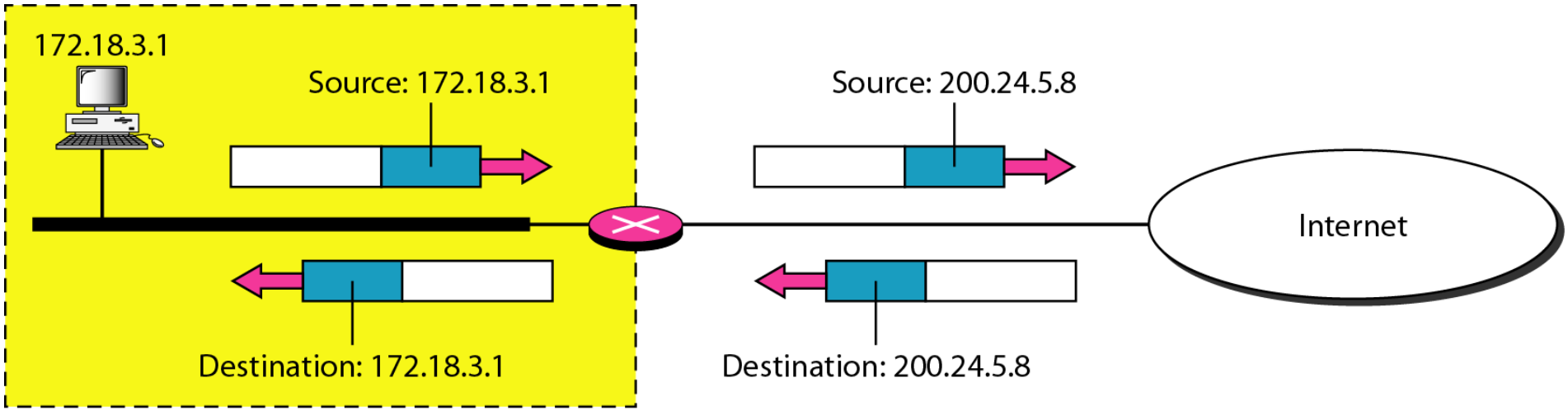


Figure 19.12 *NAT address translation*

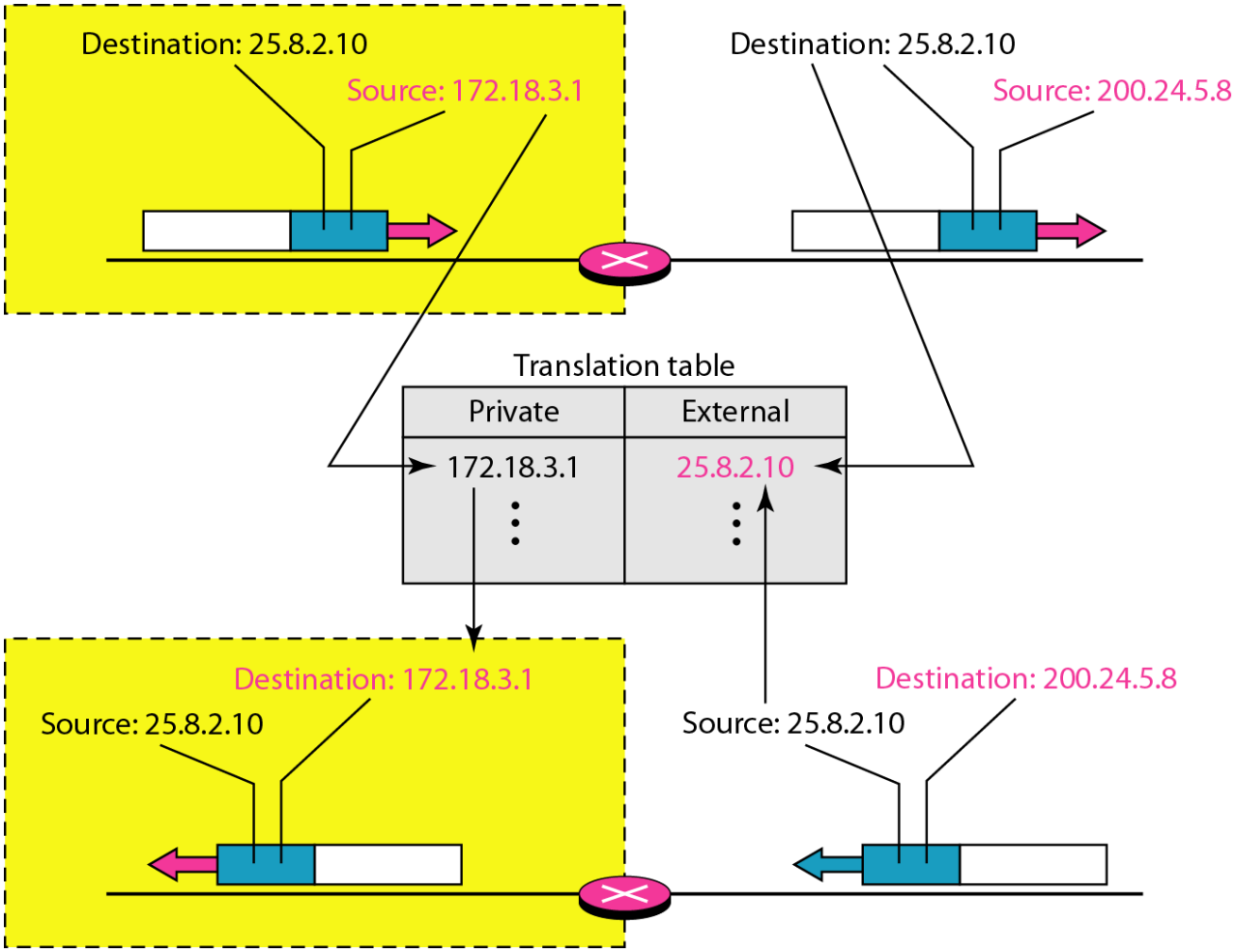


Table 19.4 ***Five-column translation table***

Private Address	*Private Port*	*External Address*	*External Port*	*Transport Protocol*
172.18.3.1	1400	25.8.3.2	80	TCP
172.18.3.2	1401	25.8.3.2	80	TCP
. . .	. . .	. . .	. . .	. . .

19-2 IPv6 ADDRESSES

Despite all short-term solutions, address depletion is still a long-term problem for the Internet. This and other problems in the IP protocol itself have been the motivation for IPv6.

Topics discussed in this section:

Structure
Address Space

Note

An IPv6 address is 128 bits long.

Figure 19.14 *IPv6 address in binary and hexadecimal colon notation*

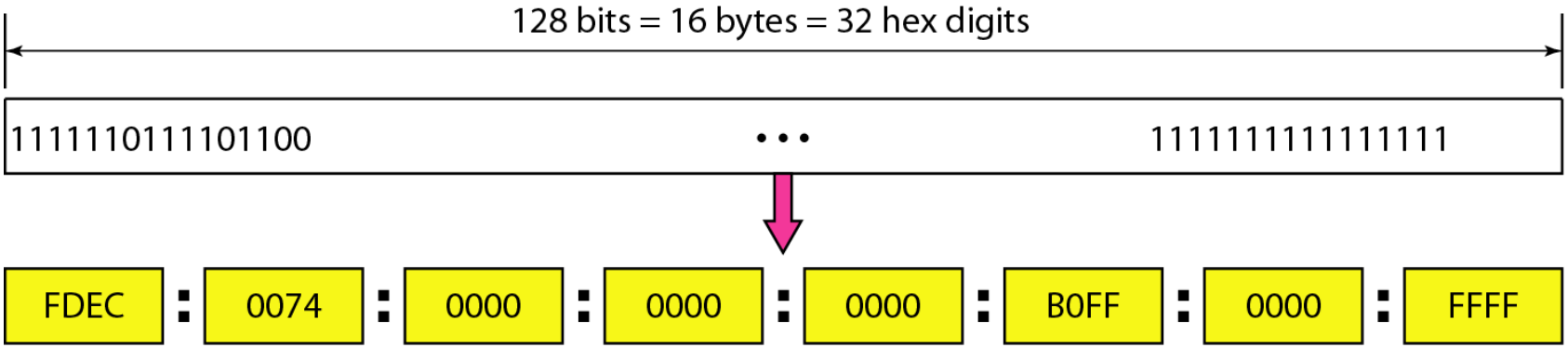
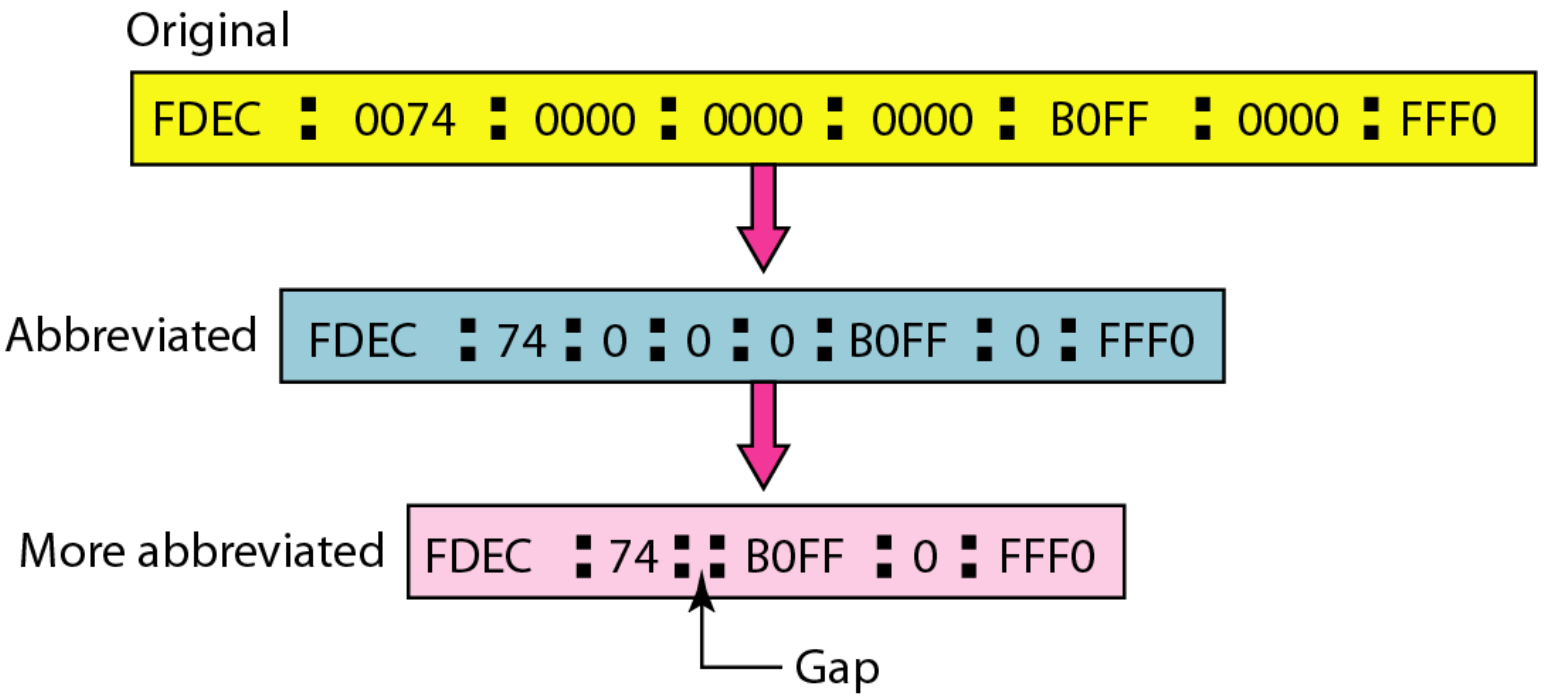


Figure 19.15 *Abbreviated IPv6 addresses*



Example 19.11

Expand the address 0:15::1:12:1213 to its original.

Solution

We first need to align the left side of the double colon to the left of the original pattern and the right side of the double colon to the right of the original pattern to find how many 0s we need to replace the double colon.

```
xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx
  0:   15:                   :    1:   12:1213
```

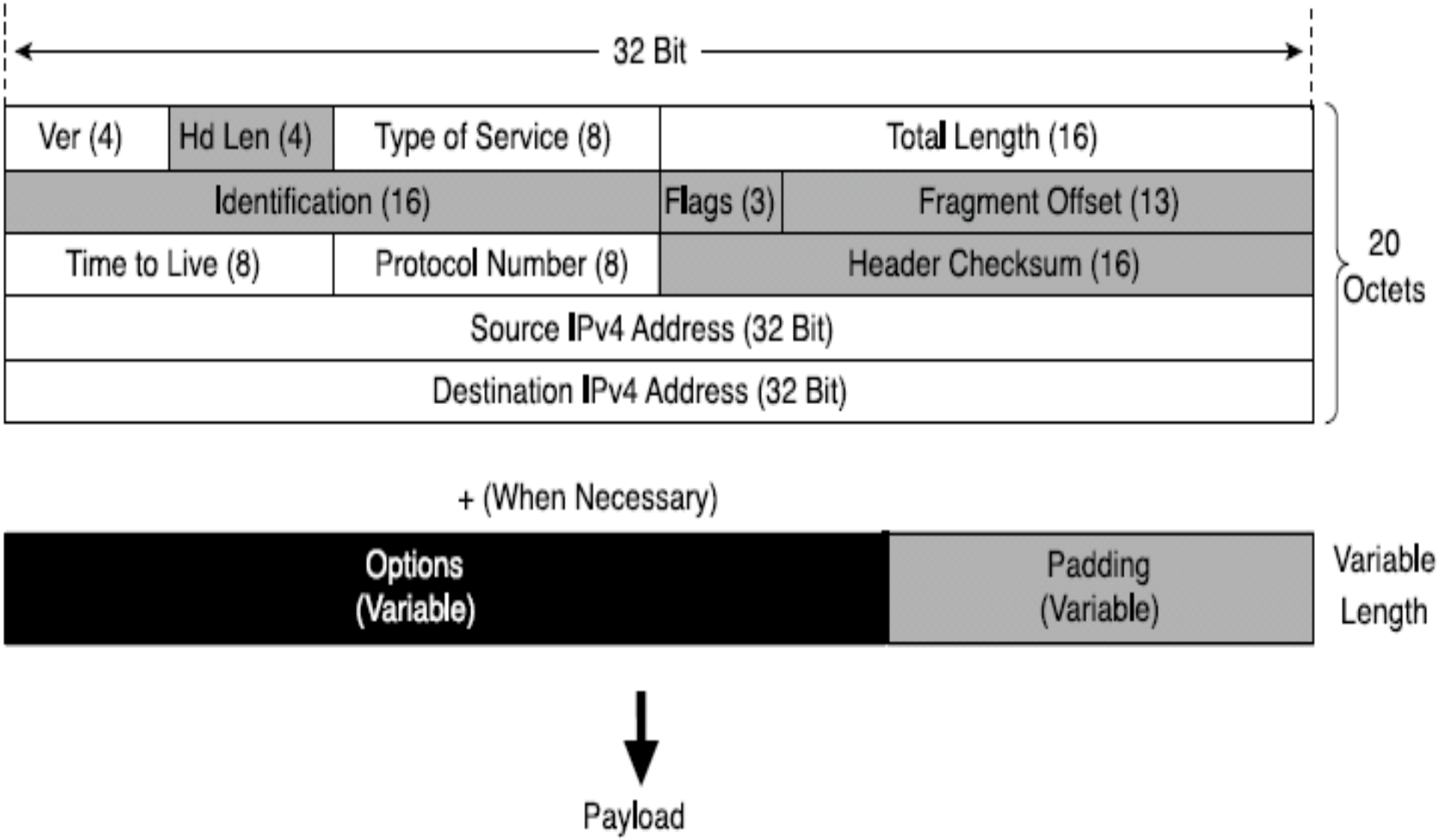
This means that the original address is.

```
0000:0015:0000:0000:0000:0001:0012:1213
```

IPv4 Addressing Concepts and Their IPv6 Equivalents

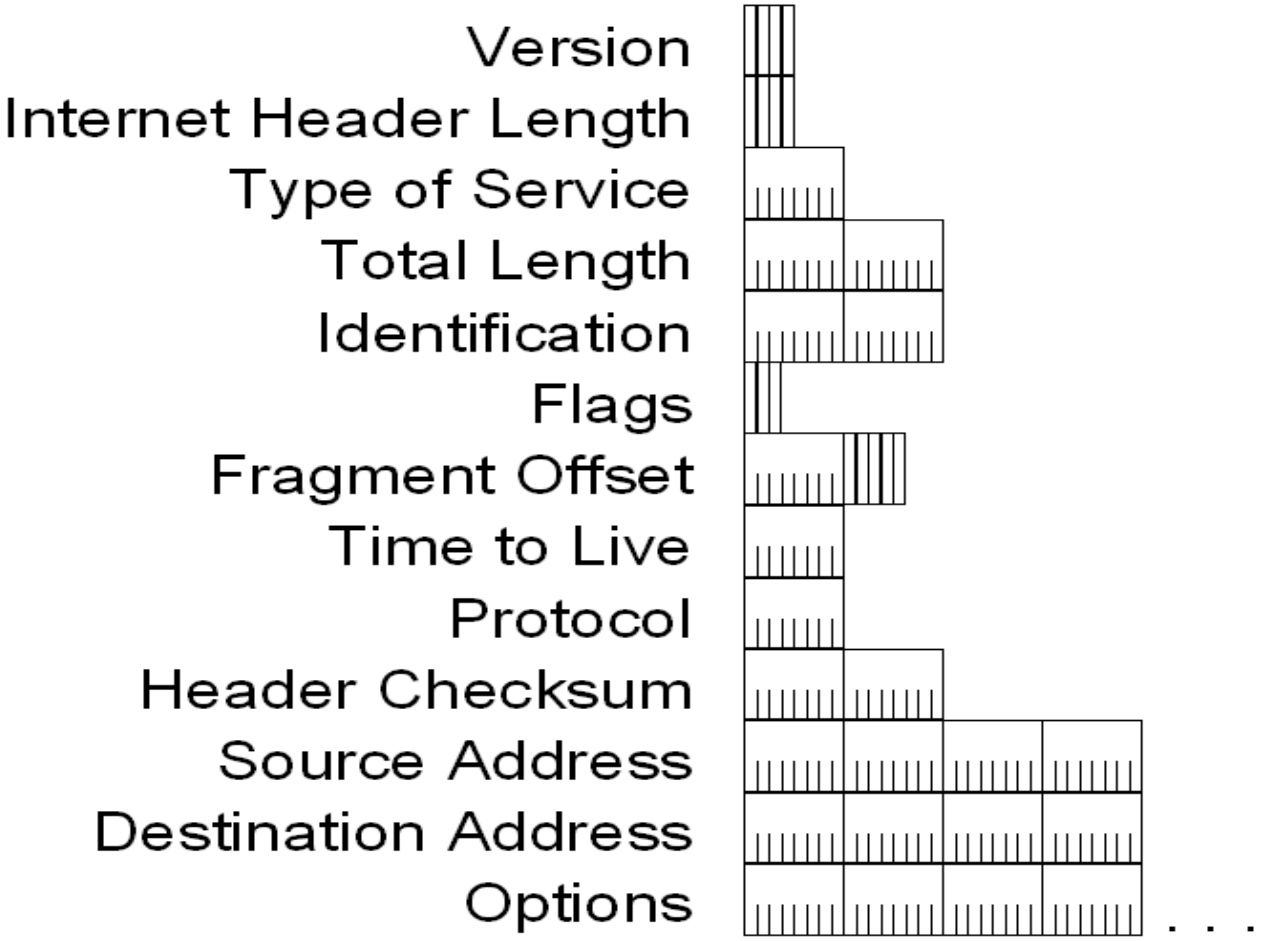
IPv4 Address	IPv6 Address
Address Length – 32 bits	128 bits
Address Representation - decimal	hexadecimal
Internet address classes	Not applicable in IPv6
Multicast addresses (224.0.0.0/4)	IPv6 multicast addresses (FF00::/8)
Broadcast addresses	Not applicable in IPv6
Unspecified address is 0.0.0.0	Unspecified address is ::
Loopback address is 127.0.0.1	Loopback address is ::1
Public IP addresses	Global unicast addresses
Private IP addresses (10.0.0.0/8, 172.16.0.0/12, and 192.168.0.0/16)	Site-local addresses (FEC0::/10)
Autoconfigured addresses (169.254.0.0/16)	Link-local addresses (FE80::/64)

IPv4 Header Structure



- basic IPv4 header contains 12 fields.
- each field of the IPv4 header has a specific use.
- Shaded field are removed in IPv6.

IPv4 Header - Review



IPv4 Header - Review

- **Version (4 bits)**
  - Indicates the version of IP and is set to 4.
- **Internet Header Length (4 bits)**
  - Indicates the number of 4-byte blocks in the IPv4 header.
  - Because an IPv4 header is a minimum of 20 bytes in size, the smallest value of the Internet Header Length (IHL) field is 5.
- **Type of Service (4 bits)**
  - Indicates the desired service expected by this packet for delivery through routers across the IPv4 internetwork.

IPv4 Header - Review

- **Total Length (16 bits)**
  - Indicates the total length of the IPv4 packet (IPv4 header + IPv4 payload) and does not include link layer framing.
- **Identification (16 bits)**
  - Identifies this specific IPv4 packet.
  - The Identification field is selected by the originating source of the IPv4 packet. If the IPv4 packet is fragmented, all of the fragments retain the Identification field value so that the destination node can group the fragments for reassembly.
- **Flags (3 bits)**
  - Identifies flags for the fragmentation process.
  - There are two flags—one to indicate whether the IPv4 packet might be fragmented and another to indicate whether more fragments follow the current fragment.
- **Fragment Offset (13 bits)**
  - Indicates the position of the fragment relative to the original IPv4 payload.

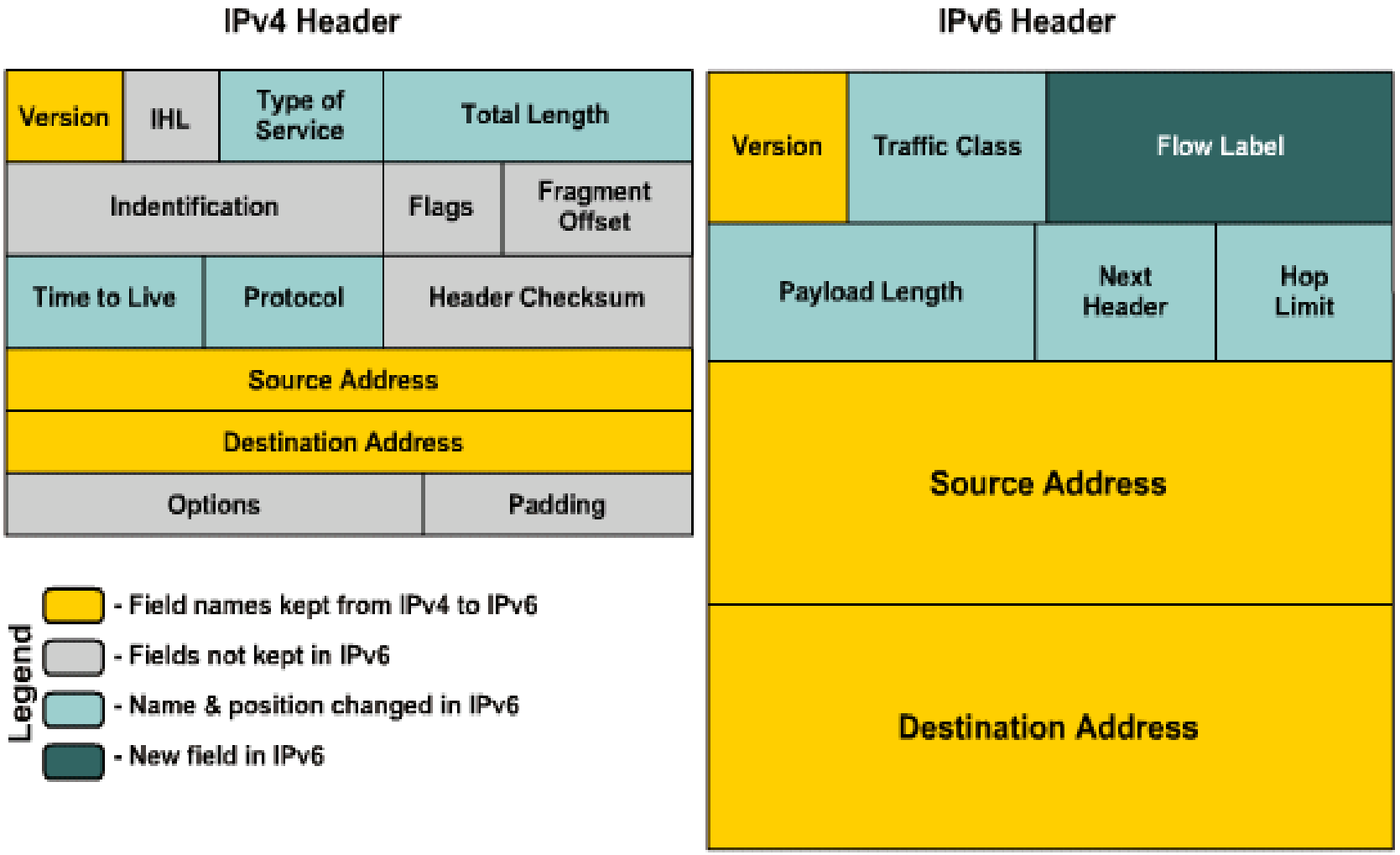
IPv4 Header - Review

- **Time to Live (8 bits)**
  - Indicate the maximum number of links on which an IPv4 packet can travel before being discarded.
  - Originally used as a time count with which an IPv4 router determined the length of time required (in seconds) to forward the IPv4 packet, decrementing the TTL accordingly. When the TTL equals 0,an ICMP Time Expired-TTL Expired in Transit message is sent to the source IPv4 address and the packet is discarded.
- **Protocol (8 bits)**
  - Identifies the upper layer protocol.
  - For example, TCP uses a Protocol of 6, UDP uses a Protocol of 17, and ICMP uses a Protocol of 1.
  - The Protocol field is used to demultiplex an IPv4 packet to the upper layer protocol.

IPv4 Header - Review

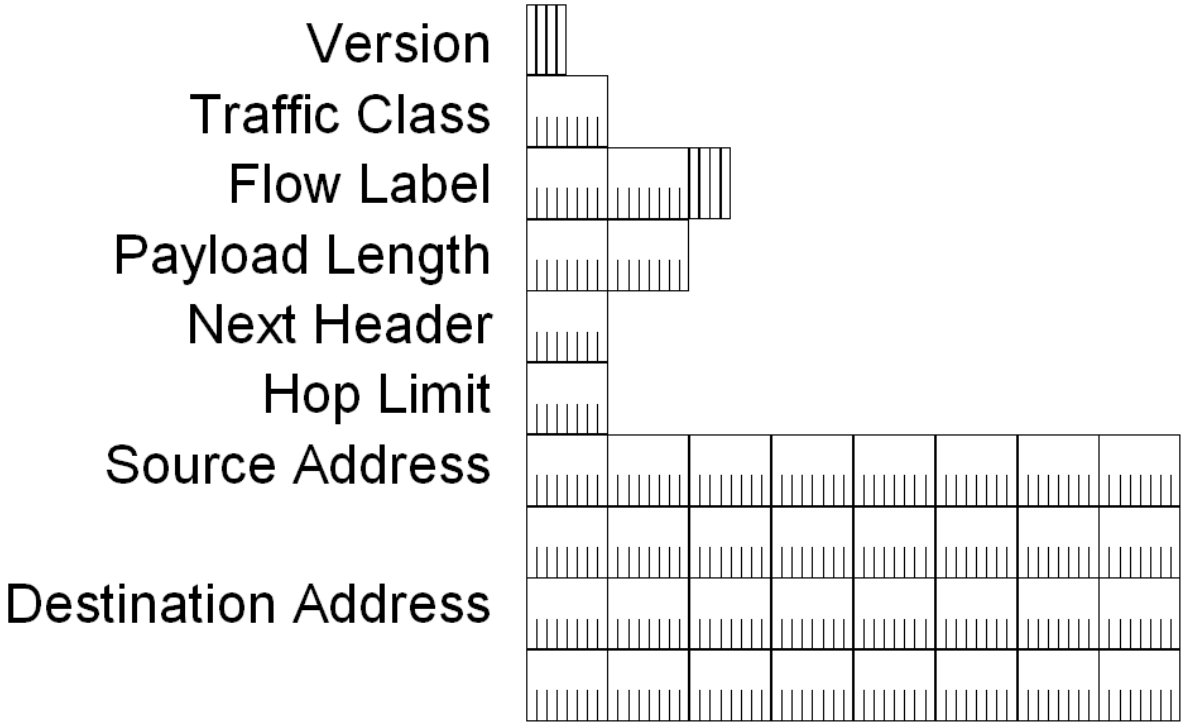
- **Header Checksum (16 Bits)**
  - Provides a checksum on the IPv4 header only.
  - The IPv4 payload is not included in the checksum calculation as the IPv4 payload and usually contains its own checksum..
- **Source Address (32 bits)**
  - Stores the IPv4 address of the originating host.
- **Destination Address (32 bits)**
  - Stores the IPv4 address of the destination host.
- **Options (multiple of 32 bits)**
  - Stores one or more IPv4 options.

IPv4 vs IPv6 Header



IPv6 Packet Format

IPv6 Header



IPv6 Packet Format

IPv6 Header Fields

- Based on these rules, RFC 2460 defines the following IPv6 header fields:

1. **Version (4 bits)**
   - 4 bits are used to indicate the version of IP and is set to 6

- **Traffic Class (8 bits)**
   - same function as the Type of Service field in the IPv4 header.

1. **Flow Label (20 bits)**
   - identifies a flow and it is intended to enable the router to identify packets that should be treated in a similar way without the need for deep lookups within those packets.
   - set by the source and should not be changed by routers along the path to destination.

IPv6 Header Fields

4. **Payload Length (16 bits)**
   - With the header length fixed at 40 bytes, it is enough to indicate the length of the payload to determine the length of the entire packet.

5. **Next Header (8 bits)**
   - Indicates either the first extension header (if present) or the protocol in the upper layer PDU (such as TCP, UDP, or ICMPv6).

6. **Hop Limit (8 bits)**
   - In IPv6, the IPv4 TTL was appropriately renamed Hop Limit because it is a variable that is decremented at each hop, and it does not have a temporal dimension.

IPv6 Header Fields

7. **Source IPv6 Address (128 bits)**
   - Stores the IPv6 address of the originating host.
8. **Destination IPv6 Address (128 bits)**
   - Stores the IPv6 address of the current destination host.

Values of the Next Header Field

Value (in decimal)	Header
0	Hop-by-Hop Options Header
6	TCP
17	UDP
41	Encapsulated IPv6 Header
43	Routing Header
44	Fragment Header
46	Resource ReSerVation Protocol
50	Encapsulating Security Payload
51	Authentication Header
58	ICMPv6
59	No next header
60	Destination Options Header