Chapter Outline

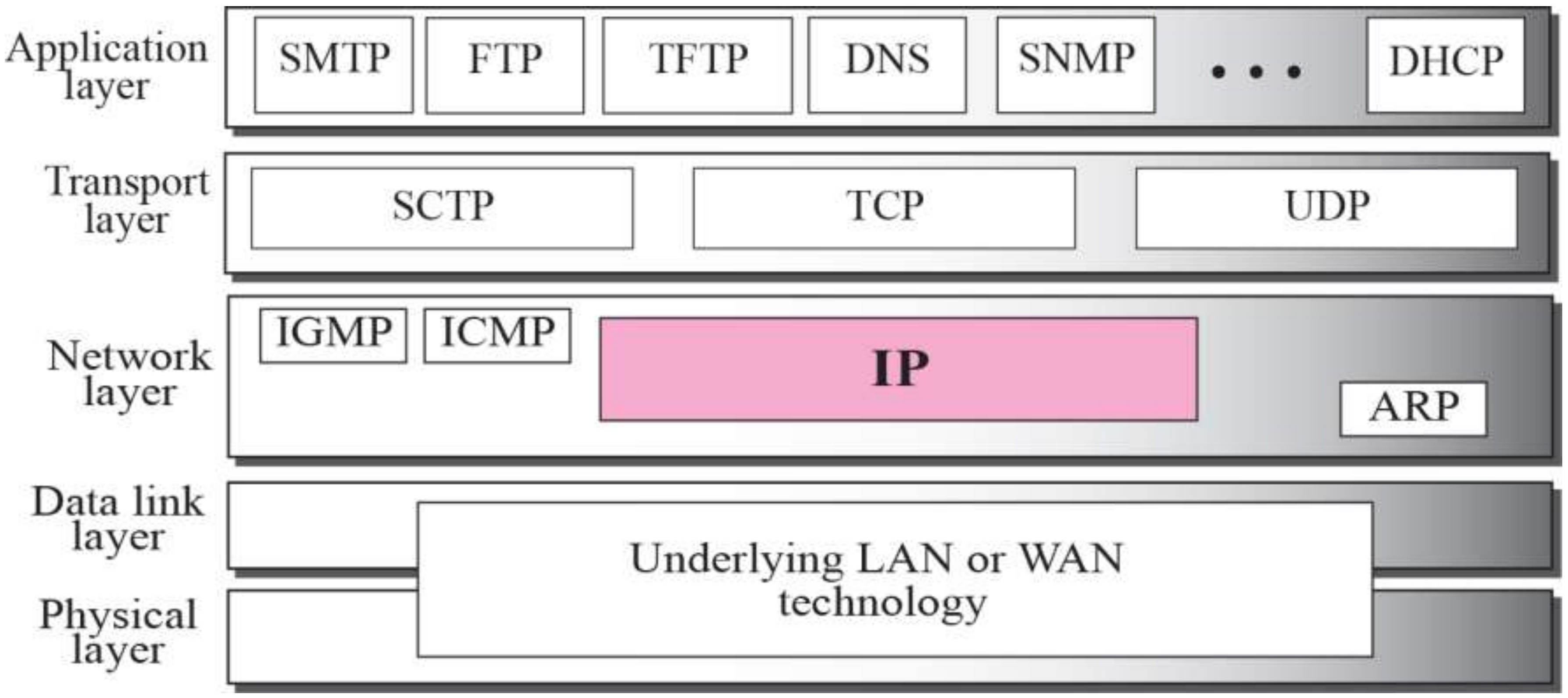
7-1 INTRODUCTION

The Internet Protocol (IP) is the transmission mechanism used by the TCP/IP protocols at the network layer.

Topics Discussed in the Section

- ✓**Relationship of IP to the rest of the TCP/IP Suite**

Figure 7.1 *Position of IP in TCP/IP protocol suite*



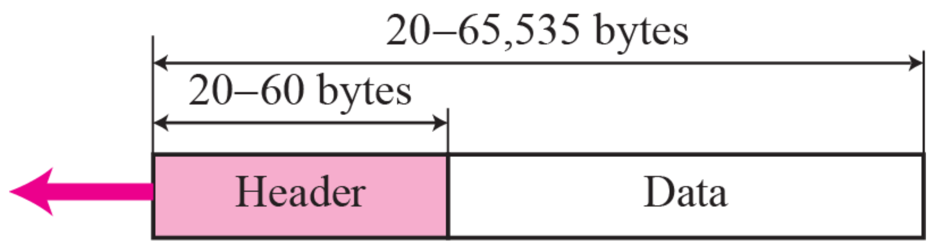
7-2 DATAGRAMS

Packets in the network (internet) layer are called *datagrams*. A datagram is a variable-length packet consisting of two parts: header and data. The header is 20 to 60 bytes in length and contains information essential to routing and delivery. It is customary in TCP/IP to show the header in 4-byte sections. A brief description of each field is in order.

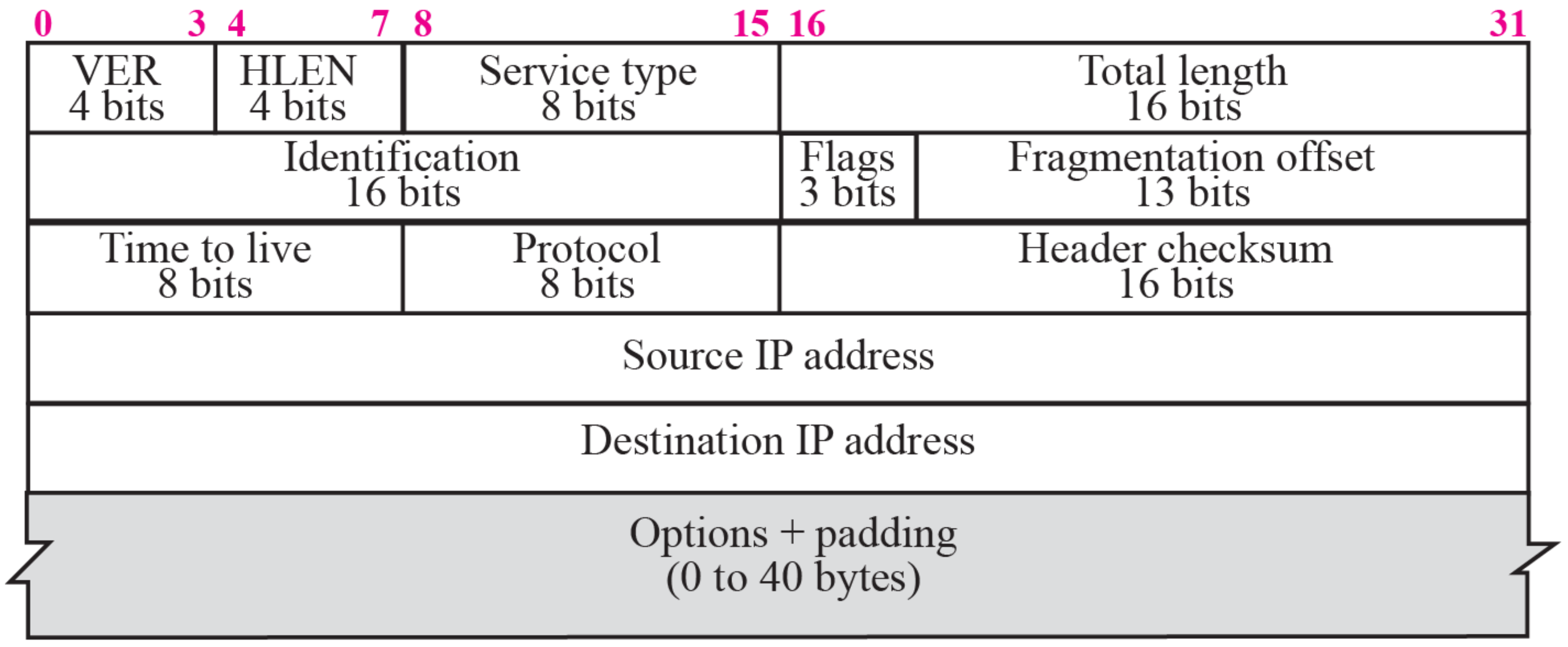
Topics Discussed in the Section

- ✓ Format of the datagram packet
- ✓ Some examples

Figure 7.2 *IP datagram*



a. IP datagram



b. Header format

Figure 7.3 *Service type*

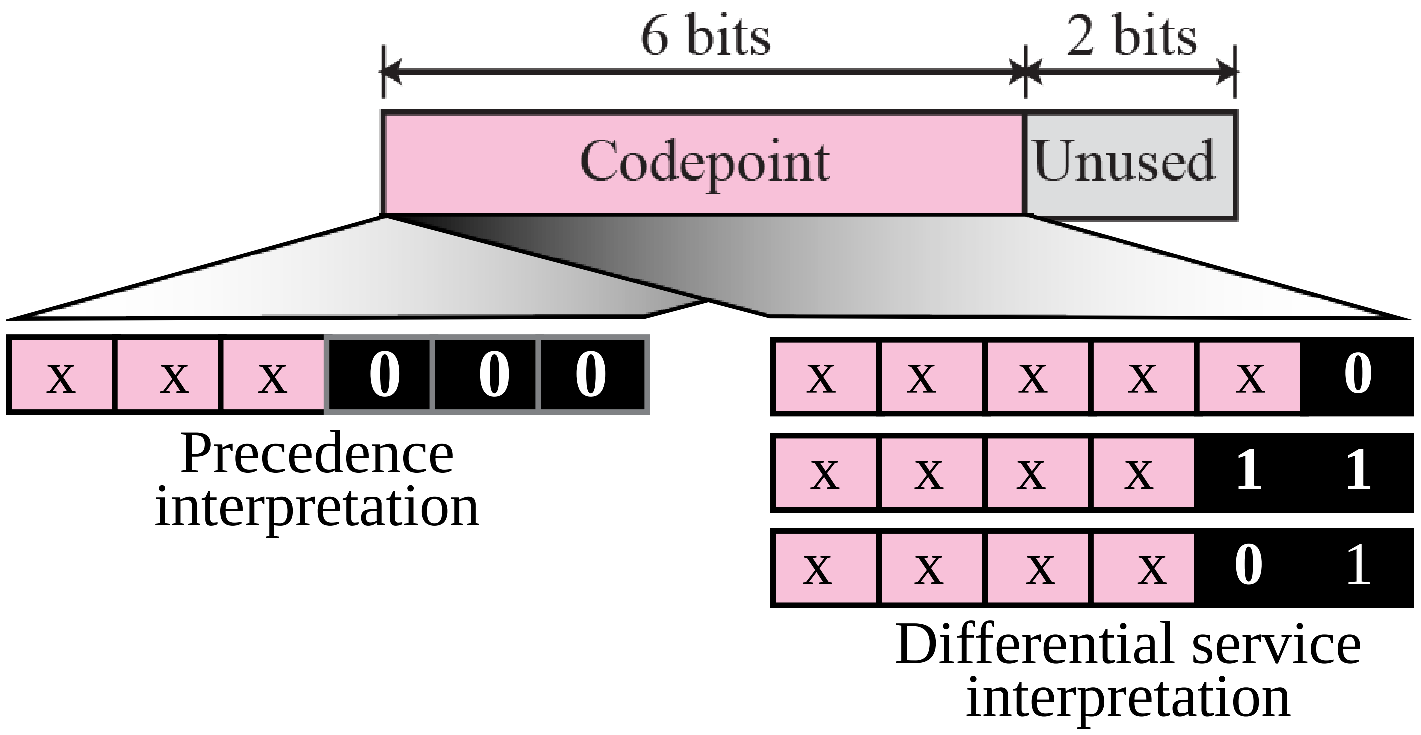


Table 7.1 *Values for codepoints*

Category	*Codepoint*	*Assigning Authority*
1	XXXXX0	Internet
2	XXXX11	Local
3	XXXX01	Temporary or experimental

Note

The total length field defines the total length of the datagram including the header.

Figure 7.4 *Encapsulation of a small datagram in an Ethernet frame*

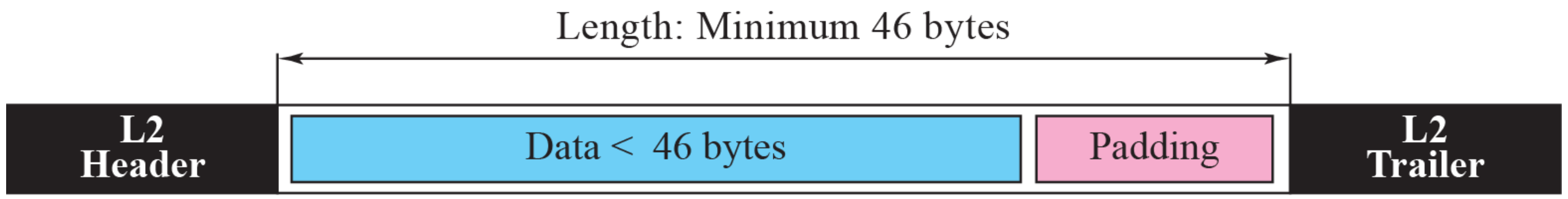


Figure 7.5 *Multiplexing*

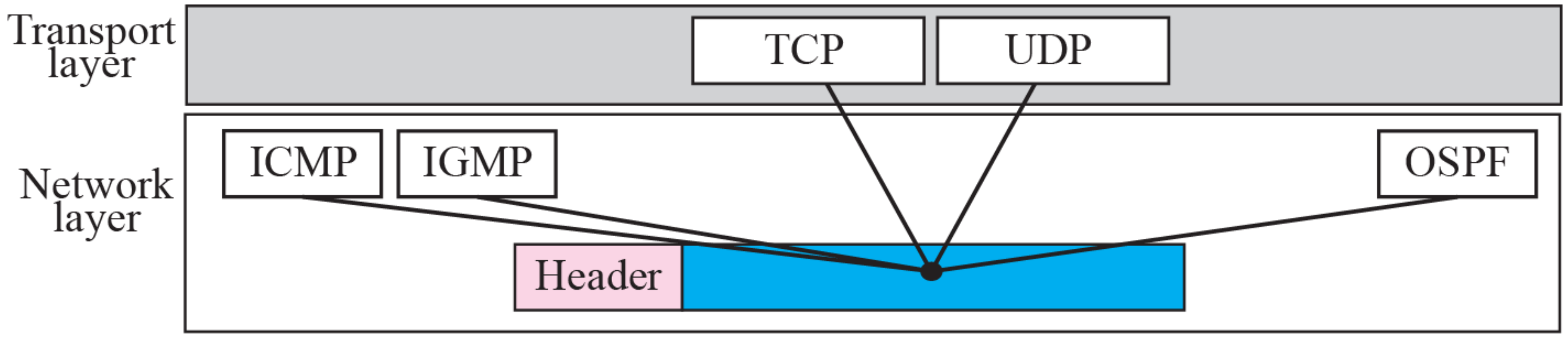


Table 7.2 *Protocols*

Value	*Protocol*	*Value*	*Protocol*
1	ICMP	17	UDP
2	IGMP	89	OSPF
6	TCP		

Example 7.1

An IP packet has arrived with the first 8 bits as shown:

01000010

The receiver discards the packet. Why?

Solution

There is an error in this packet. The 4 left-most bits (0100) show the version, which is correct. The next 4 bits (0010) show the wrong header length ($2 \times 4 = 8$). The minimum number of bytes in the header must be 20. The packet has been corrupted in transmission.

Example 7.2

In an IP packet, the value of HLEN is 1000 in binary. How many bytes of options are being carried by this packet?

Solution

The HLEN value is 8, which means the total number of bytes in the header is 8 × 4 or 32 bytes. The first 20 bytes are the base header, the next 12 bytes are the options.

Example 7.3

In an IP packet, the value of HLEN is 5_{16} and the value of the total length field is 0028_{16}. How many bytes of data are being carried by this packet?

Solution

The HLEN value is 5, which means the total number of bytes in the header is 5×4 or 20 bytes (no options). The total length is 40 bytes, which means the packet is carrying 20 bytes of data (40 − 20).

Example 7.4

An IP packet has arrived with the first few hexadecimal digits as shown below:

```
45000028000100000102 . . .
```

How many hops can this packet travel before being dropped? The data belong to what upper layer protocol?

Solution

To find the time-to-live field, we skip 8 bytes (16 hexadecimal digits). The time-to-live field is the ninth byte, which is 01. This means the packet can travel only one hop. The protocol field is the next byte (02), which means that the upper layer protocol is IGMP (see Table 7.2)

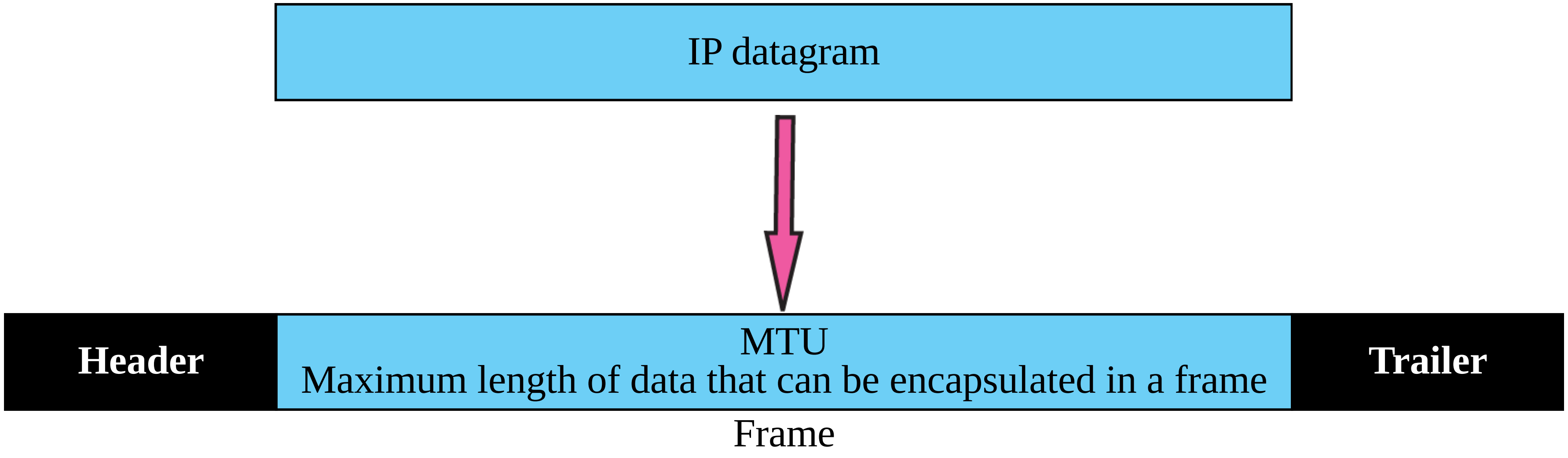
7-3 FRAGMENTATION

A datagram can travel through different networks. Each router decapsulates the IP datagram from the frame it receives, processes it, and then encapsulates it in another frame. The format and size of the received frame depend on the protocol used by the physical network through which the frame has just traveled. The format and size of the sent frame depend on the protocol used by the physical network through which the frame is going to travel.

Topics Discussed in the Section

- ✓ Maximum Transfer Unit (MTU)
- ✓ Fields Related to Fragmentation

Figure 7.6 *MTU*



Note

Only data in a datagram is fragmented.

Figure 7.7 *Flags field*

D: Do not fragment
M: More fragments

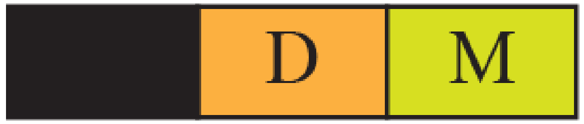


Figure 7.8 *Fragmentation example*

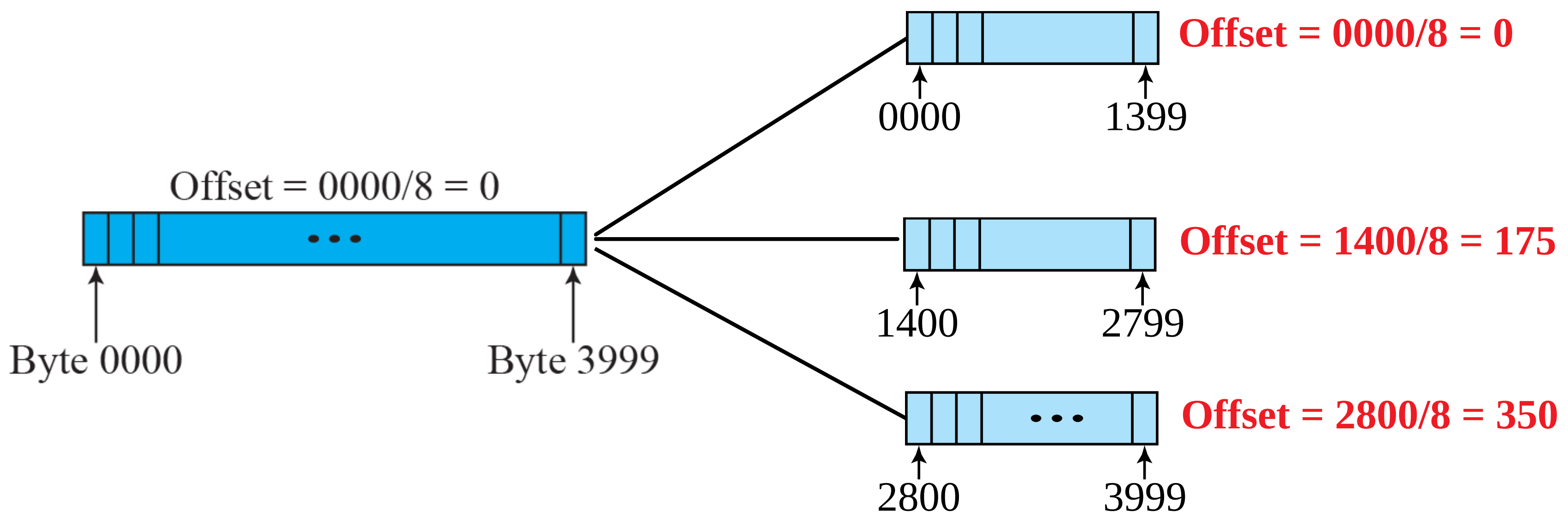
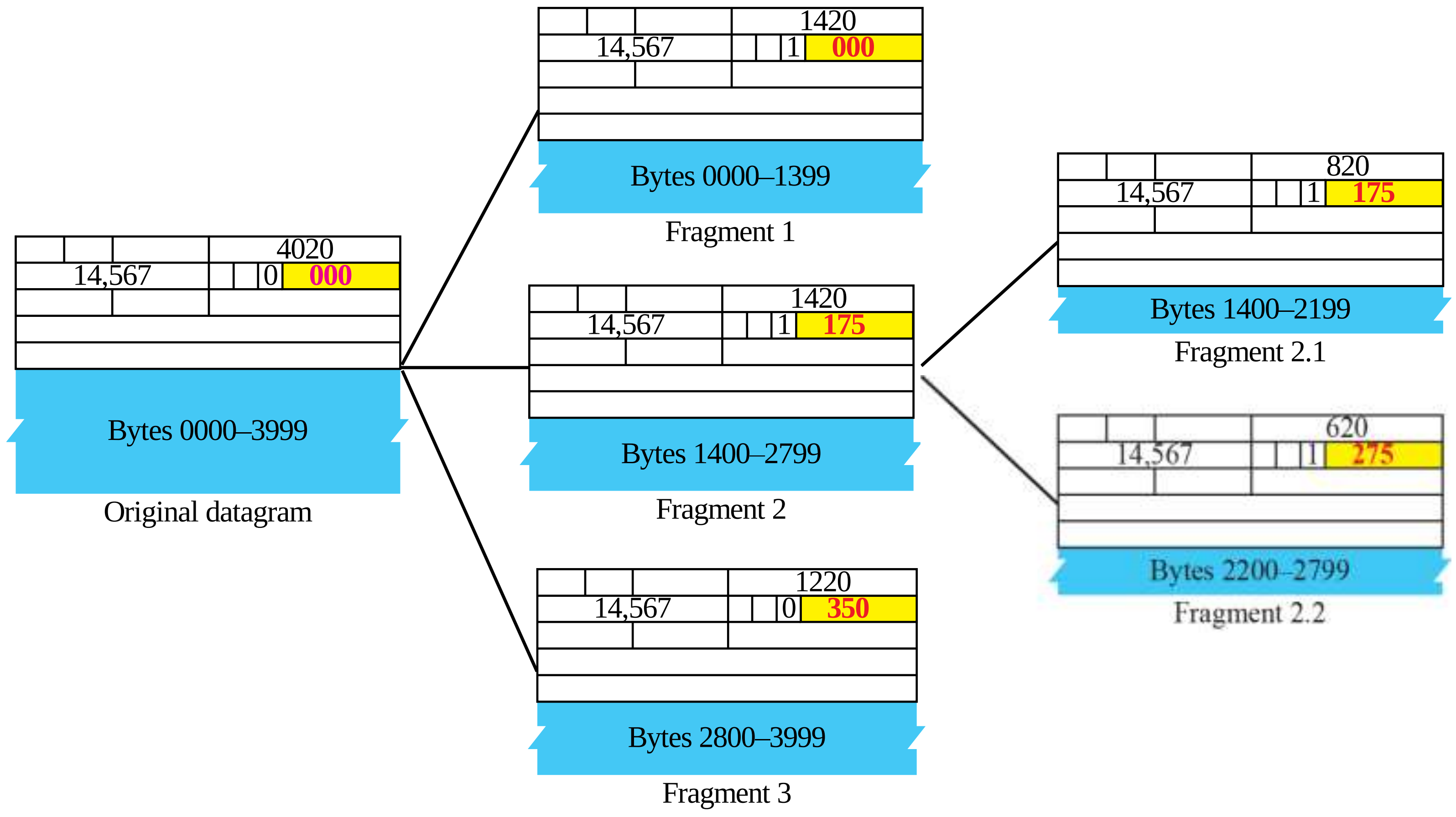


Figure 7.9 *Detailed fragmentation example*



Example 7.5

A packet has arrived with an M bit value of 0. Is this the first fragment, the last fragment, or a middle fragment? Do we know if the packet was fragmented?

Solution

If the M bit is 0, it means that there are no more fragments; the fragment is the last one. However, we cannot say if the original packet was fragmented or not. A nonfragmented packet is considered the last fragment.

Example 7.6

A packet has arrived with an M bit value of 1. Is this the first fragment, the last fragment, or a middle fragment? Do we know if the packet was fragmented?

Solution

If the M bit is 1, it means that there is at least one more fragment. This fragment can be the first one or a middle one, but not the last one. We don’t know if it is the first one or a middle one; we need more information (the value of the fragmentation offset). See also the next example.

Example 7.7

A packet has arrived with an M bit value of 1 and a fragmentation offset value of zero. Is this the first fragment, the last fragment, or a middle fragment?

Solution

Because the M bit is 1, it is either the first fragment or a middle one. Because the offset value is 0, it is the first fragment.

Example 7.8

A packet has arrived in which the offset value is 100. What is the number of the first byte? Do we know the number of the last byte?

Solution

To find the number of the first byte, we multiply the offset value by 8. This means that the first byte number is 800. We cannot determine the number of the last byte unless we know the length of the data.

Example 7.9

A packet has arrived in which the offset value is 100, the value of HLEN is 5 and the value of the total length field is 100. What is the number of the first byte and the last byte?

Solution

The first byte number is 100 × 8 = 800. The total length is 100 bytes and the header length is 20 bytes (5 × 4), which means that there are 80 bytes in this datagram. If the first byte number is 800, the last byte number must be 879.

7-4 OPTIONS

The header of the IP datagram is made of two parts: a fixed part and a variable part. The fixed part is 20 bytes long and was discussed in the previous section. The variable part comprises the options, which can be a maximum of 40 bytes.

Options, as the name implies, are not required for a datagram. They can be used for network testing and debugging. Although options are not a required part of the IP header, option processing is required of the IP software.

Topics Discussed in the Section

- ✓ **Format**
- ✓ **Option Types**

Figure 7.10 *Option format*

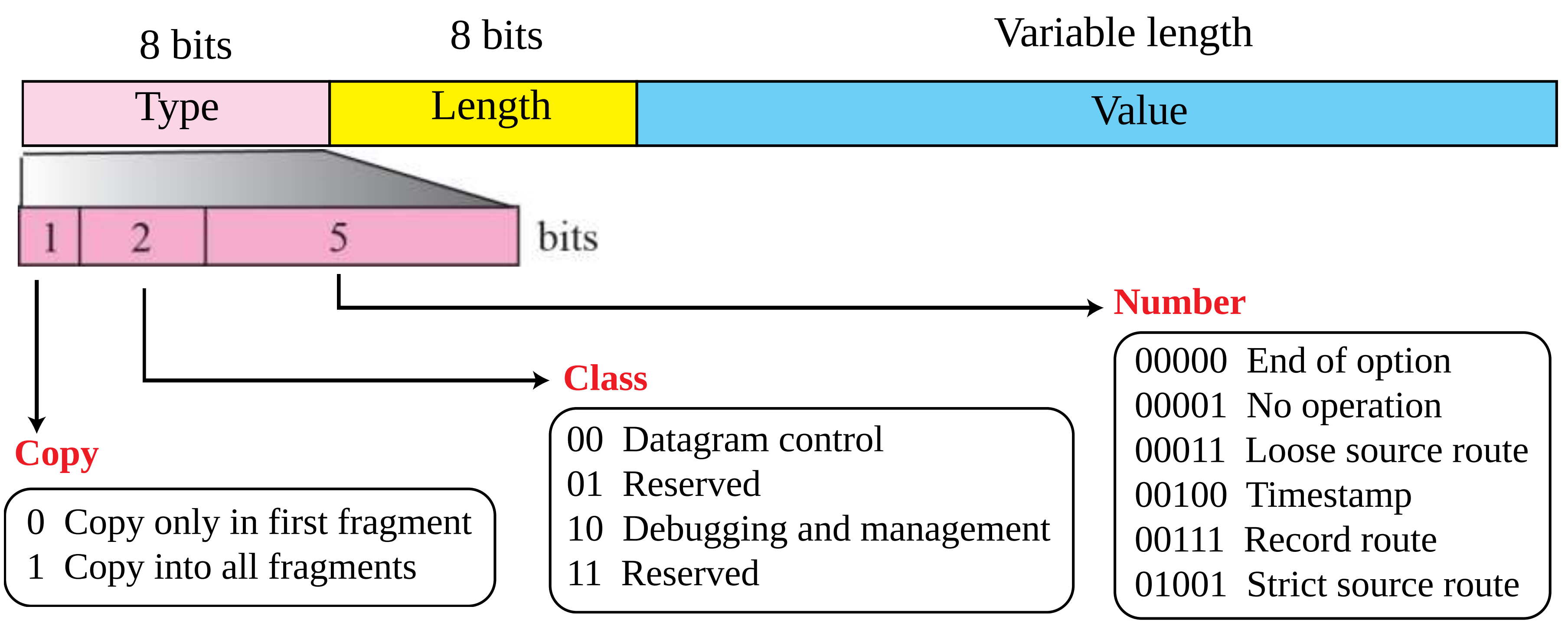


Figure 7.11 *Categories of options*

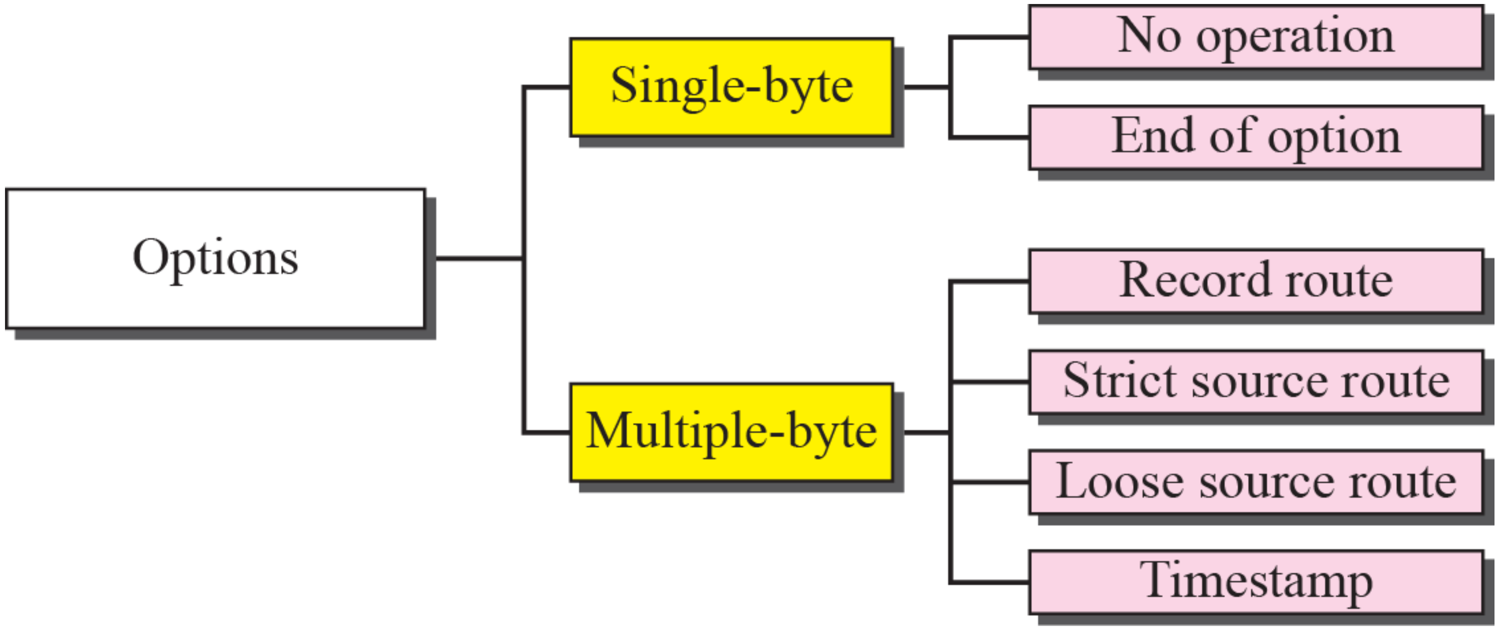
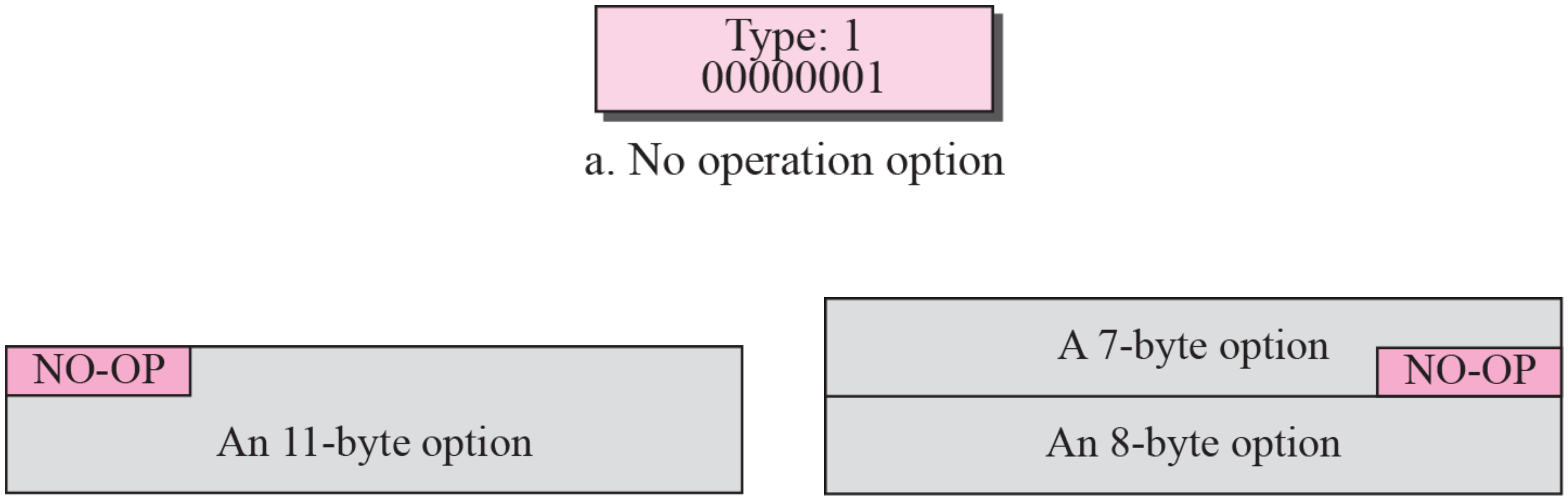


Figure 7.12 *No operation option*

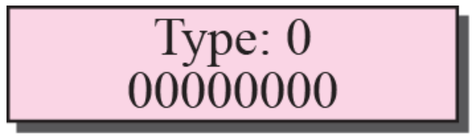


a. No operation option

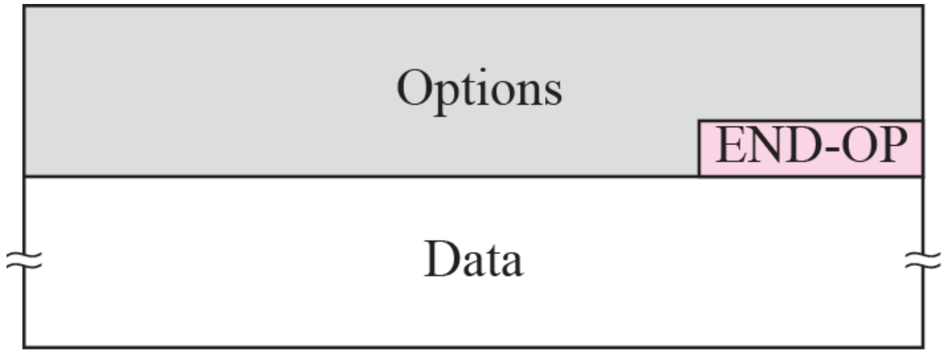
b. Used to align beginning of an option

c. Used to align the next option

Figure 7.13 *Endo-of-option option*



a. End of option



b. Used for padding

Figure 7.14 *Record-route option*

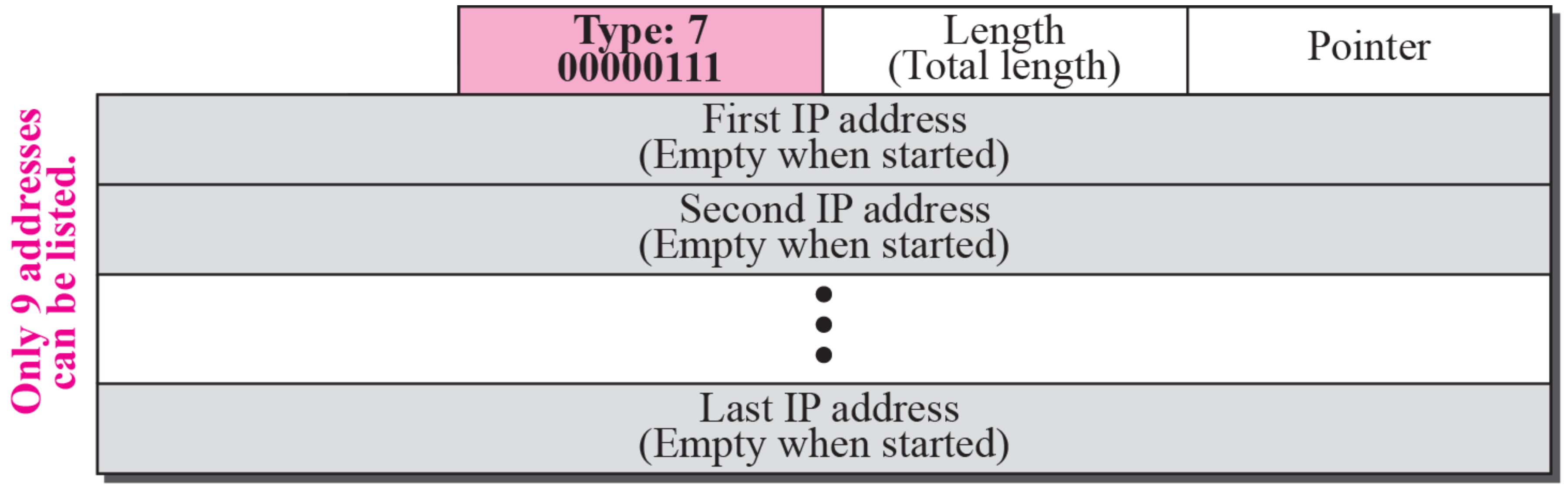


Figure 7.15 *Record-route concept*

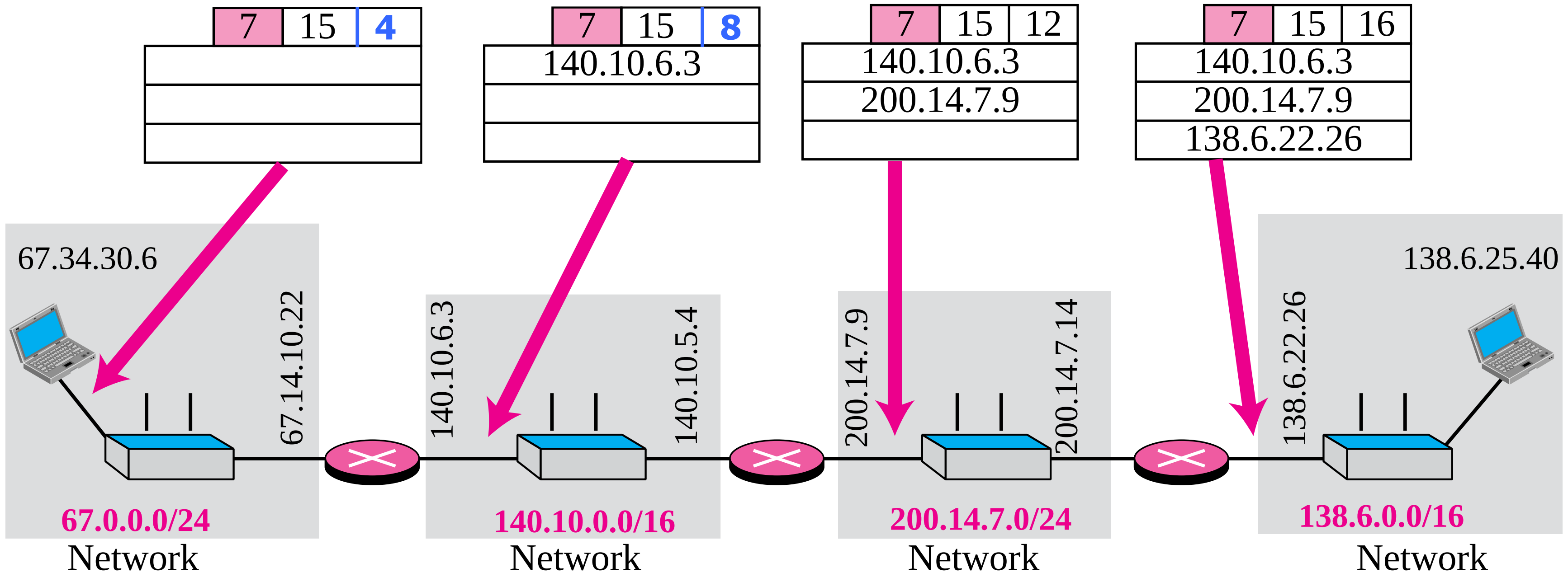


Figure 7.16 *Strict-source-route option*

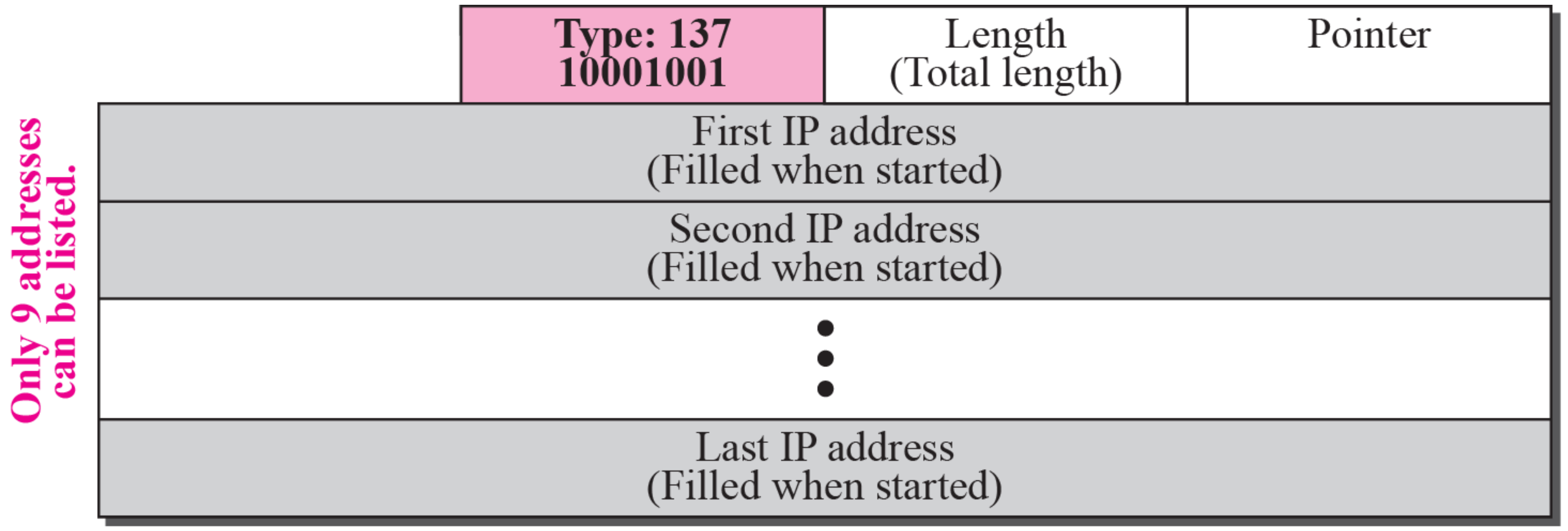


Figure 7.17 *Strict-source-route option*

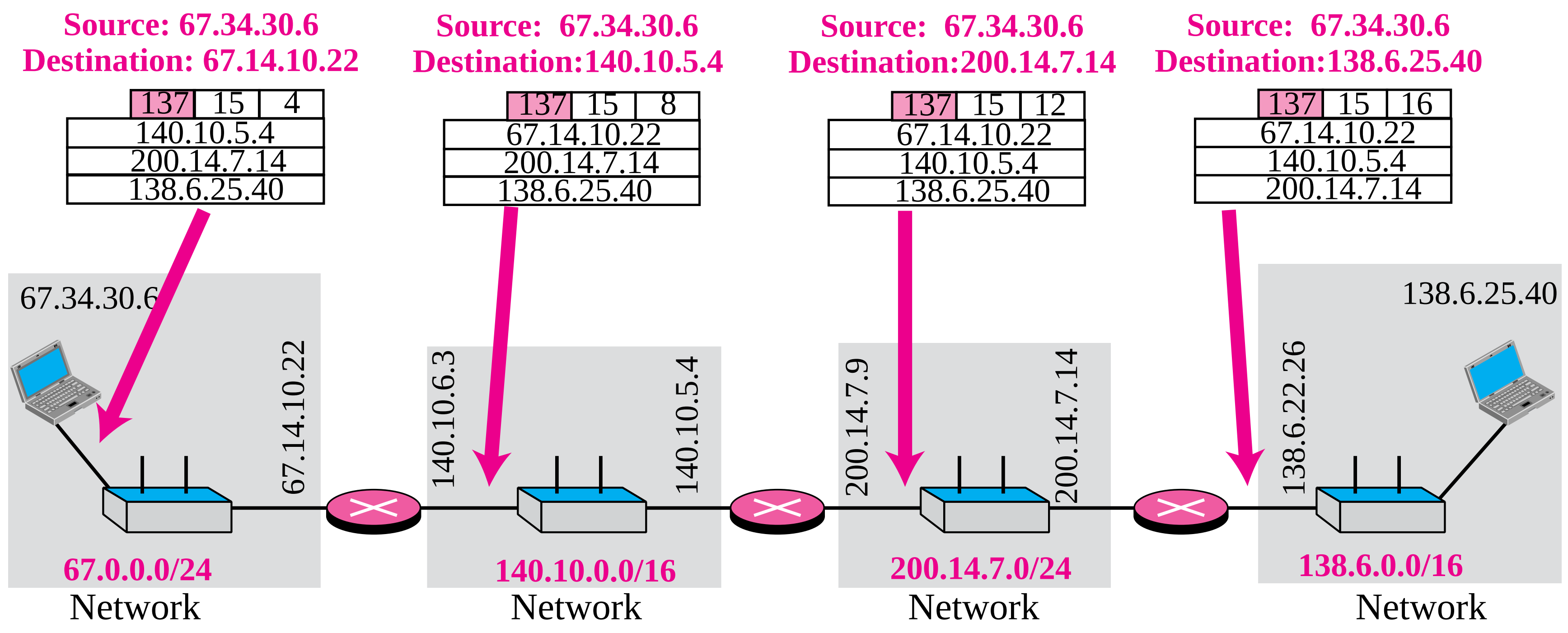


Figure 7.18 *Loose-source-route option*

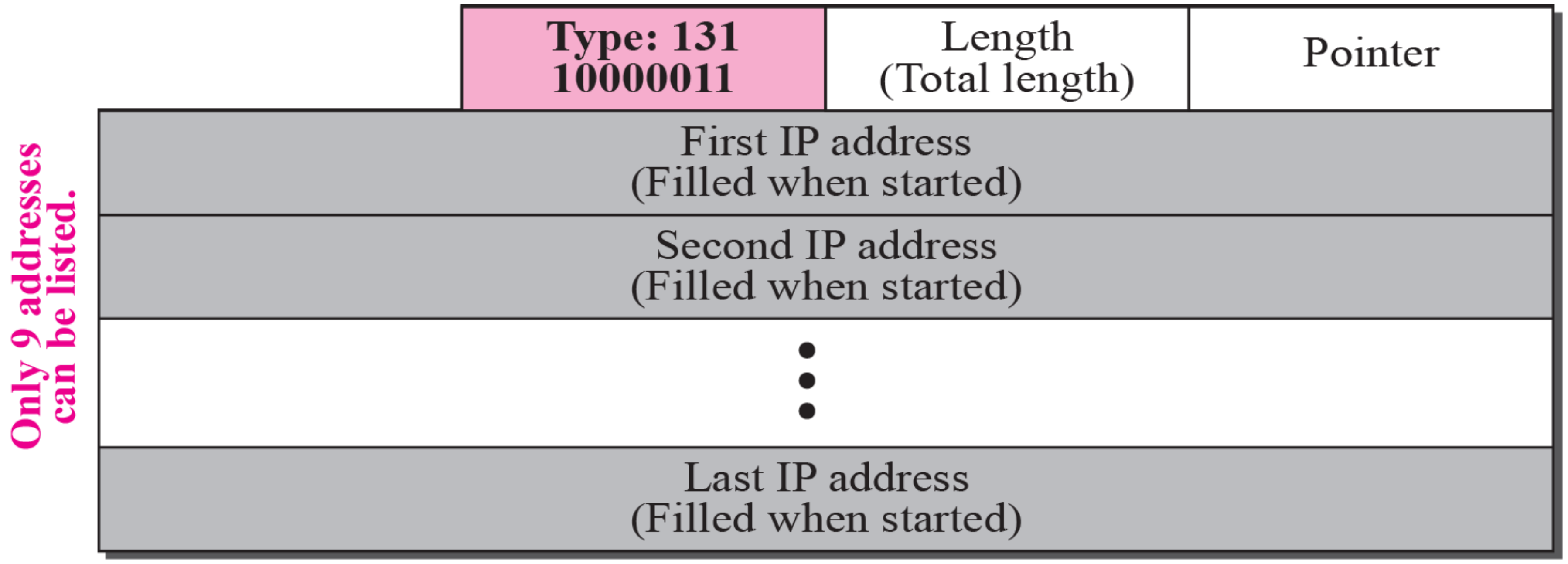


Figure 7.19 *Time-stamp option*

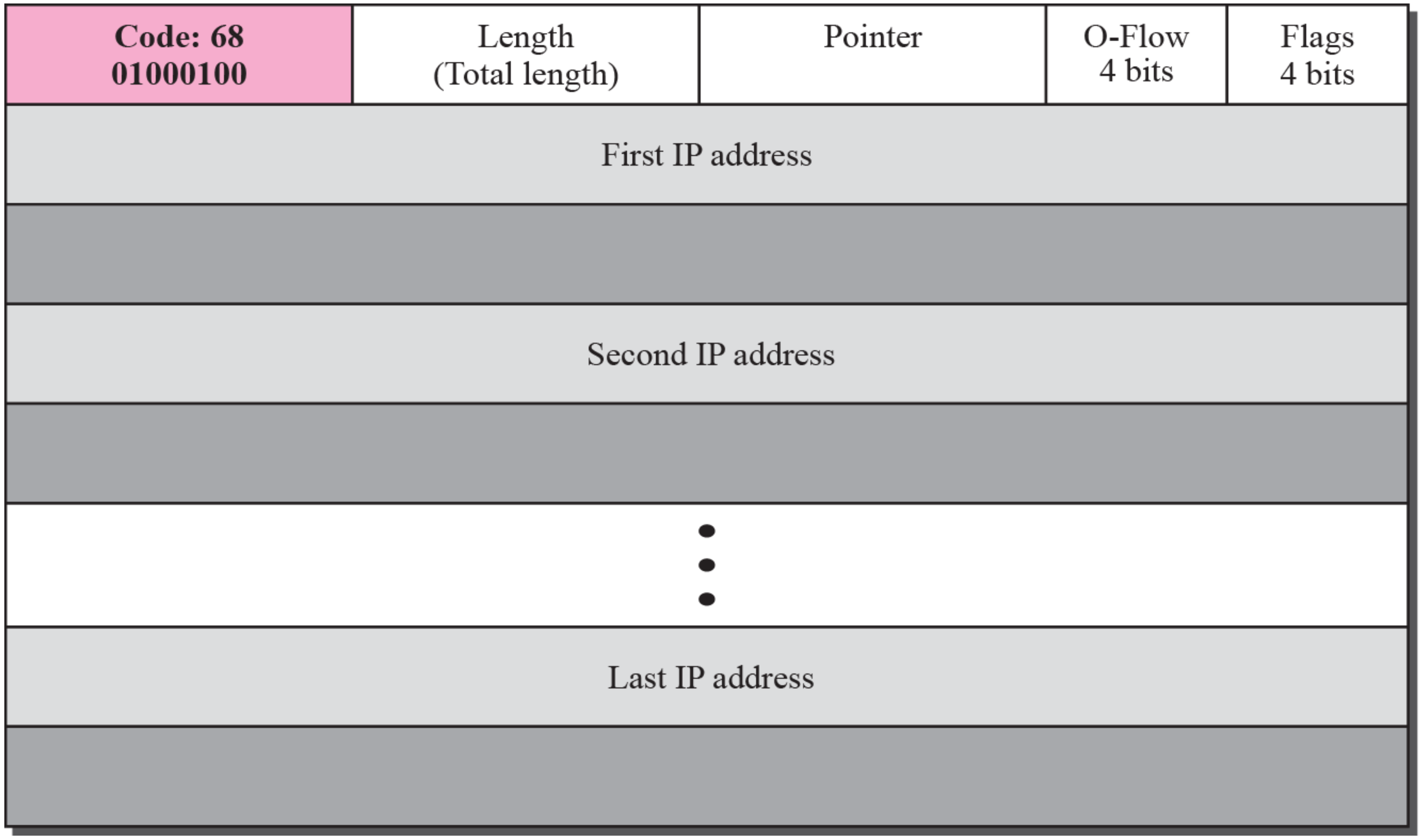


Figure 7.20 *Use of flags in timestamp*

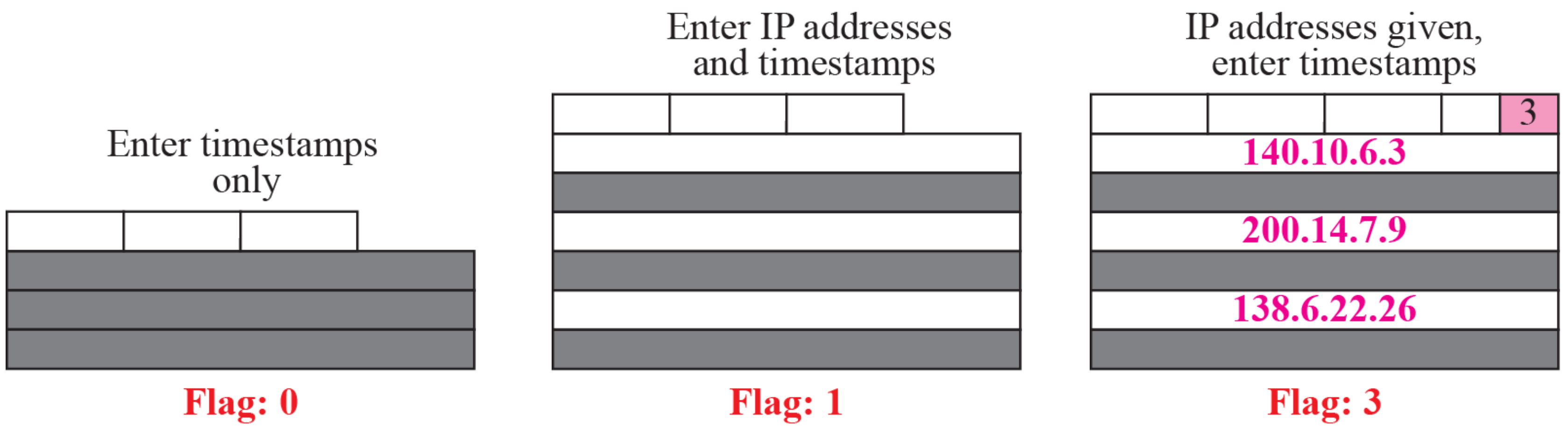
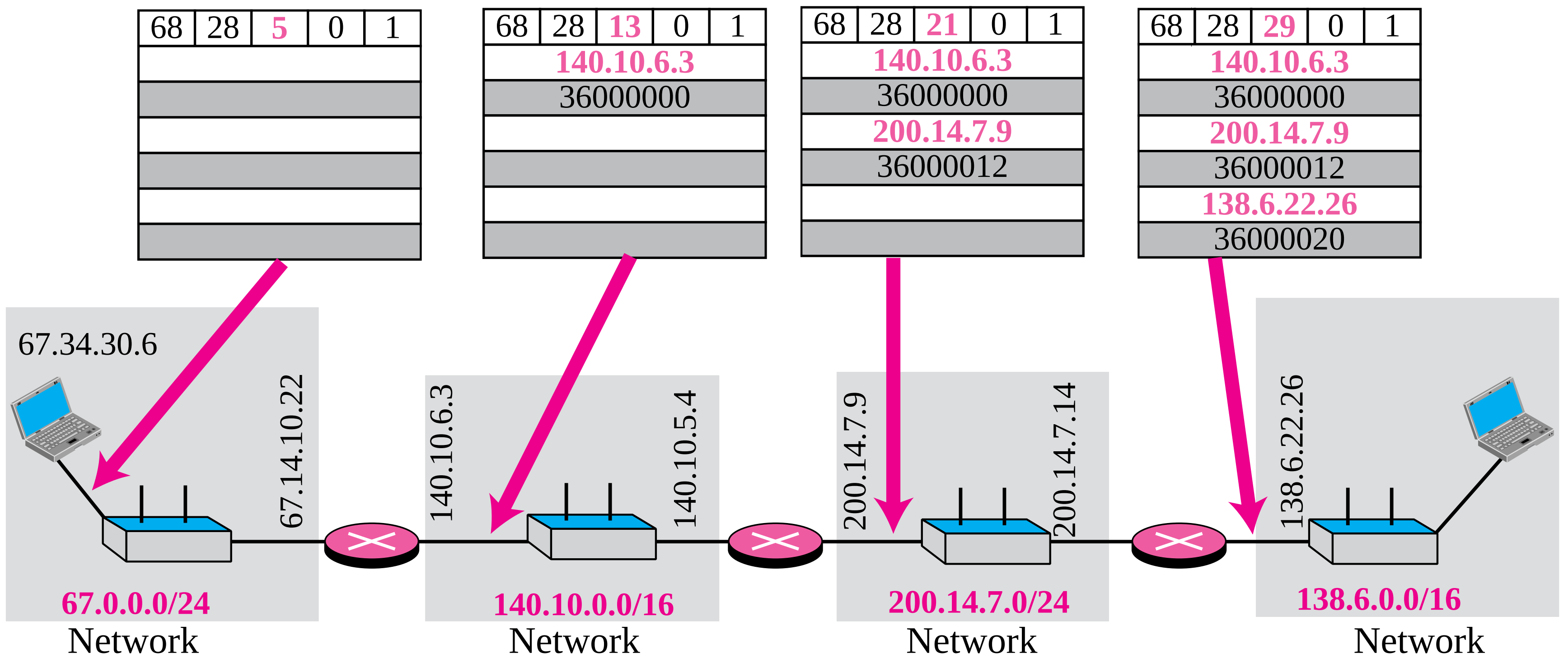


Figure 7.21 *Timestamp concept*



Example 7.10

Which of the six options must be copied to each fragment?

Solution

We look at the first (left-most) bit of the type for each option.

a. No operation: type is 00000001; not copied.
b. End of option: type is 00000000; not copied.
c. Record route: type is 00000111; not copied.
d. Strict source route: type is 10001001; copied.
e. Loose source route: type is 10000011; copied.
f. Timestamp: type is 01000100; not copied.

Example 7.11

Which of the six options are used for datagram control and which for debugging and managements?

Solution

We look at the second and third (left-most) bits of the type.

a. No operation: type is 00000001; datagram control.

b. End of option: type is 00000000; datagram control.

c. Record route: type is 00000111; datagram control.

d. Strict source route: type is 10001001; datagram control.

e. Loose source route: type is 10000011; datagram control.

f. Timestamp: type is 01000100; debugging and management control.

Example 7.12

One of the utilities available in UNIX to check the traveling of the IP packets is ping. In the next chapter, we talk about the ping program in more detail. In this example, we want to show how to use the program to see if a host is available. We ping a server at De Anza College named fhda.edu. The result shows that the IP address of the host is 153.18.8.1. The result also shows the number of bytes used.

```
$  ping fhda.edu
PING fhda.edu (153.18.8.1) 56(84) bytes of data.
64 bytes from tiptoe.fhda.edu (153.18.8.1): icmp_seq =
0 ttl=62 time=1.87 ms
...
```

Example 7.13

We can also use the ping utility with the −R option to implement the record route option. The result shows the interfaces and IP addresses.

```
$ ping -R fhda.edu
PING fhda.edu (153.18.8.1) 56(124) bytes of data.
64 bytes from tiptoe.fhda.edu
(153.18.8.1): icmp_seq=0 ttl=62 time=2.70 ms
RR:   voyager.deanza.fhda.edu (153.18.17.11)
      Dcore_G0_3-69.fhda.edu (153.18.251.3)
      Dbackup_V13.fhda.edu (153.18.191.249)
      tiptoe.fhda.edu (153.18.8.1)
      Dbackup_V62.fhda.edu (153.18.251.34)
      Dcore_G0_1-6.fhda.edu (153.18.31.254)
      voyager.deanza.fhda.edu (153.18.17.11)
```

Example 7.14

The traceroute utility can also be used to keep track of the route of a packet. The result shows the three routers visited.

```
$ traceroute fhda.edu
traceroute to fhda.edu (153.18.8.1), 30 hops max, 38 byte packets
 1 Dcore_G0_1-6.fhda.edu (153.18.31.254)  0.972 ms  0.902 ms
   0.881 ms
 2 Dbackup_V69.fhda.edu (153.18.251.4)  2.113 ms  1.996 ms
   2.059 ms
 3 tiptoe.fhda.edu (153.18.8.1)  1.791 ms  1.741 ms  1.751 ms
```

Example 7.15

The traceroute program can be used to implement loose source routing. The –g option allows us to define the routers to be visited, from the source to destination. The following shows how we can send a packet to the fhda.edu server with the requirement that the packet visit the router 153.18.251.4.

```
$ traceroute -g  153.18.251.4 fhda.edu.
traceroute to fhda.edu (153.18.8.1), 30 hops max, 46 byte packets
 1   Dcore_G0_1-6.fhda.edu (153.18.31.254)   0.976 ms   0.906 ms
     0.889 ms
 2   Dbackup_V69.fhda.edu (153.18.251.4)   2.168 ms   2.148 ms
     2.037 ms
```

Example 7.16

The traceroute program can also be used to implement strict source routing. The –G option forces the packet to visit the routers defined in the command line. The following shows how we can send a packet to the fhda.edu server and force the packet to visit only the router 153.18.251.4.

```
$ traceroute -G  153.18.251.4 fhda.edu.
traceroute to fhda.edu (153.18.8.1), 30 hops max, 46 byte packets
  1  Dbackup_V69.fhda.edu (153.18.251.4)  2.168 ms  2.148 ms
     2.037 ms
```

7-5 CHECKSUM

The error detection method used by most TCP/IP protocols is called the checksum. The checksum protects against the corruption that may occur during the transmission of a packet. It is redundant information added to the packet. The checksum is calculated at the sender and the value obtained is sent with the packet. The receiver repeats the same calculation on the whole packet including the checksum. If the result is satisfactory (see below), the packet is accepted; otherwise, it is rejected.

Topics Discussed in the Section

- ✓ Checksum Calculation at the Sender
- ✓ Checksum Calculation at the Receiver
- ✓ Checksum in the Packet

Figure 7.22 *Checksum concept*

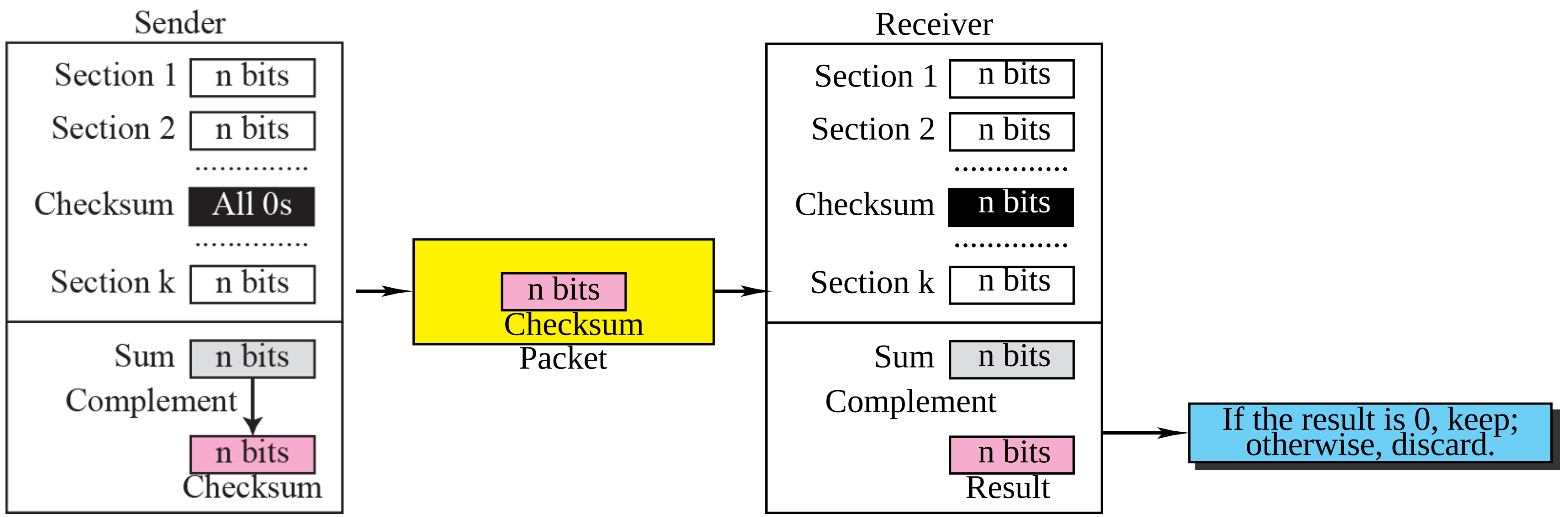
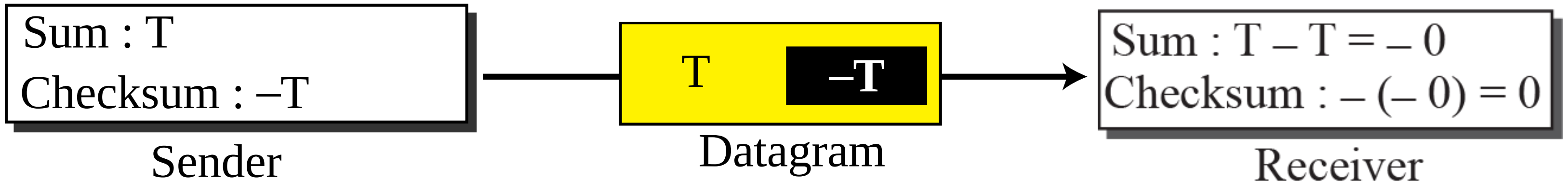


Figure 7.23 *Checksum in one's complement arithmetic*



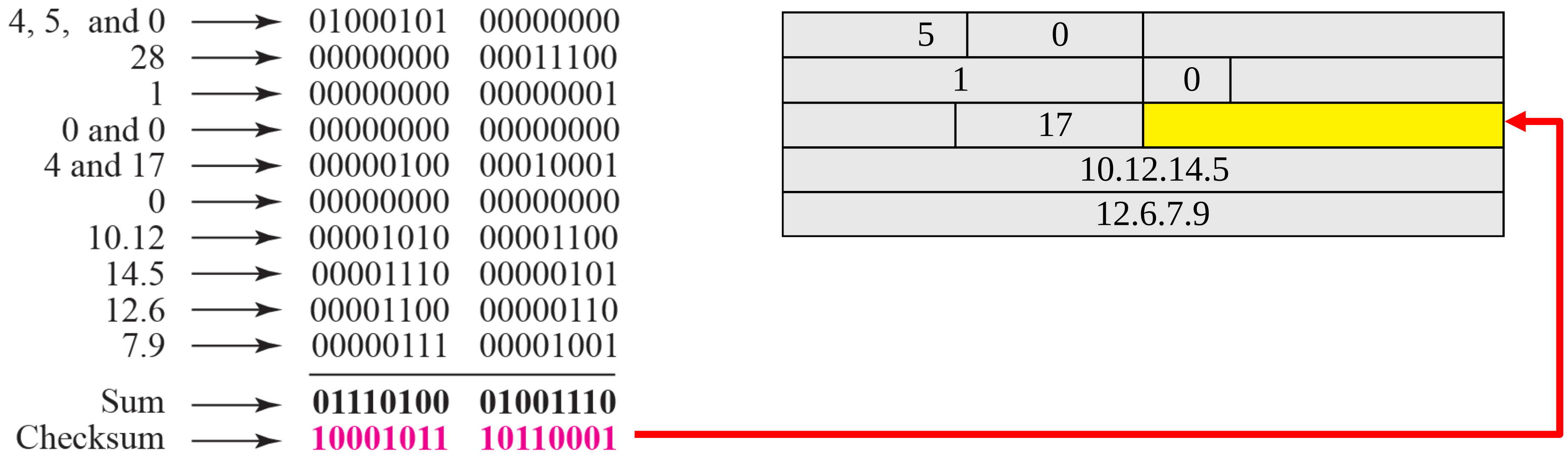
Note

Checksum in IP covers only the header, not the data.

Example 7.17

Figure 7.24 shows an example of a checksum calculation at the sender site for an IP header without options. The header is divided into 16-bit sections. All the sections are added and the sum is complemented. The result is inserted in the checksum field.

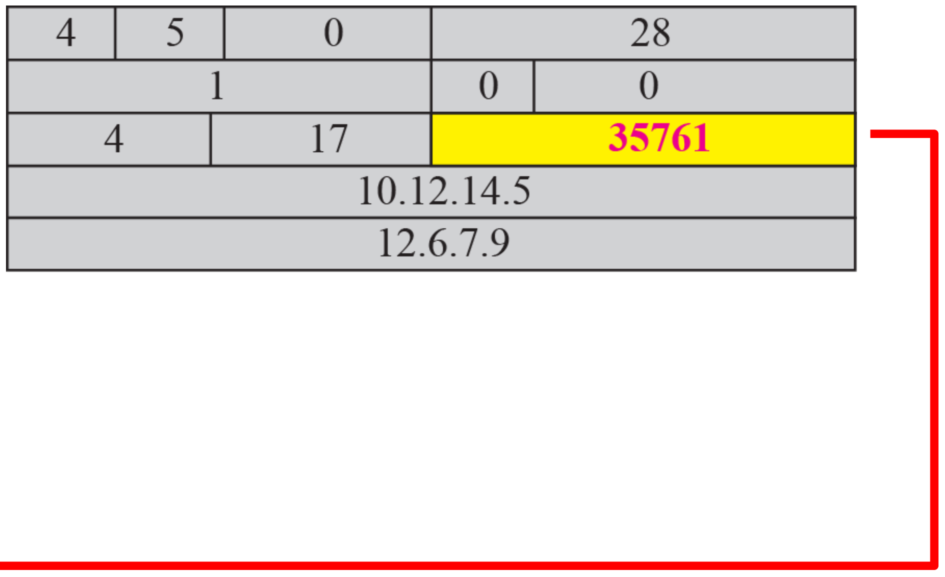
Figure 7.24 *Example of checksum calculation at the sender*



Example 7.18

Figure 7.25 shows the checking of checksum calculation at the receiver site (or intermediate router) assuming that no errors occurred in the header. The header is divided into 16-bit sections. All the sections are added and the sum is complemented. Since the result is 16 0s, the packet is accepted.

Figure 7.25 *Example of checksum calculation at the receiver*



```
4, 5, and 0  ──►  01000101  00000000
         28  ──►  00000000  00011100
          1  ──►  00000000  00000001
    0 and 0  ──►  00000000  00000000
   4 and 17  ──►  00000100  00010001
   Checksum  ──►  10001011  10110001
      10.12  ──►  00001010  00001100
       14.5  ──►  00001110  00000101
       12.6  ──►  00001100  00000110
        7.9  ──►  00000111  00001001
                  ──────────────────
        Sum  ──►  1111 1111  1111 1111
   Checksum  ──►  0000 0000  0000 0000
```

Note

Appendix D gives an algorithm for checksum calculation.

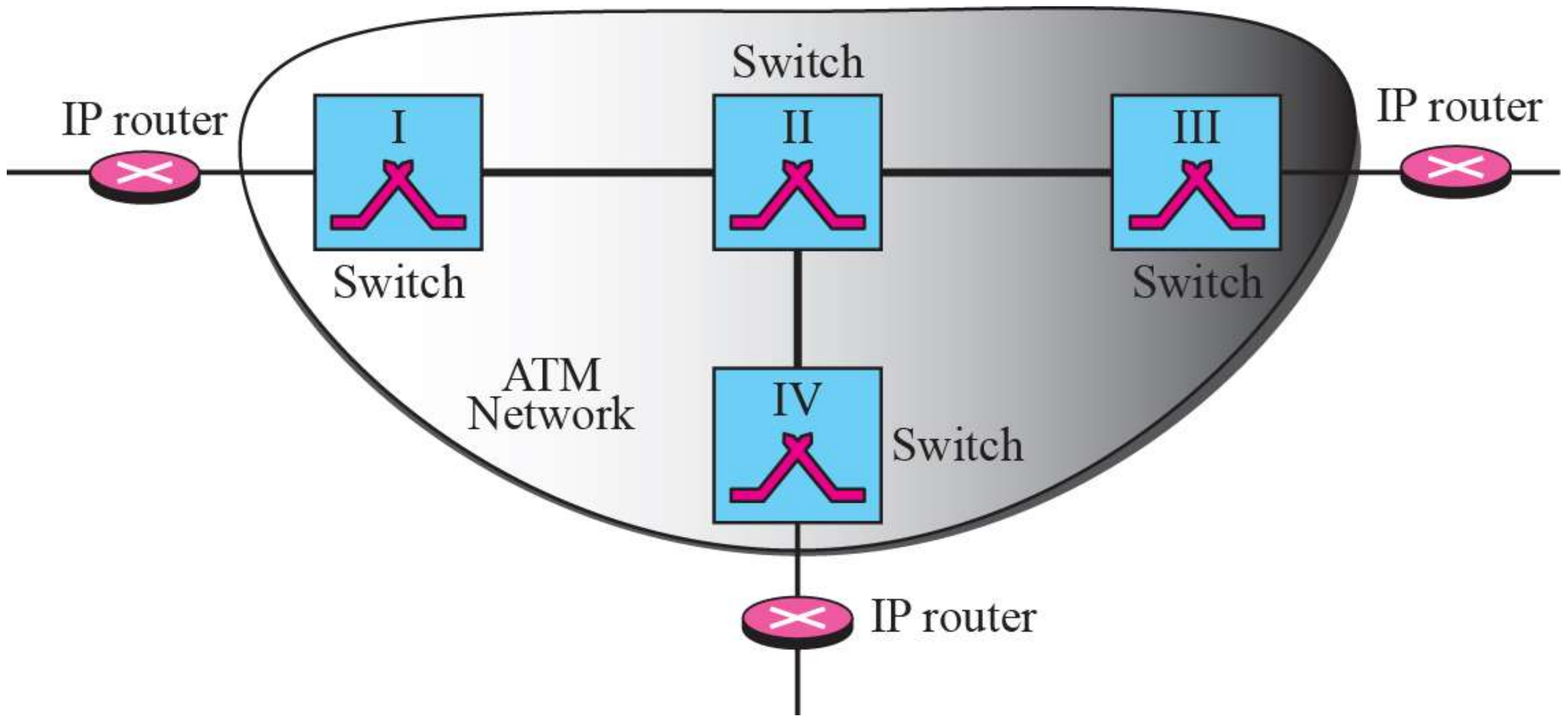
7-6 IP OVER ATM

In the previous sections, we assumed that the underlying networks over which the IP datagrams are moving are either LANs or point-to-point WANs. In this section, we want to see how an IP datagram is moving through a switched WAN such as an ATM. We will see that there are similarities as well as differences. The IP packet is encapsulated in cells (not just one). An ATM network has its own definition for the physical address of a device. Binding between an IP address and a physical address is attained through a protocol called ATMARP.

Topics Discussed in the Section

- ✓ **ATM WANs**
- ✓ **Routing the Cells**

Figure 7.26 *An ATM WAN in the Internet*



Note

The AAL layer used by the IP protocol is AAL5.

Figure 7.27 *Entering-point and exiting-point routers*

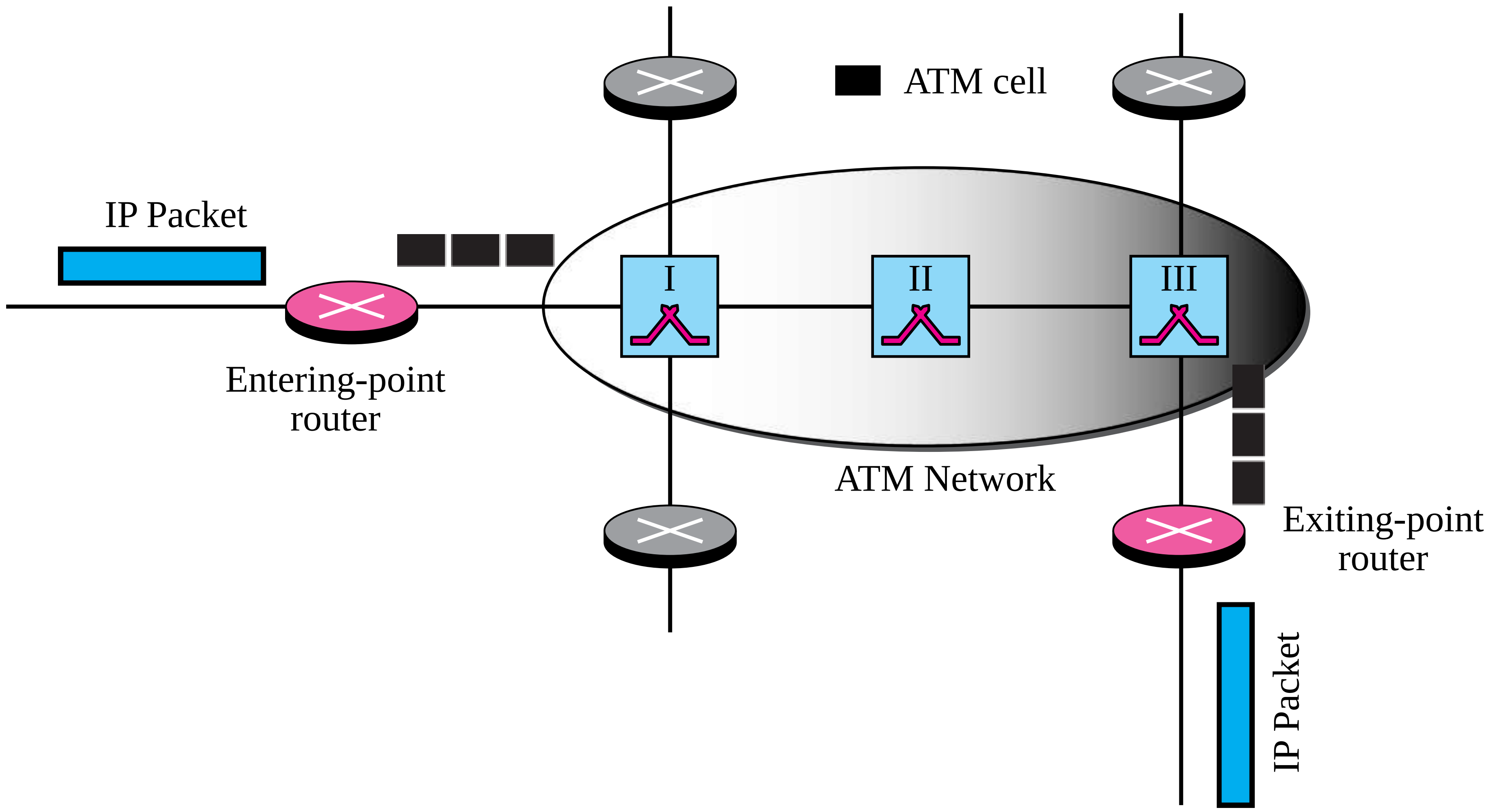
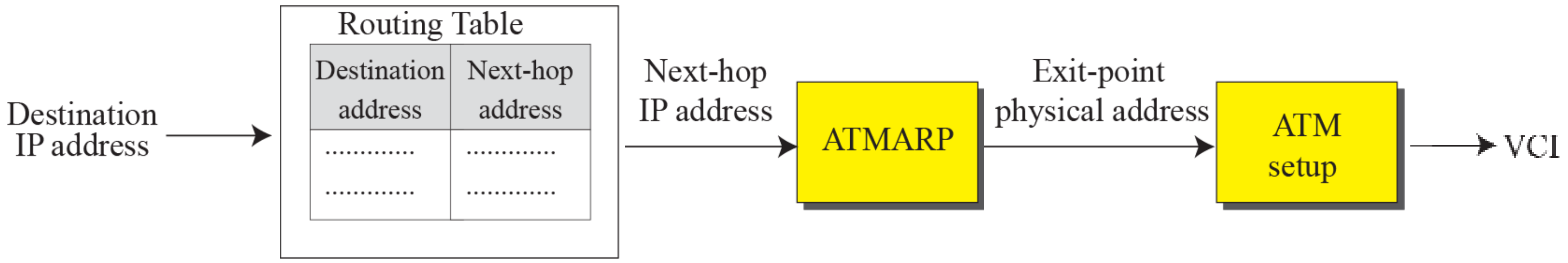


Figure 7.28 *Address binding in IP over ATM*



7-7 SECURITY

The IPv4 protocol, as well as the whole Internet, was started when the Internet users trusted each other. No security was provided for the IPv4 protocol. Today, however, the situation is different; the Internet is not secure any more. Although we discuss network security in general and IP security in particular in Chapters 29 and 30, we give a brief idea about the security issues in IP protocol and the solution.

Topics Discussed in the Section

- ✓ Security Issues
- ✓ IPSec

7-8 IP PACKAGE

In this section, we present a simplified example of a hypothetical IP package. Our purpose is to show the relationships between the different concepts discussed in this chapter.

Topics Discussed in the Section

- ✓ Header-Adding Module
- ✓ Processing Module
- ✓ Queues
- ✓ Routing Table
- ✓ Forwarding Module
- ✓ MTU Table
- ✓ Fragmentation Module
- ✓ Reassembly Table
- ✓ Reassembly Module

Figure 7.29 *IP components*

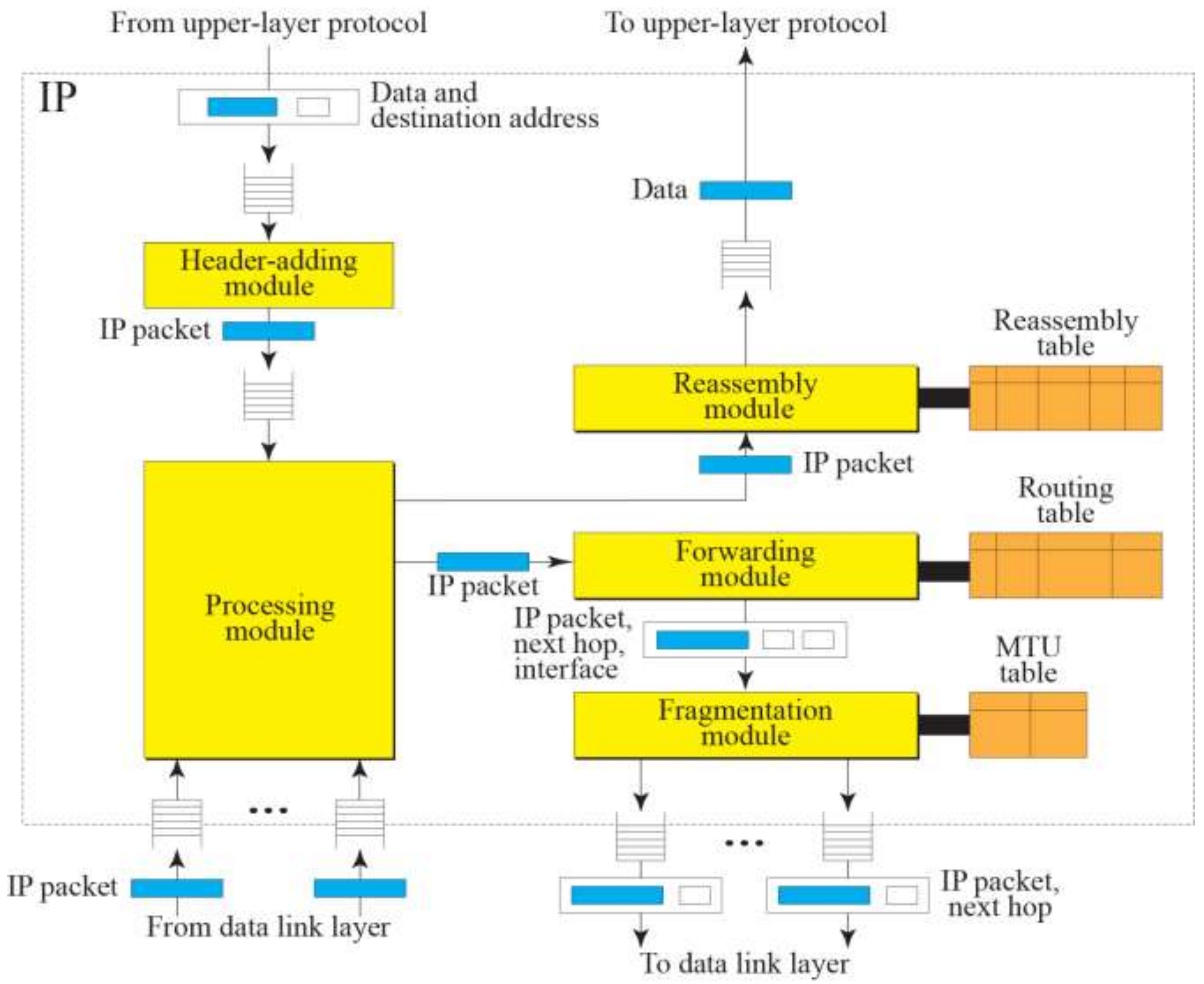


Table 7.3 *Adding module*

```
IP_Adding_Module (data, destination_address)
{
    Encapsulate data in an IP datagram
    Calculate checksum and insert it in the checksum field
    Send data to the corresponding queue
    Return
}
```

Table 7.4 *Processing module*

```
IP_Processing_Module (Datagram)
{
        Remove one datagram from one of the input queues.
        If (destination address matches a local address)
        {
            Send the datagram to the reassembly module.
            Return.
        }
        If (machine is a router)
        {
            Decrement TTL.
        }
        If (TTL less than or equal to zero)
        {
            Discard the datagram.
            Send an ICMP error message.
            Return.
        }
        Send the datagram to the forwarding module.
        Return.
}
```

Table 7.5 *Fragmentation module*

```
IP_Fragmentation_Module (datagram)
{
     Extract the size of datagram
     If (size > MTU of the corresponding network)
     {
          If (D bit is set)
          {
               Discard datagram
               Send an ICMP error message
               return
          }
          Else
          {
               Calculate maximum size
               Divide the segment into fragments
               Add header to each fragment
               Add required options to each fragment
```

Table 7.5 *Fragmentation module (continued)*

```
                    Send fragment
                    return
              }
        }
        Else
        {
              Send the datagram
        }
        Return.
}
```

Figure 7.30 *Reassembly table*

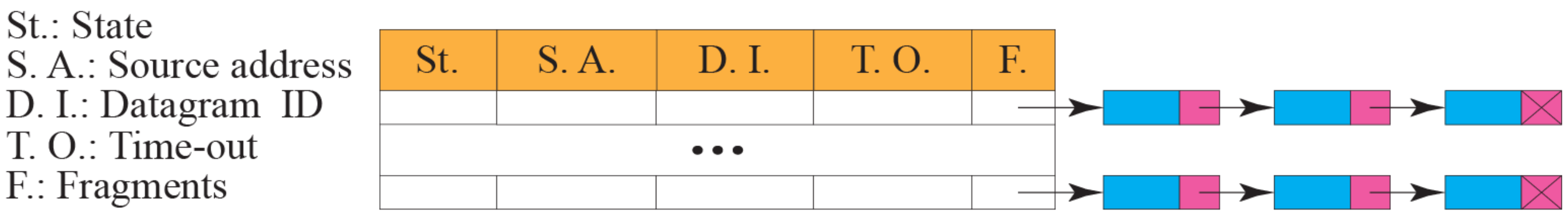


Table 7.6 *Reassembly module*

```
IP_Reassembly_Module (datagram)
{
    If (offset value = 0 AND M = 0)
    {
        Send datagram to the appropriate queue
        Return
    }
    Search the reassembly table for the entry
    If (entry not found)
    {
        Create a new entry
    }
    Insert datagram into the linked list
    If (all fragments have arrived)
    {
        Reassemble the fragment
        Deliver the fragment to upper-layer protocol
        return
    }
    Else
    {
        If (time-out expired)
        {
            Discard all fragments
            Send an ICMP error message
        }
    }
    Return.
}
```