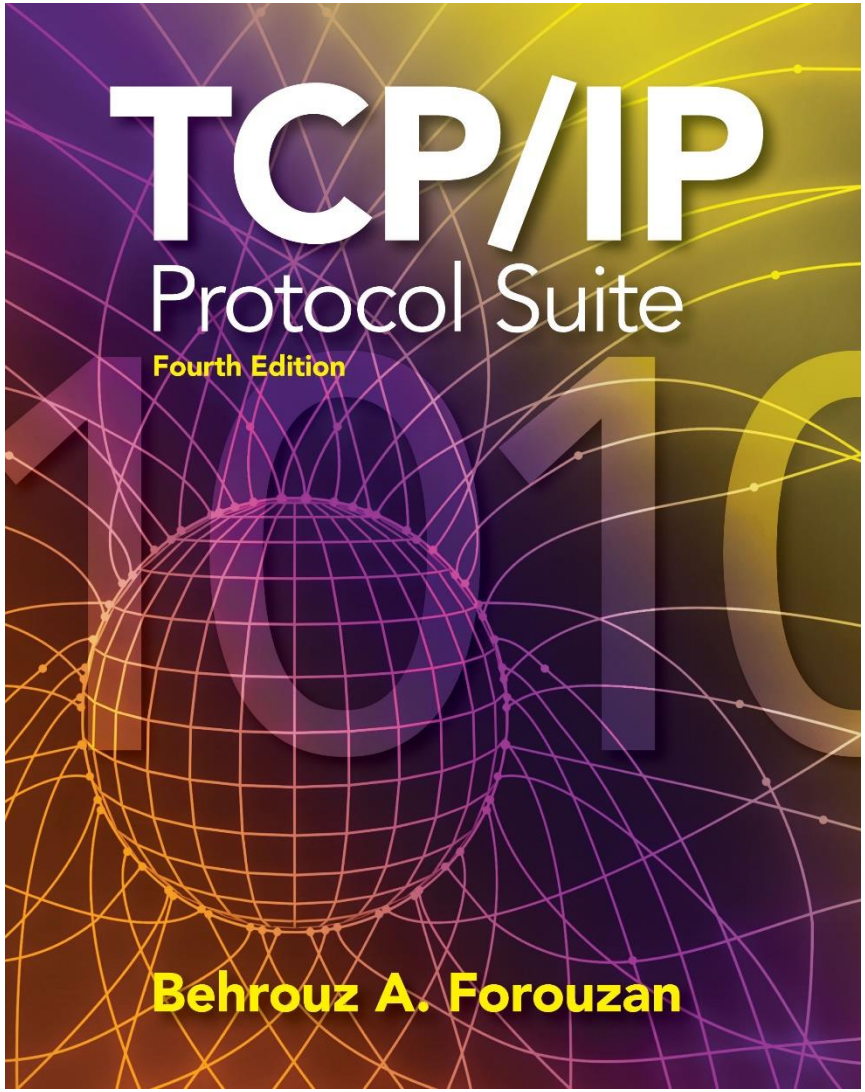
Chapter 7

Internet Protocol Version4 (IPv4)



OBJECTIVES:

- To explain the general idea behind the IP protocol and the position of IP in TCP/IP protocol suite.
- To show the general format of an IPv4 datagram.
- To discuss fragmentation and reassembly of datagrams.
- To discuss several options that can be in an IPv4 datagram and their applications.
- To show how a checksum is calculated for the header of an IPv4 datagram at the sending site and how the checksum is checked at the receiver site.
- To discuss IP over ATM and compare it with IP over LANs and/or point-to-point WANs.
- To show a simplified version of the IP package and give the pseudocode for some modules.

Chapter Outline

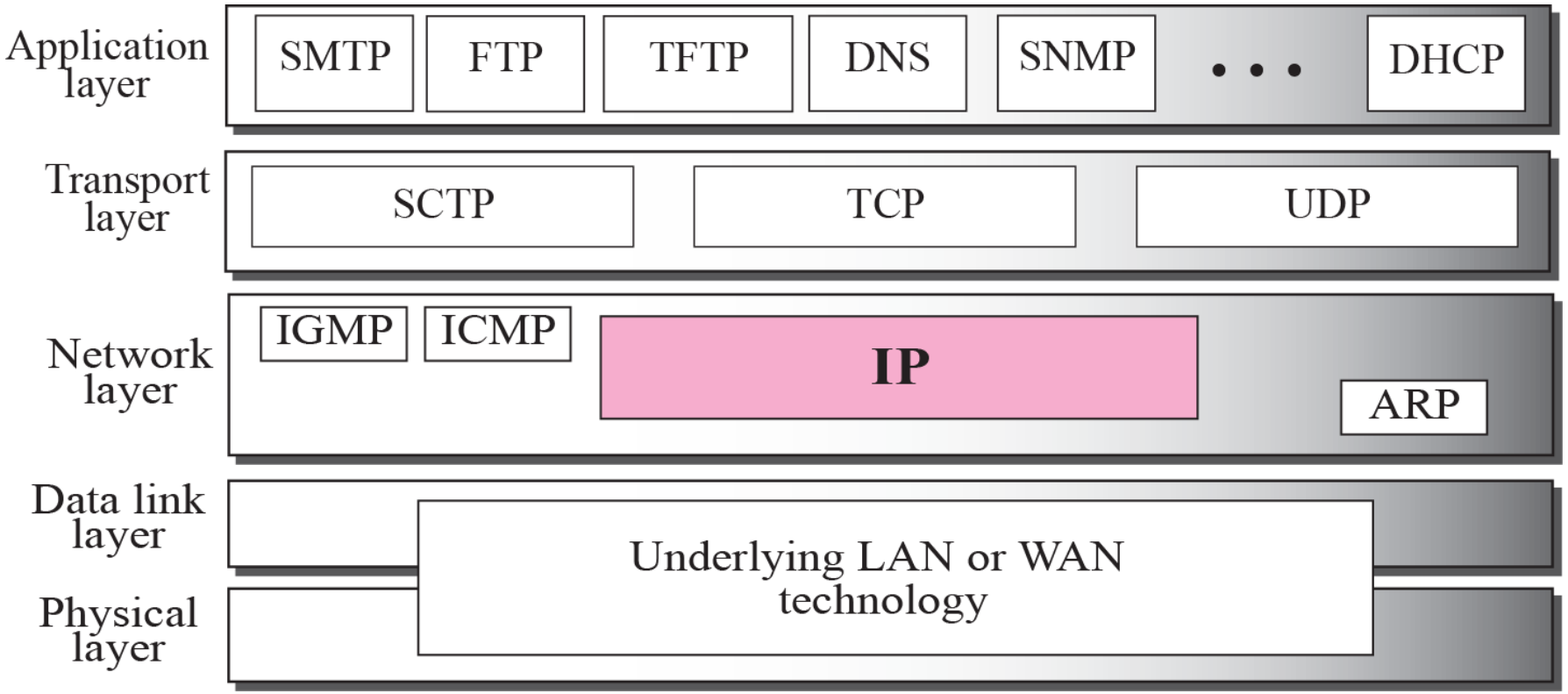
7-1 INTRODUCTION

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*



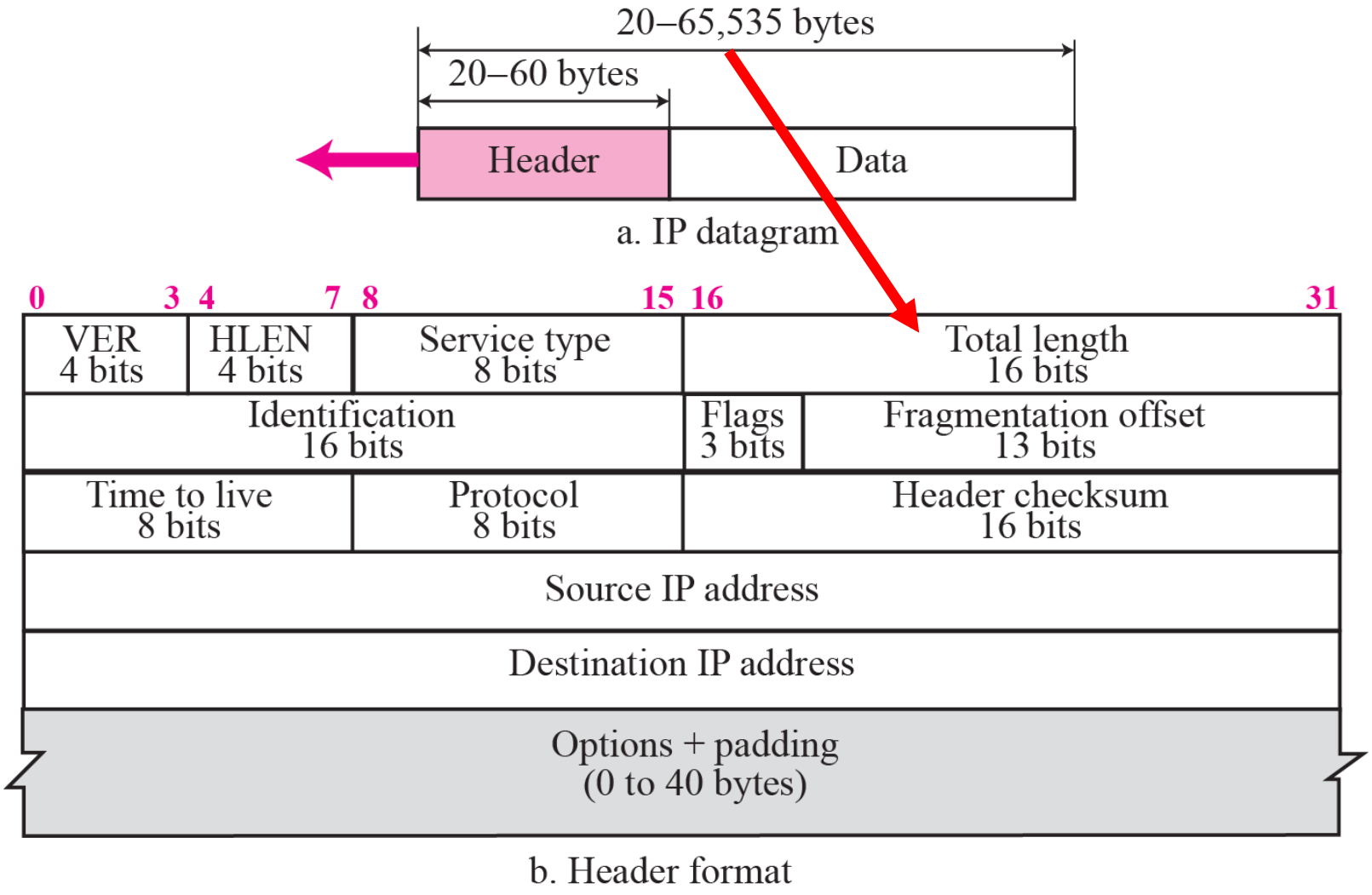
7-2 DATAGRAMS

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*

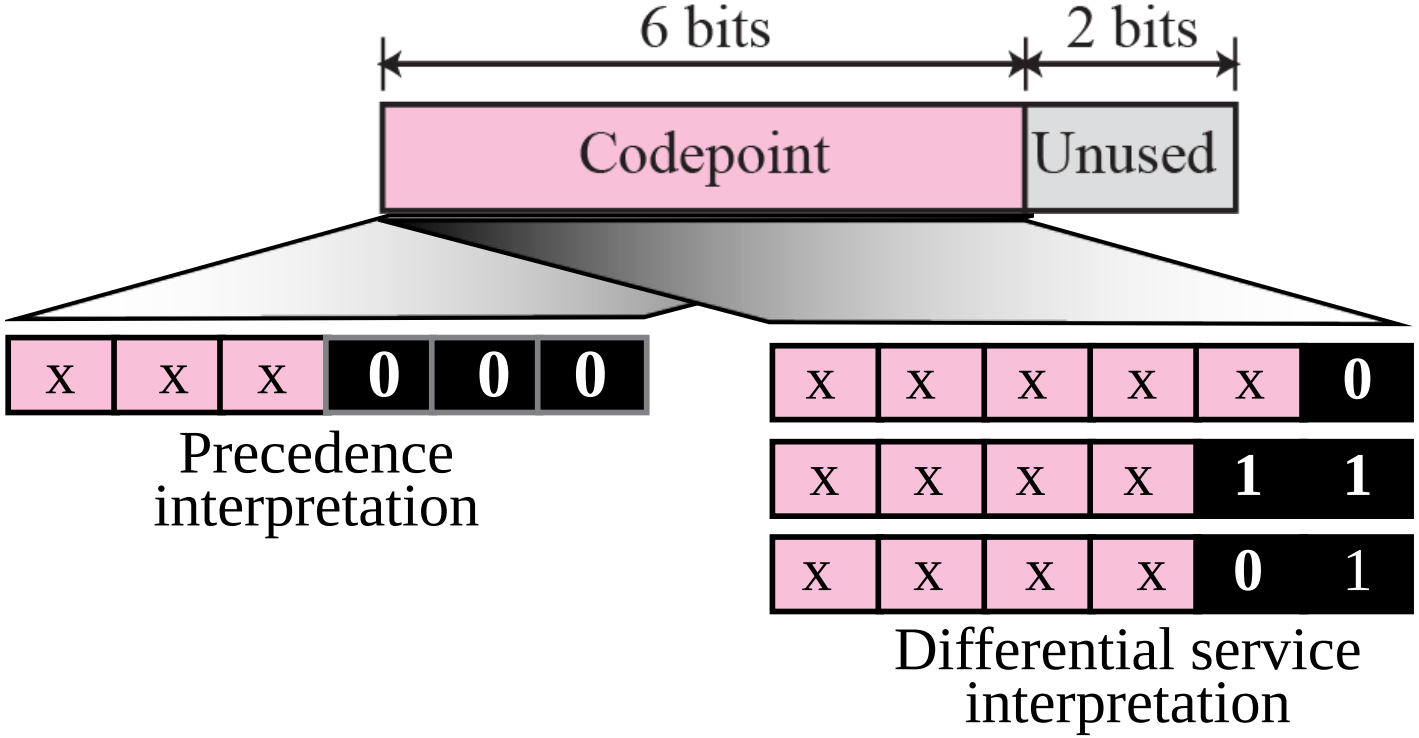


IP datagram fields

- **Version (VER).** This 4-bit field defines the version of the IP protocol.
- **Header length (HLEN).** This 4-bit field defines the total length of the datagram header in 4-byte words.
- **Service type.** In the original design of IP header, this field was referred to as type of service (TOS), which defined how the datagram should be handled. Part of the field was used to define the precedence**(**الأولوية**)** of the datagram; the rest defined the type of service (low delay, high throughput, and so on).
- **Total length**. This is a 16-bit field that defines the total length (header plus data) of the IP datagram in bytes.
- **Identification.** This field is used in fragmentation (discussed in the next section).
- **Flags.** This field is used in fragmentation (discussed in the next section).
- **Fragmentation offset**. This field is used in fragmentation (discussed in the next section).
- **Time to live.** A datagram has a limited lifetime in its travel through an internet.
- **Protocol.** This 8-bit field defines the higher-level protocol that uses the services of the IP layer.
- **Checksum.** The checksum concept and its calculation are discussed later in this chapter.

Figure 7.3 *Service type*

At now. IETF has changed the interpretation of this 8-bit field. This field now defines a set of differentiated services. The new interpretation is shown in Figure 7.3.



When the 3 right-most bits are 0s, the 3 left-most bits are interpreted the same as the precedence bits in the service type interpretation. Define the priority of the datagram). If a router is congested and needs to discard some datagrams, those datagrams with lowest precedence are discarded first.

- When the 3 right-most bits are not all 0s, the 6 bits define 56 (64 - 8) services based on the priority assignment by the Internet or local authorities(سلطة). Define the service type

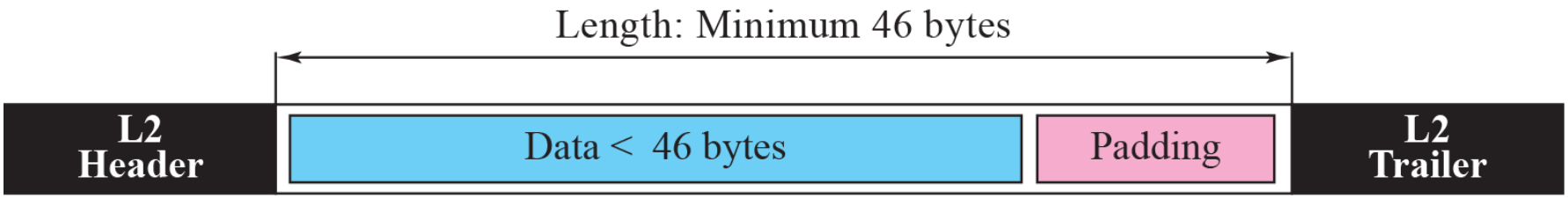
Table 7.1 *Values for codepoints*

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*



❑ **Protocol.** This 8-bit field defines the higher-level protocol that uses the services of the IP layer. An IP datagram can encapsulate data from several higher level protocols such as TCP, UDP, ICMP, and IGMP. This field specifies the final destination protocol to which the IP datagram should be delivered.

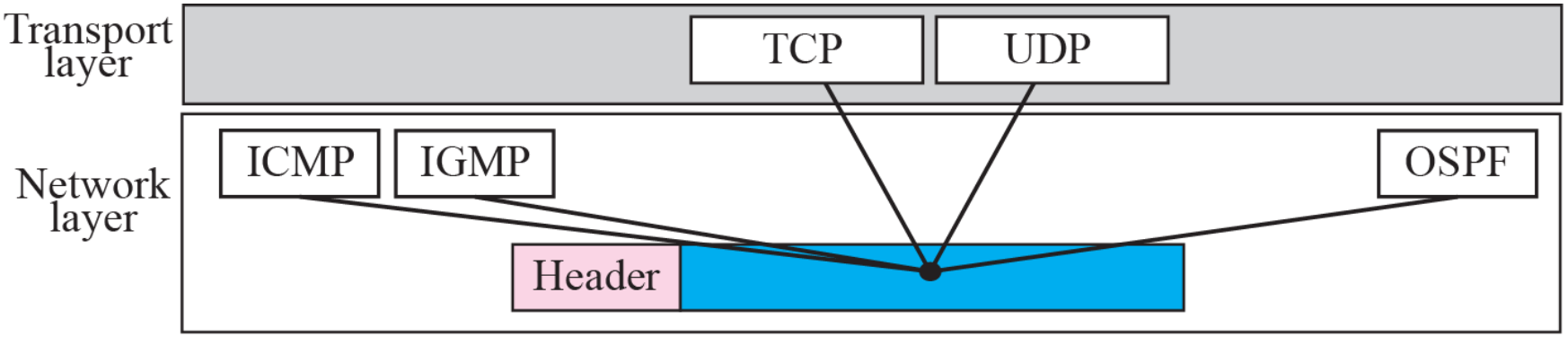


Table 7.2 *Protocols*

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)

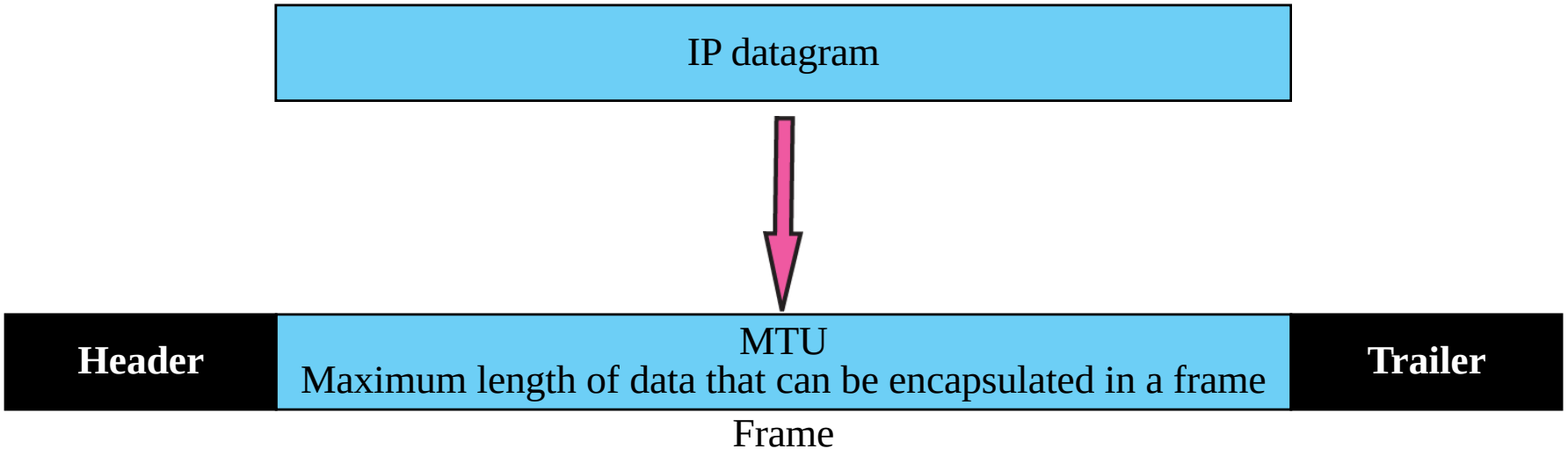
7-3 FRAGMENTATION

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*



When a datagram is encapsulated in a frame, the total size of the datagram must be less than this maximum size, which is defined by the restrictions imposed by the hardware and software used in the network

The value of the MTU differs from one physical network protocol to another. For example, the value for the Ethernet LAN is 1500 bytes, for FDDI LAN is 4352 bytes, and for PPP is 296 bytes.

Note

Only data in a datagram is fragmented.

The host or router that fragments a datagram must change the values of three fields: flags, fragmentation offset, and total length. The rest of the fields must be copied. Of course, the value of the checksum must be recalculated regardless of fragmentation.

Identification field

The value in the identification field is copied into all fragments. In other words, all fragments have the same identification number, which is also the same as the original datagram. The identification number helps the destination in reassembling the datagram. It knows that all fragments having the same identification value should be assembled into one datagram.

Figure 7.7 *Flags field*

D: Do not fragment
M: More fragments

Figure 7.8 *Fragmentation example*

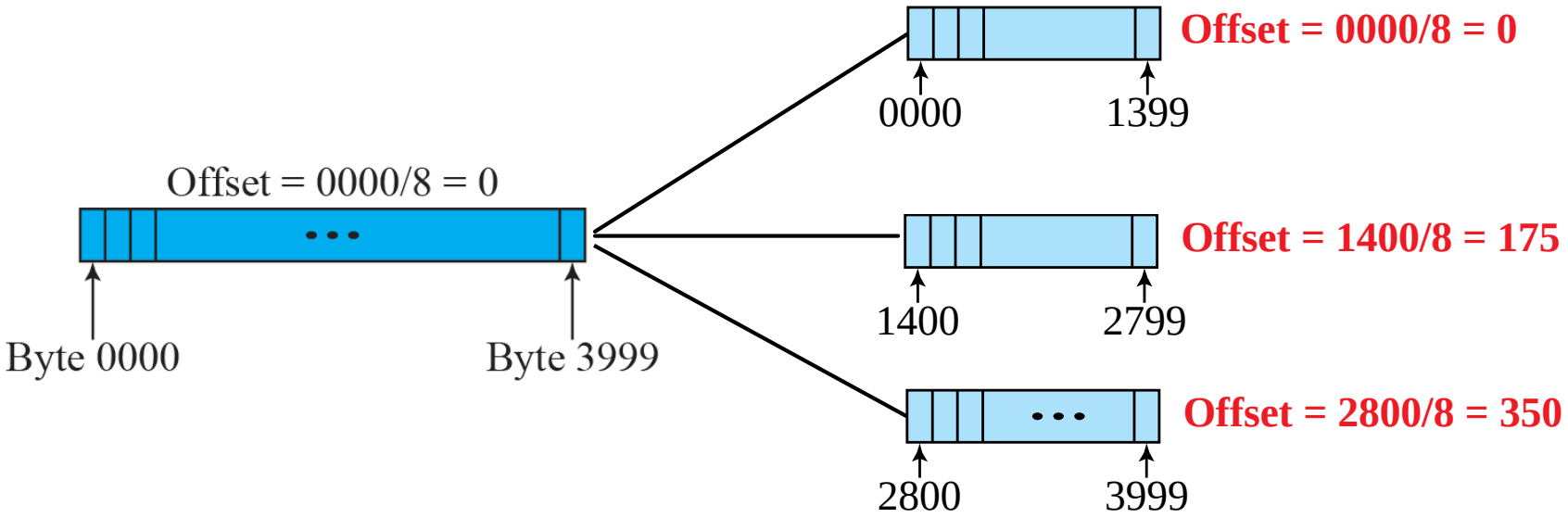
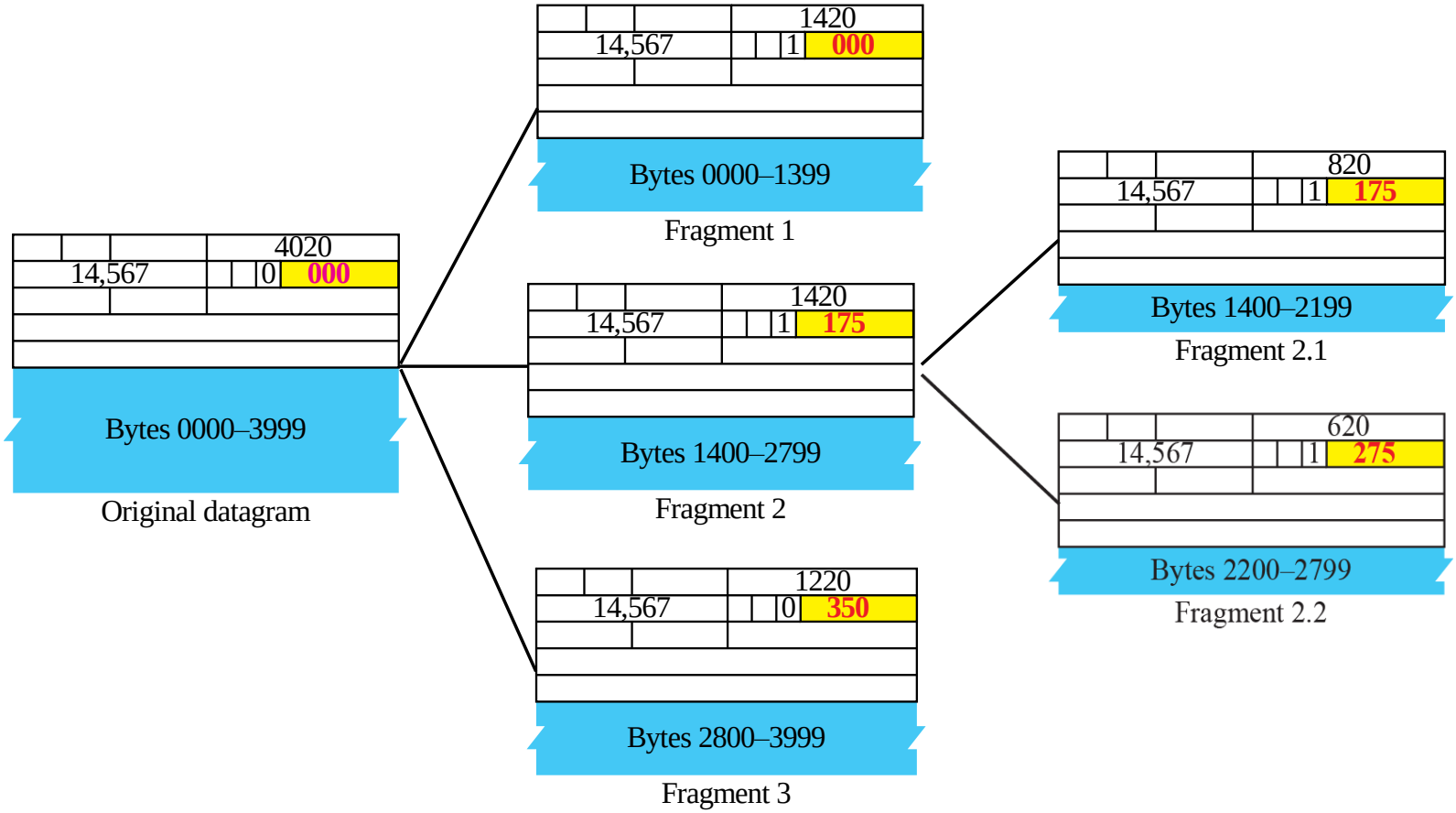


Figure 7.9 *Detailed fragmentation example*



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 (of that fragment). 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 $100 \times 8 = 800$. 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

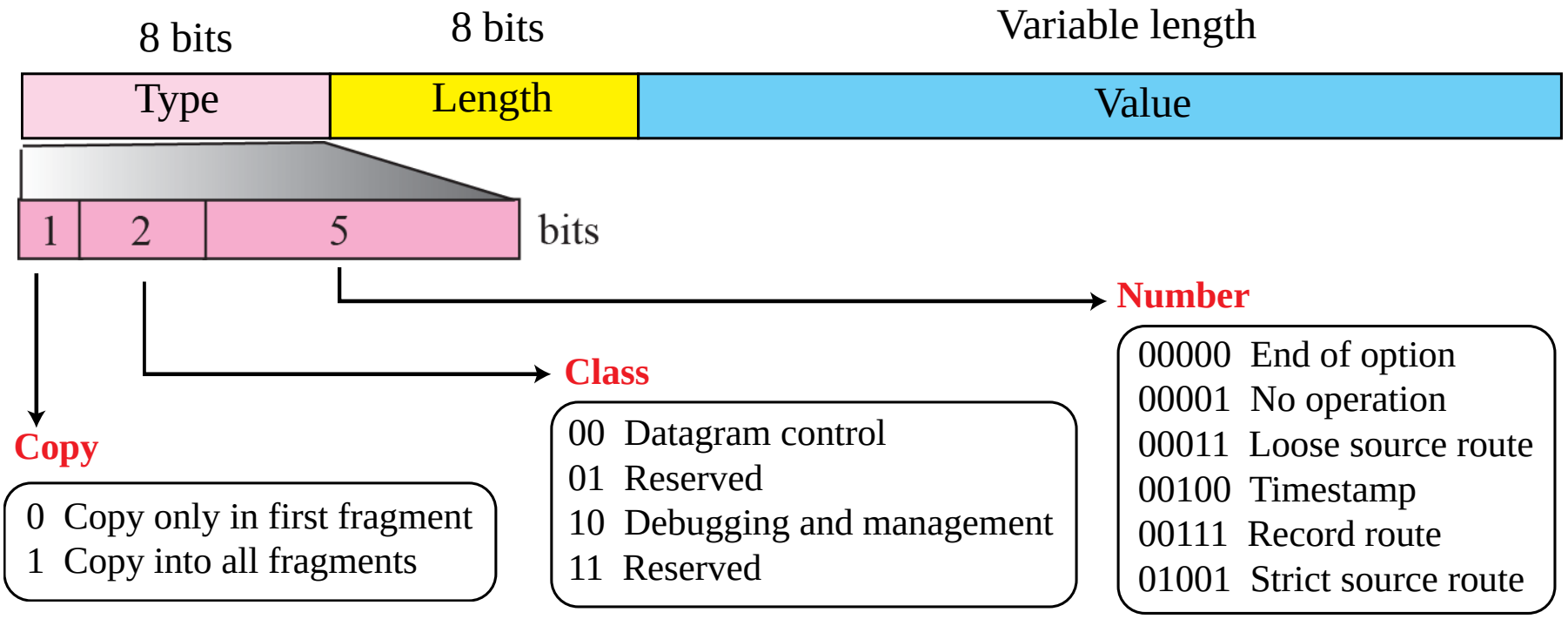
The header of the IP datagram is made of two parts: a fixed part and a variable part. The fixed part is 20 bytes long and was discussed in the previous section. The variable part comprises the options, which can be a maximum of 40 bytes.

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*



Copy: This 1-bit subfield controls the presence of the option in fragmentation

Class: This 2-bit subfield defines the general purpose of the option. When its value is 00, it means that the option is used for datagram control. When its value is 10, it means that the option is used for debugging and management.

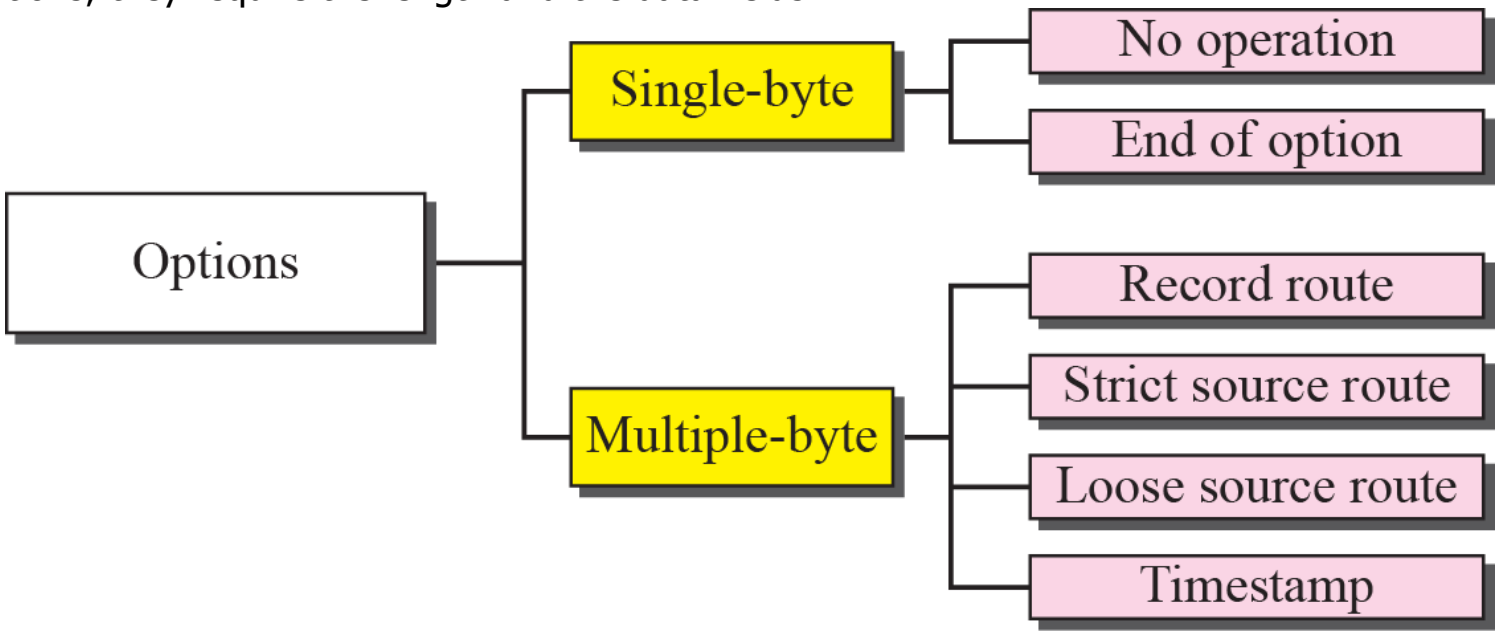
Number: This 5-bit subfield defines the type of option. Although 5 bits can define up to 32 different types, currently, only six options are being used.

Figure 7.10 : *Option format*

- **Length:** The length field defines the total length of the option including the type field and the length field itself. This field is not present in all of the option types.
- **Value:** The value field contains the data that specific options require. Like the length field, this field is also not present in all option types.

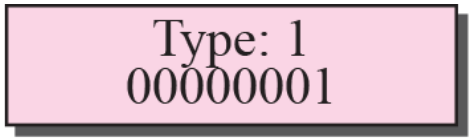
Figure 7.11 *Categories of options*

As mentioned previously, only six options are currently being used. Two of these are 1-byte options, and they do not require the length or the data fields. Four of them are multiple-byte options; they require the length and the data fields .



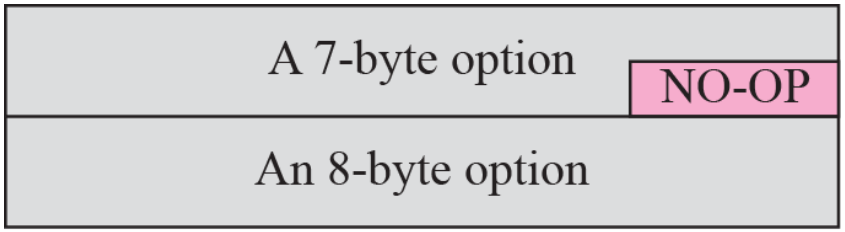
A no-operation option is a 1-byte option used as a filler between options. it can be used to align the next option on a 16-bit or 32-bit boundary

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*

An end-of-option option: is also a 1-byte option used for padding at the end of the option field. It, however, can only be used as the last option. Only one end-of-option option can be used. After this option, the receiver looks for the payload data.

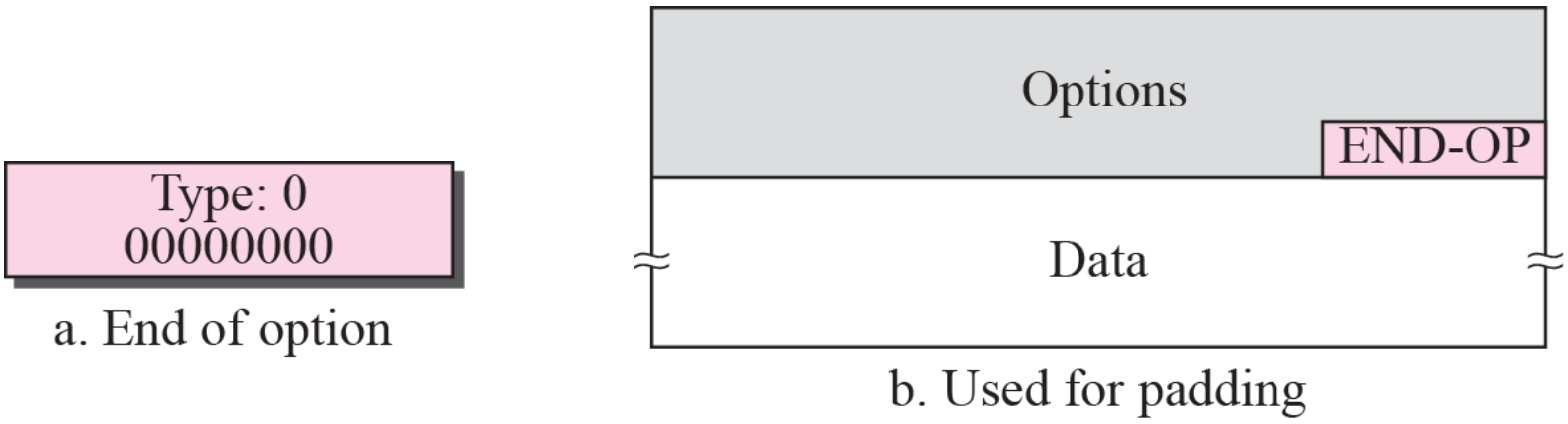


Figure 7.14 *Record-route option*

A record-route option: is used to record the internet routers that handle the datagram. It can list up to nine router IP addresses since the maximum size of the header is 60 bytes, The source creates placeholder fields in the option to be filled by the visited routers.

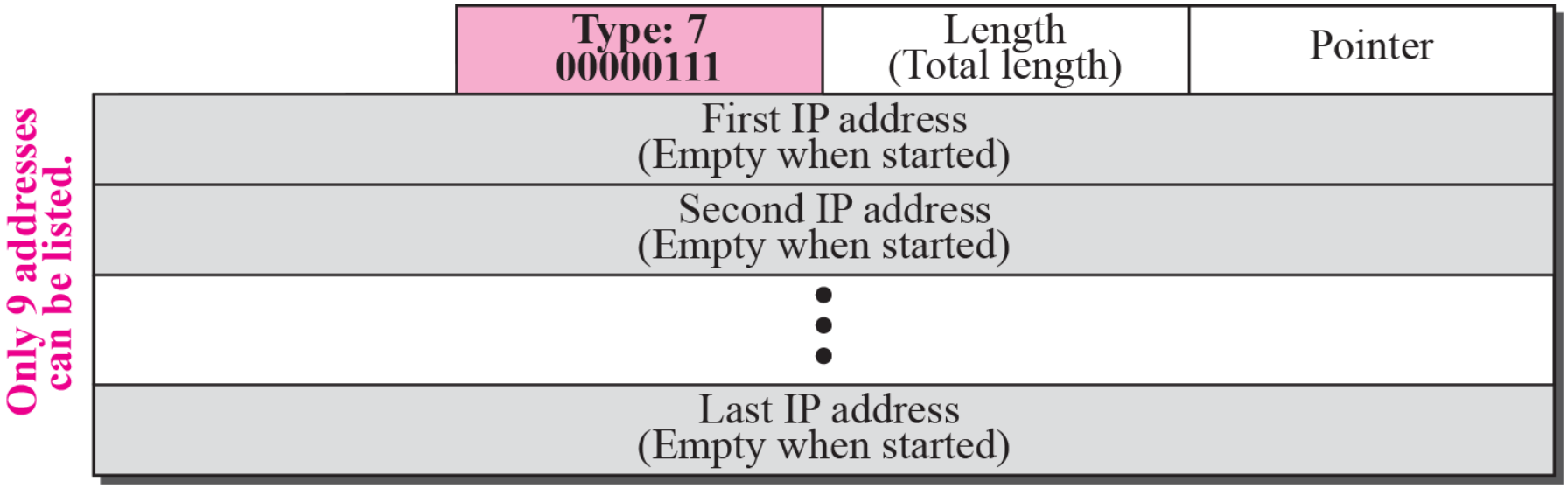


Figure 7.15 *Record-route concept*

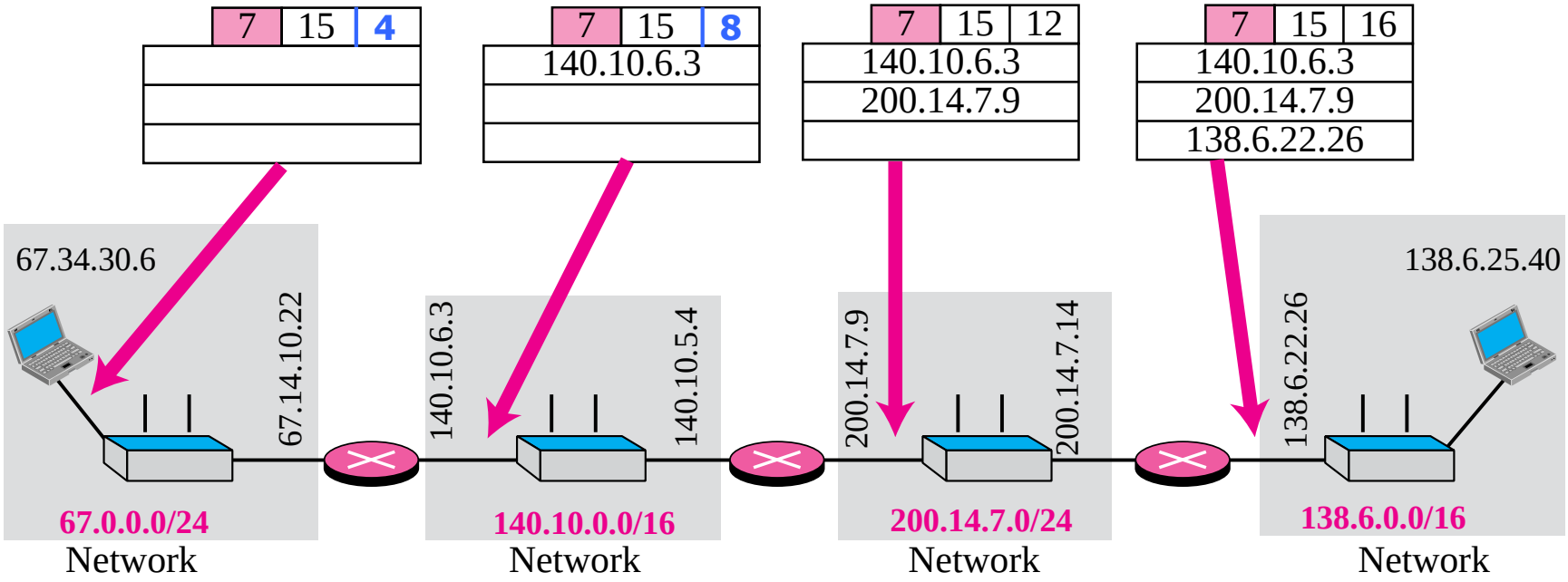


Figure 7.16 *Strict-source-route option*

A strict-source-route option: is used by the source to predetermine a route for the datagram as it travels through the Internet. Dictation of a route by the source can be useful for several purposes. The sender can choose a route with a specific type of service, such as minimum delay or maximum throughput. Alternatively, it may choose a route that is safer or more reliable for the sender's purpose.
If the datagram visits a router that is not on the list, the datagram is discarded and an error message is issued. And If the datagram arrives at the destination and some of the entries were not visited, it will also be discarded and an error message issued.

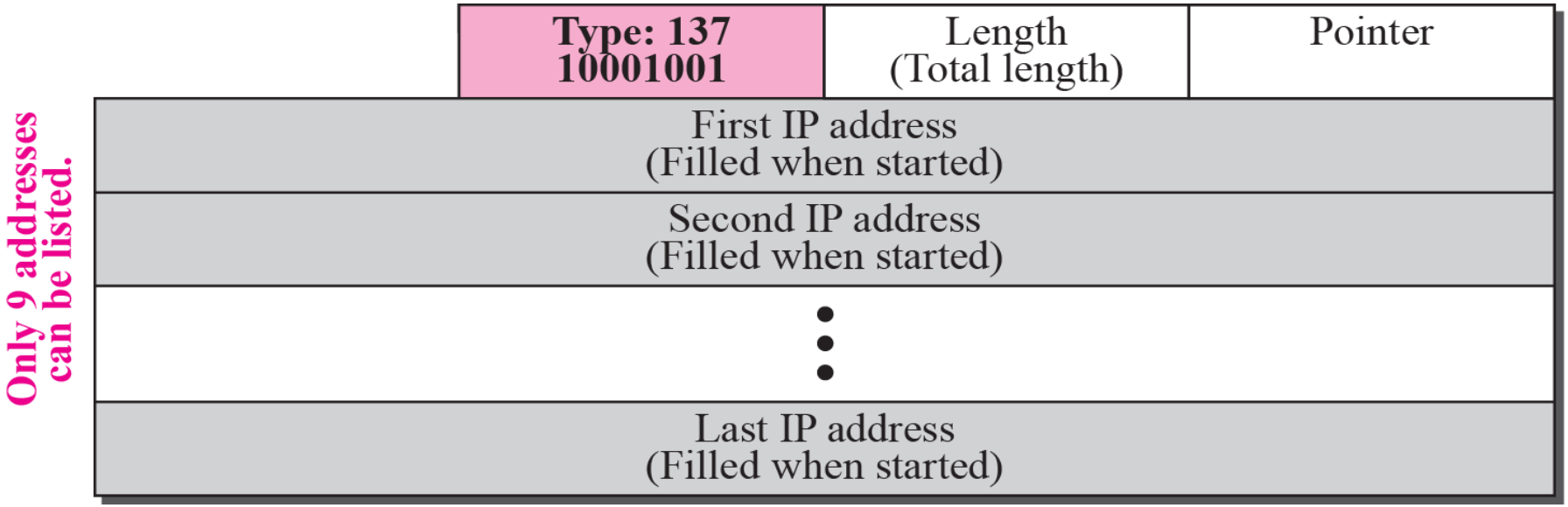


Figure 7.17 *Strict-source-route option*

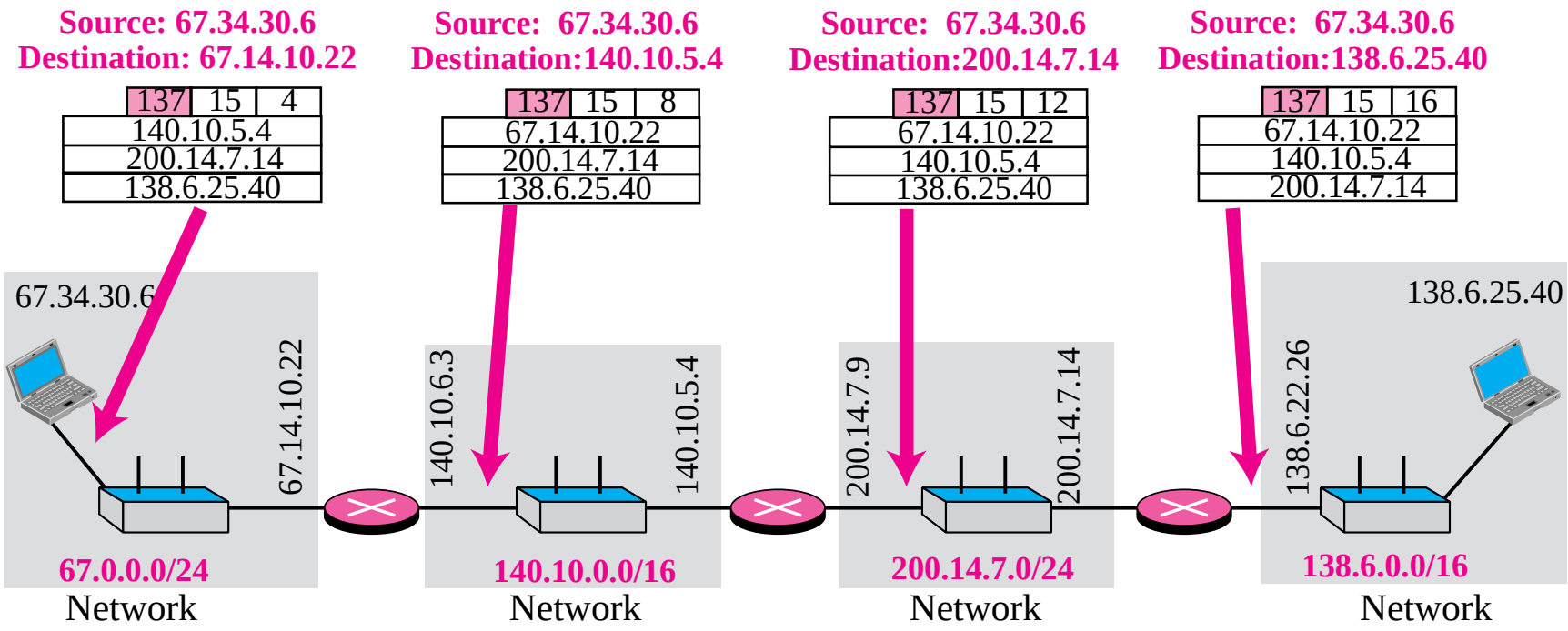


Figure 7.18 *Loose-source-route option*

A loose-source-route option: is similar to the strict source route, but it is more relaxed. Each router in the list must be visited, but the datagram can visit other routers as well.

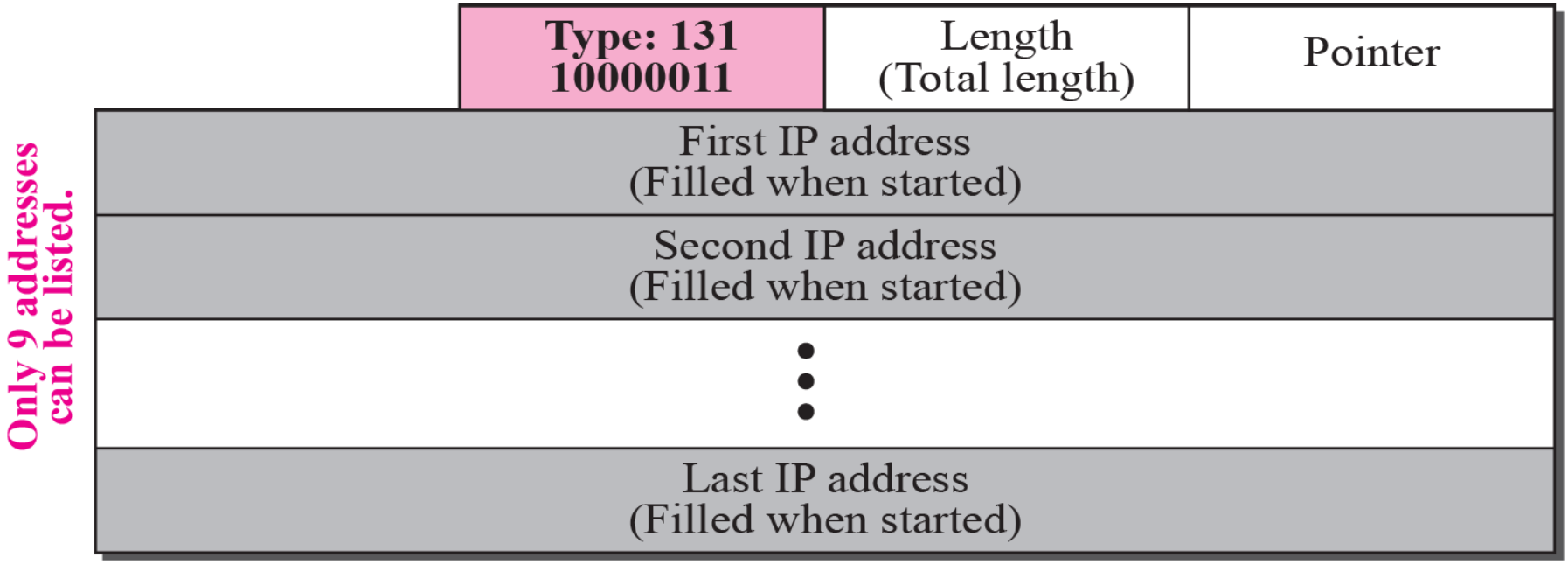


Figure 7.19 *Time-stamp option*

A timestamp option: is used to record the time of datagram processing by a router. The time is expressed in milliseconds from midnight, Universal Time. Knowing the time a datagram is processed can help users and managers track the behaviour of the routers in the Internet. We can estimate the time it takes for a datagram to go from one router to another.

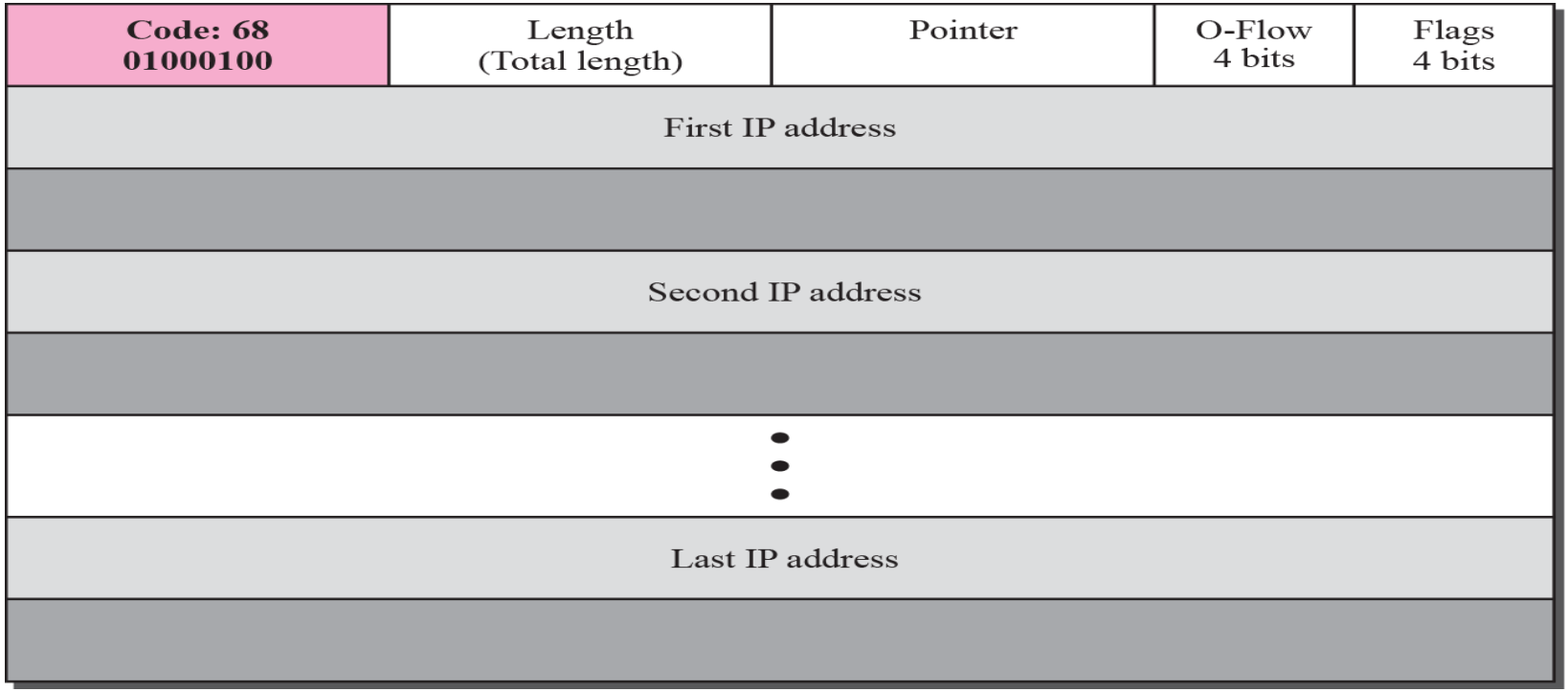


Figure 7.20 *Use of flags in timestamp*

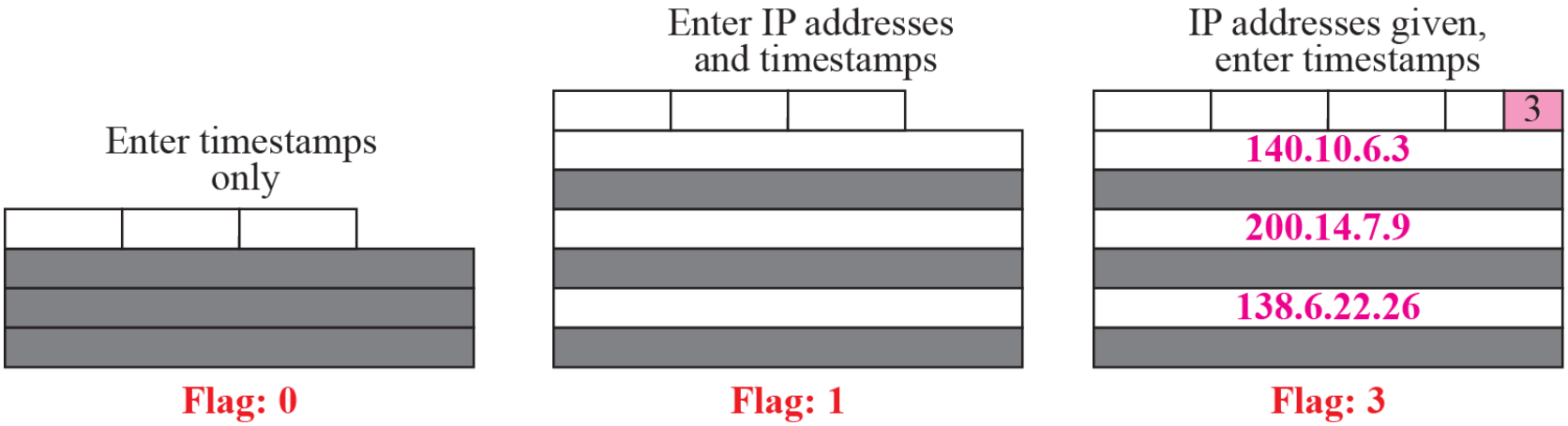
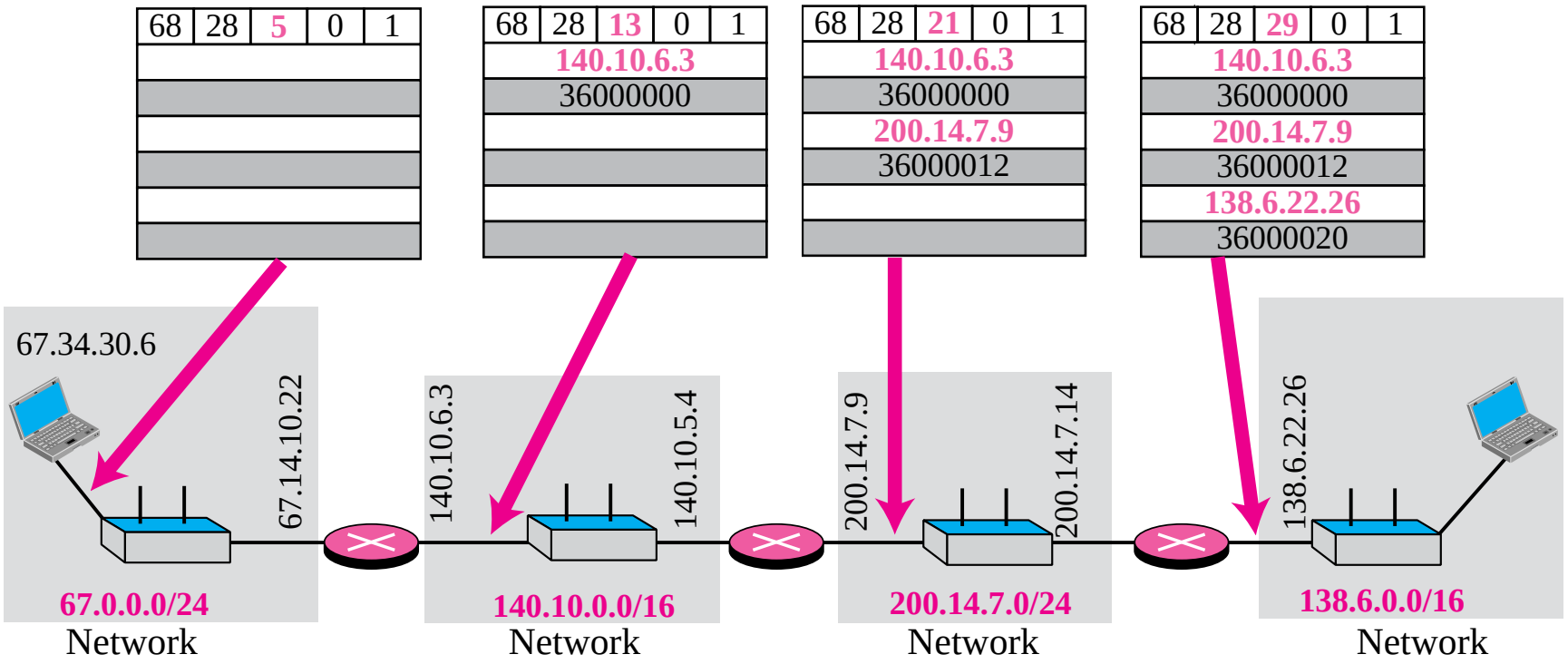


Figure 7.21 *Timestamp concept*



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*

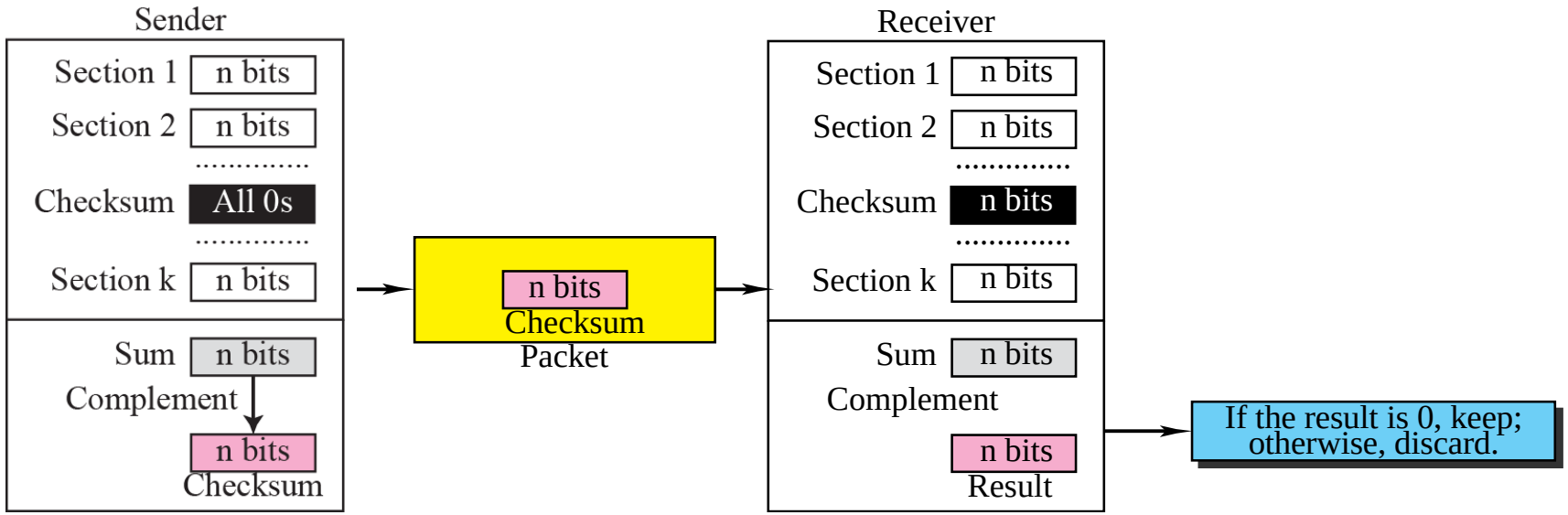
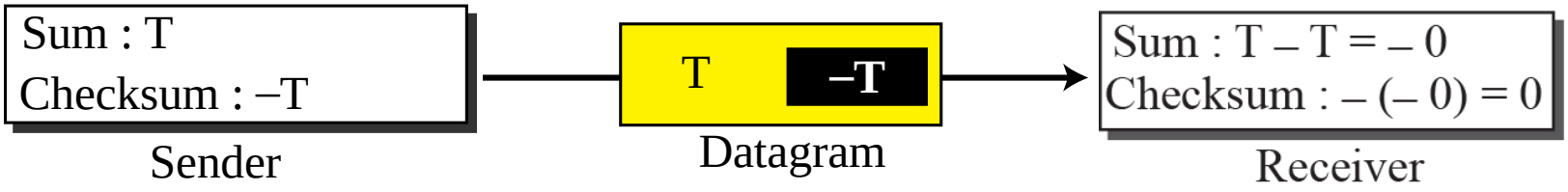


Figure 7.23 *Checksum in one's complement arithmetic*



Note

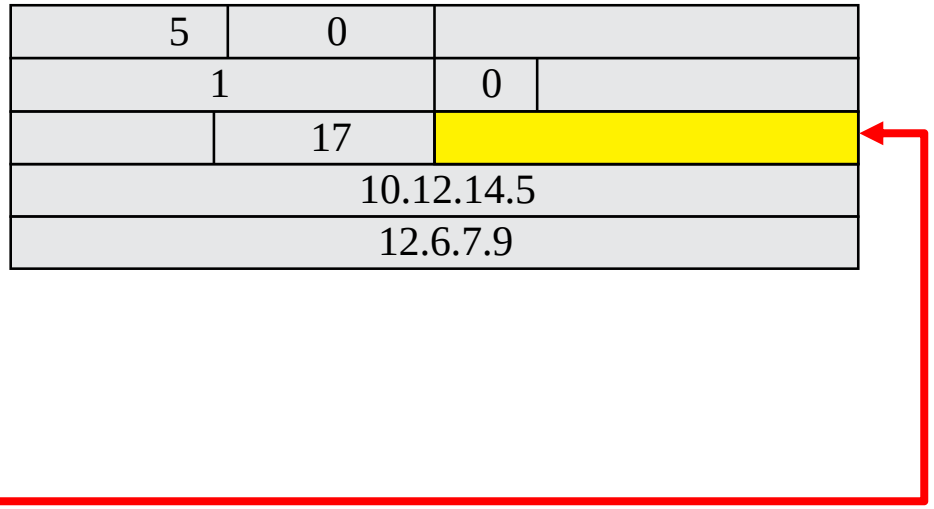
Checksum in IP covers only the header, not the data.

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*

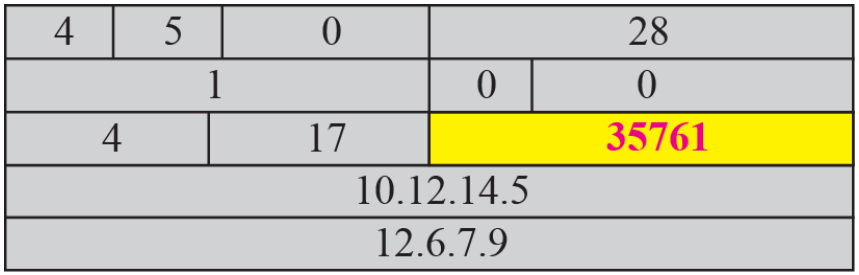
4, 5, and 0	01000101	00000000
28	00000000	00011100
1	00000000	00000001
0 and 0	00000000	00000000
4 and 17	00000100	00010001
0	00000000	00000000
10.12	00001010	00001100
14.5	00001110	00000101
12.6	00001100	00000110
7.9	00000111	00001001
Sum	**01110100**	**01001110**
Checksum	**10001011**	**10110001**



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**