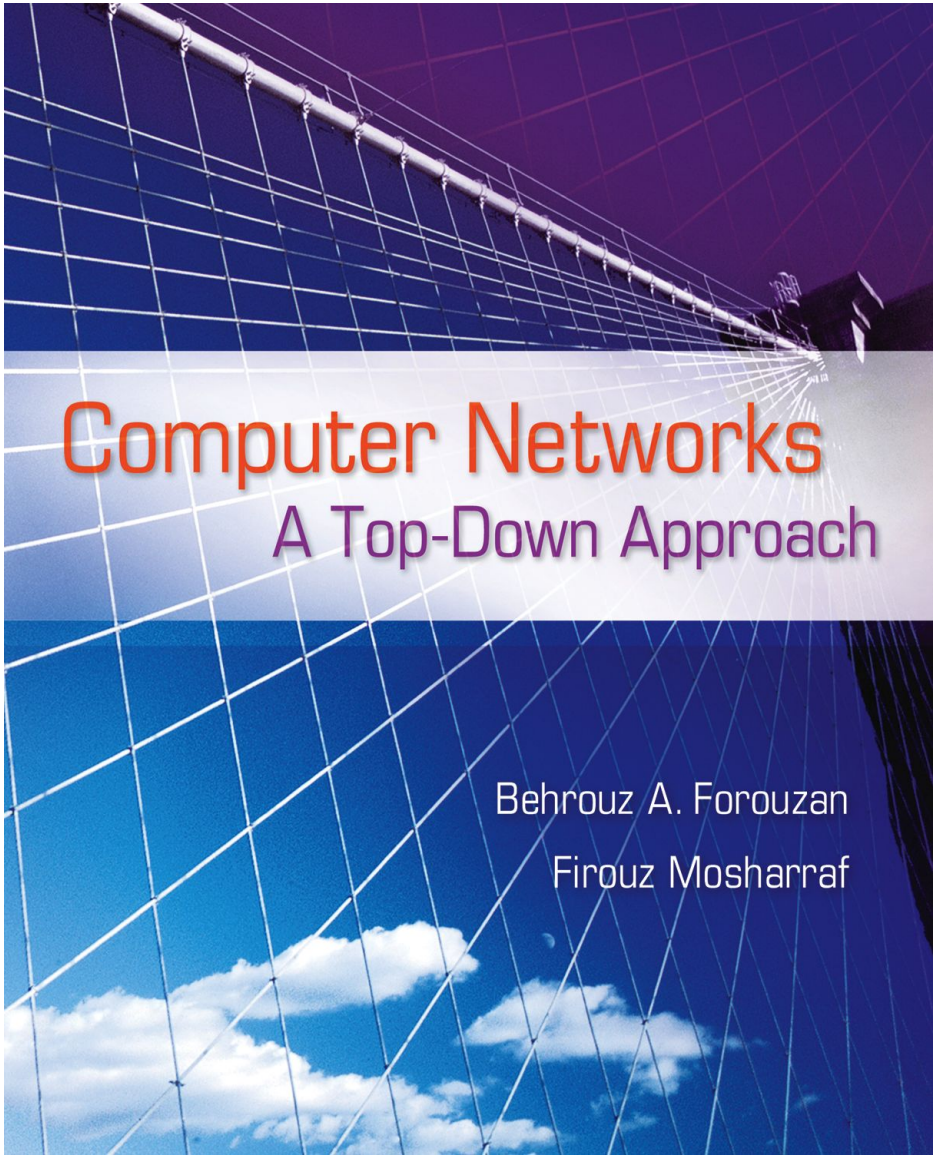
Chapter 2

Application Layer



Chapter 2: Outline

2.1 INTRODUCTION

2.2 CLIENT-SERVER PARADIGM

2.3 STANDARD APPLICATIONS

2.4 PEER-TO-PEER PARADIGM

2.5 SOCKET-INTERFACE PROGRAMMING

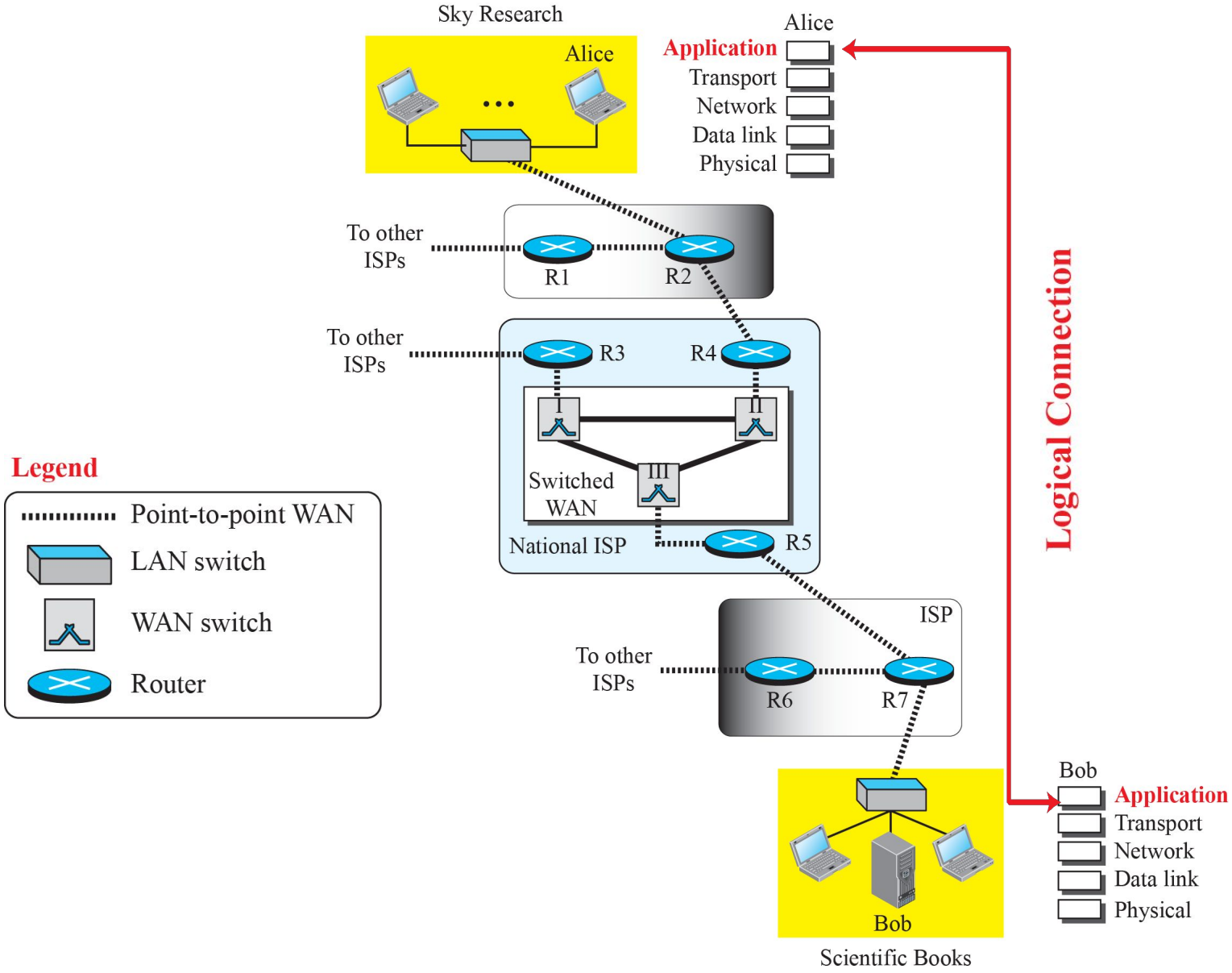
Chapter 2: Objective

- *We introduce the nature of services provided by the Internet: the client-server paradigm and the peer-to-peer paradigm.*
- *We discuss the concept of the client-server paradigm.*
- *We discuss some predefined or standard applications based on the client-server paradigm such as surfing the Web, file transfer, e-mail, and so on.*
- *We discuss the concept and protocols in the peer-to-peer paradigm such as Chord, Pastry, and Kademlia.*
- *We show how a new application can be created in the client-server paradigm by writing two programs in the C language.*

2-1 INTRODUCTION

The application layer provides services to the user. Communication is provided using a logical connection, which means that the two application layers assume that there is an imaginary direct connection through which they can send and receive messages. Figure 2.1 shows the idea behind this logical connection.

Figure 2.1: Logical connection at the application layer



2.1.1 Providing Services

The Internet was originally designed to provide service to users around the world. Since the application layer is the only layer that provides services to the Internet user, it allows new application protocols to be easily added to the Internet, which has been occurring during the lifetime of the Internet. When the Internet was created, only a few application protocols were available to the users; today we cannot give a number for these protocols because new ones are being added constantly.

2.1.1 Providing Services (Cont.)

- **Standard and Nonstandard Protocols**
  - **Standard Application-Layer Protocols**
  - **Nonstandard Application-Layer Protocols**

2.1.2 Application-Layer Paradigm

It should be clear that to use the Internet we need two application programs to interact with each other: one running on a computer somewhere in the world, the other running on another computer somewhere else in the world. The two programs need to send messages to each other through the Internet infrastructure. However, we have not discussed what the relationship should be between these programs. Should both application programs be able to request services and provide services, or should the application programs just do one or the other?

2.1.2 Application-Layer Paradigm (cont)

- *Traditional Paradigm: Client-Server*
- *New Paradigm: Peer-to-Peer*
- *Mixed Paradigm*

Figure 2.2: Example of a client-server paradigm

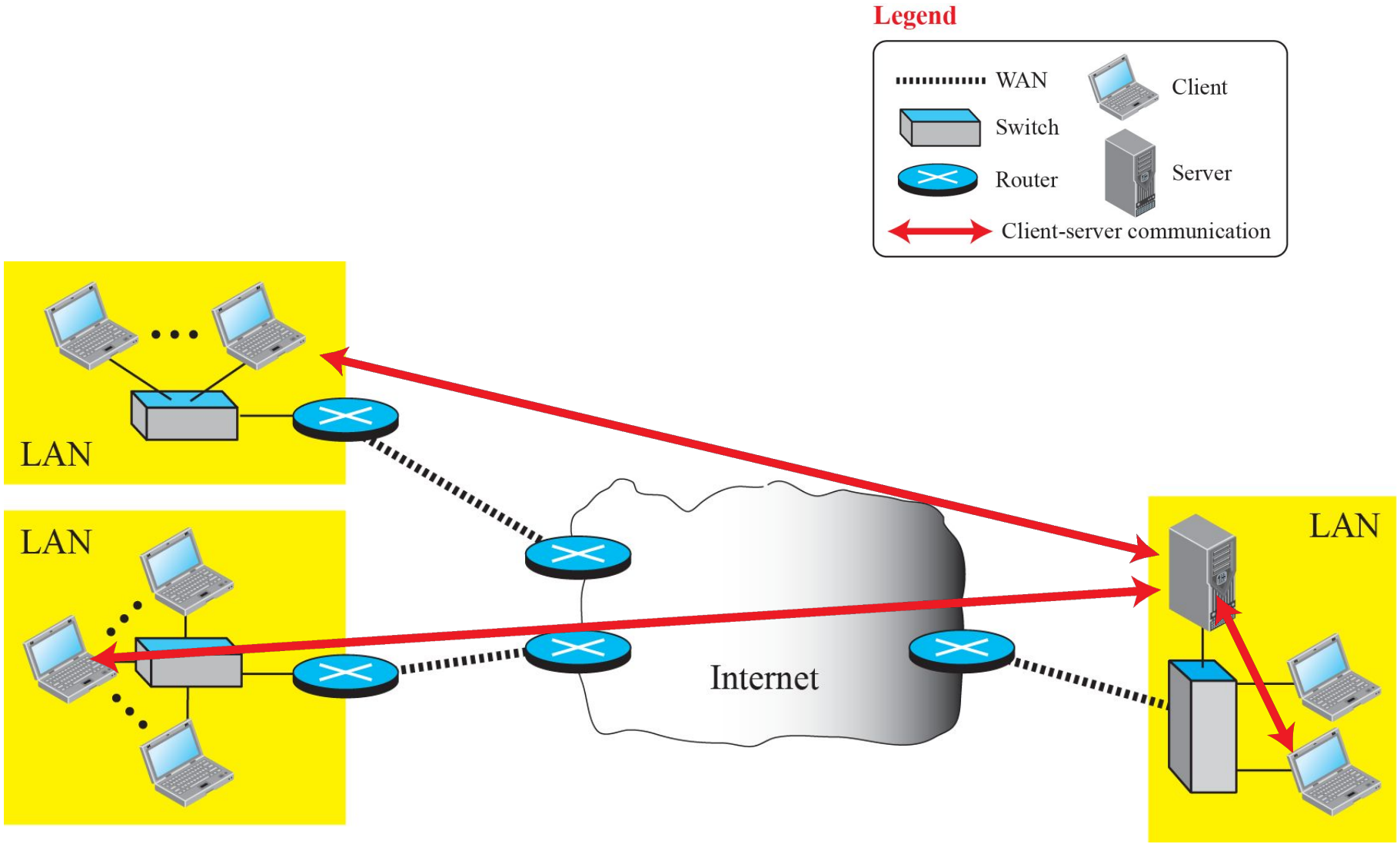
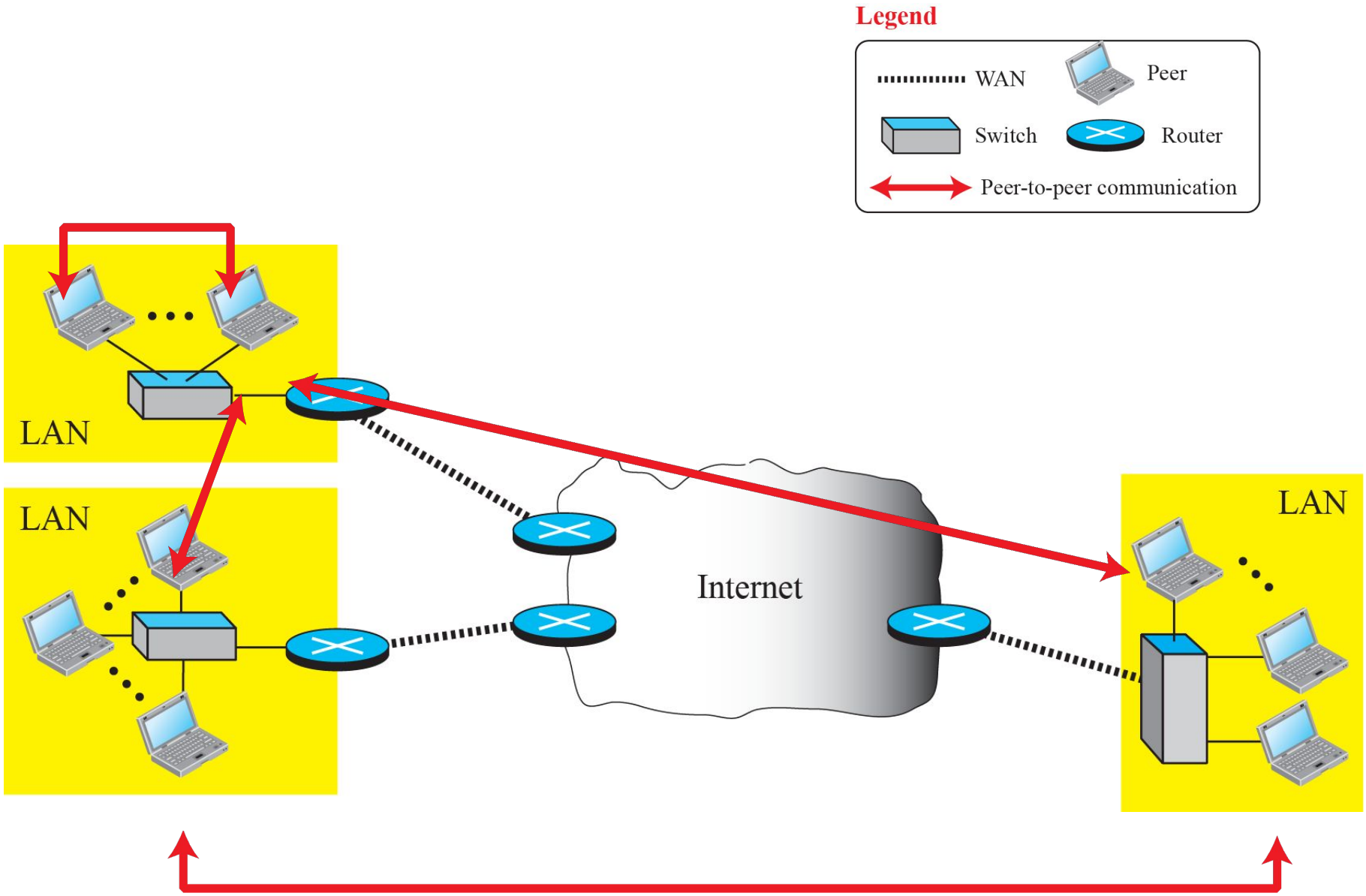


Figure 2.3: Example of a peer-to-peer paradigm



2-2 CLIENT-SERVER PARADIGM

In this paradigm, communication at the application layer is between two running application programs called processes: a client and a server. A client is a running program that initializes the communication by sending a request; a server is another application program that waits for a request from a client.

2.2.1 Application Programming Interface

A computer language has a set of instructions for mathematical operations, a set of instructions for string manipulation, a set of instructions for input/output access, and so on. **If we need a process to be able to communicate with another process, we need a new set of instructions to tell the lowest four layers** ***of the TCP/IP suite to open the connection, send and receive data from the other end, and close the connection. A set of instructions of this kind is normally referred to as Application Programming Interface (API).***

2.2.1 (continued)

- *Sockets*
- *Socket Addresses*
- *Finding Socket Addresses*
  - *Server Site*
  - *Client Site*

Figure 2.4: Position of the socket interface

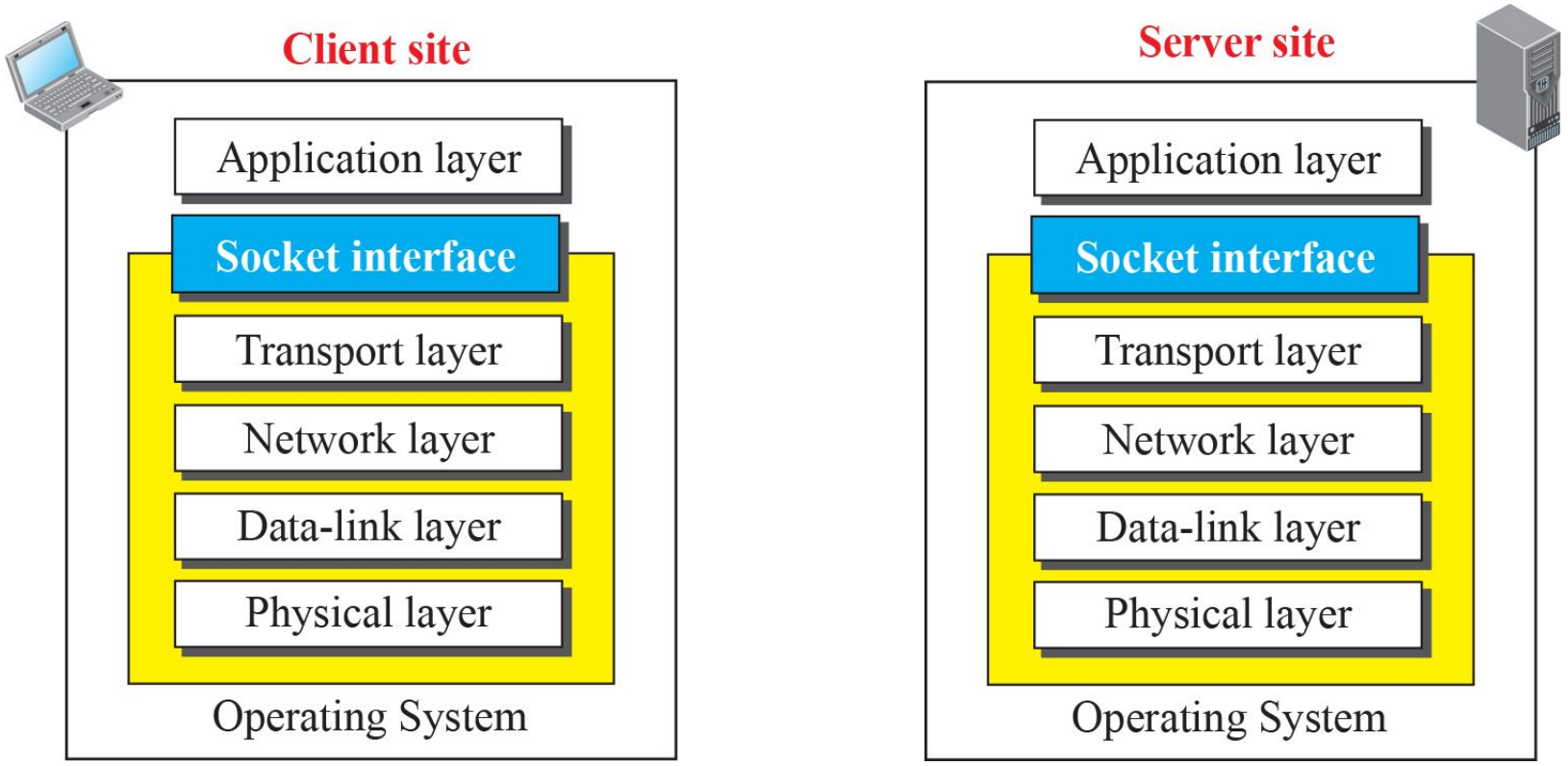


Figure 2.5: A Sockets used like other sources and sinks

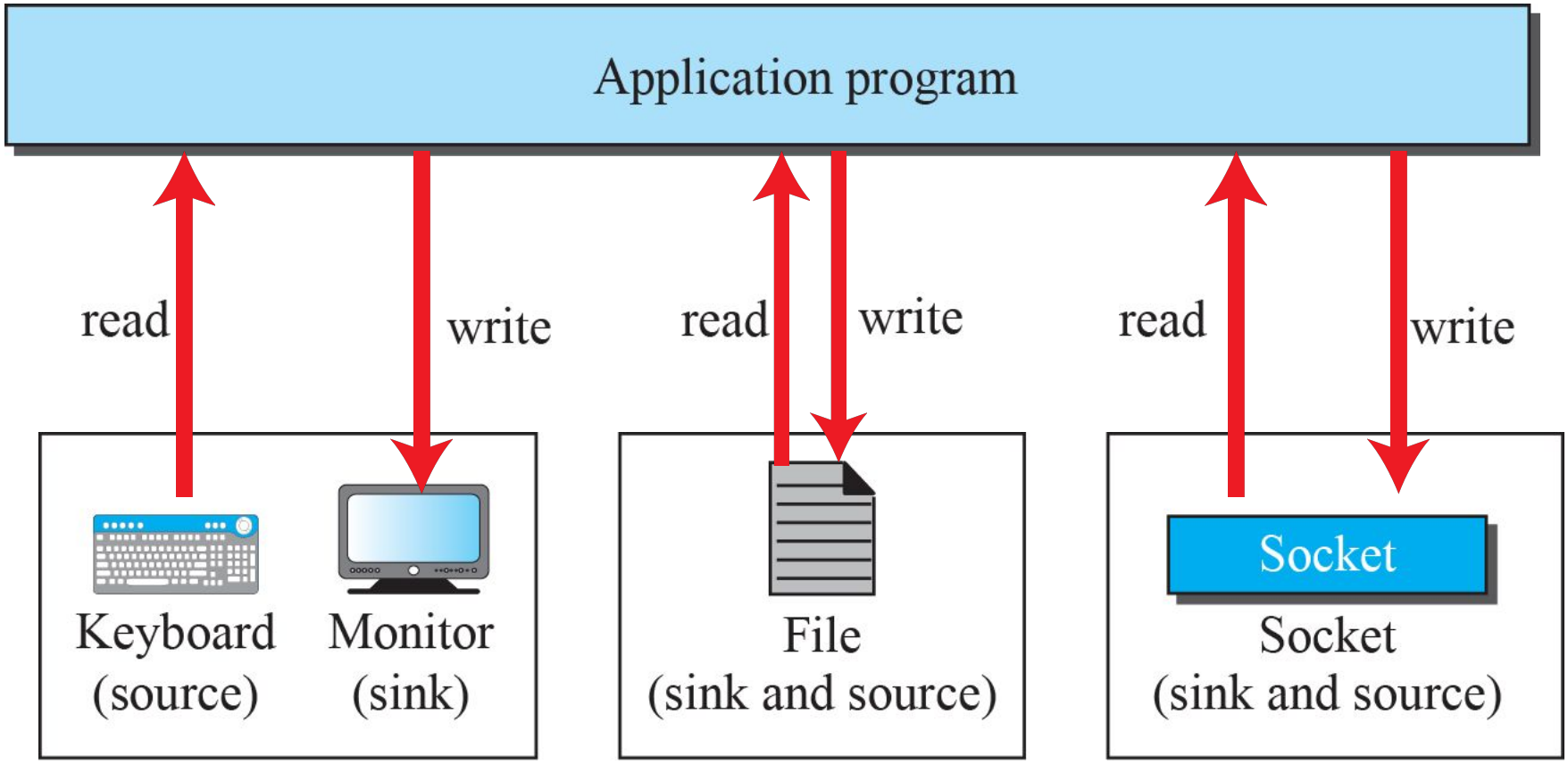


Figure 2.6: Use of sockets in process-to-process communication

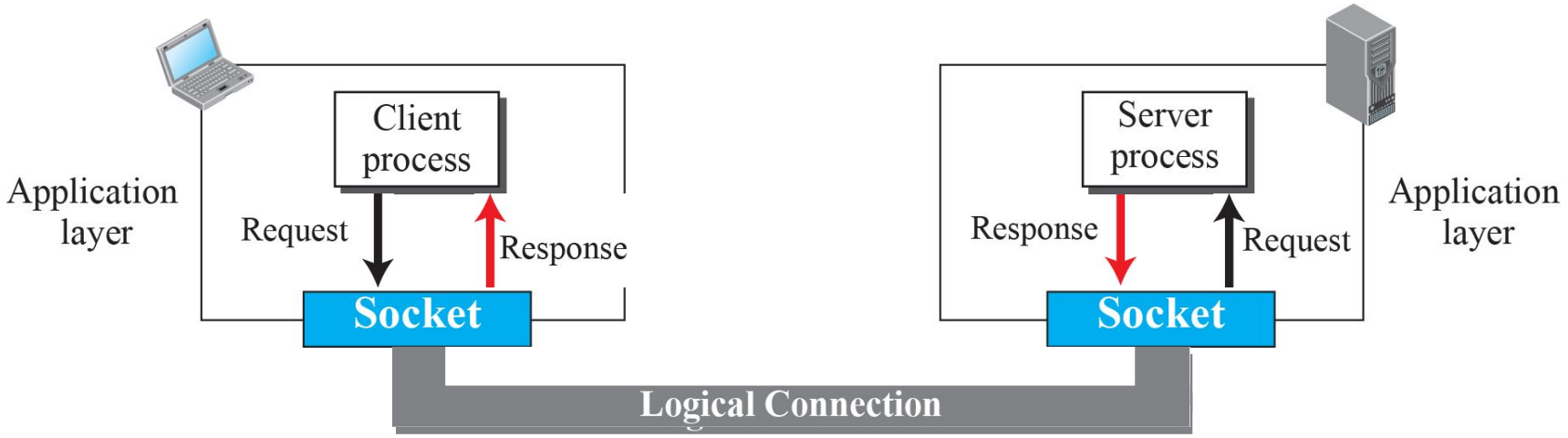


Figure 2.7: A socket address

Example 2.1

We can find a two-level address in telephone communication. A telephone number can define an organization, and an extension can define a specific connection in that organization. The telephone number in this case is similar to the IP address, which defines the whole organization; the extension is similar to the port number, which defines the particular connection.

2.2.2 Using Services of Transport Layer

A pair of processes provide services to the users of the Internet, human or programs. A pair of processes, however, need to use the services provided by the transport layer for communication because there is no physical communication at the application layer. There are three common transport layer protocols in the TCP/IP suite: UDP, TCP, and SCTP.

- *UDP Protocol*
- *TCP Protocol*
- *SCTP Protocol*

2-3 STANDARD CLIENT-SERVER APPLICATIONS

During the lifetime of the Internet, several application programs have been developed. We do not have to redefine them, but we need to understand what they do. For each application, we also need to know the options available to us. The study of these applications can help us to create customized applications in the future.

2.3.1 World Wide Web and HTTP

In this section, we first introduce the World Wide Web (abbreviated WWW or Web). We then discuss the HyperText Transfer Protocol (HTTP), the most common client-server application program used in relation to the Web.

2.3.1 (continued)

- **World Wide Web**
  - Architecture
  - Uniform Resource Locator (URL)
  - Web Documents
- **HyperText Transfer Protocol (HTTP)**
  - Nonpersistent versus Persistent Connections
  - Message Formats
  - Conditional Request
  - Cookies

2.3.1 (continued)

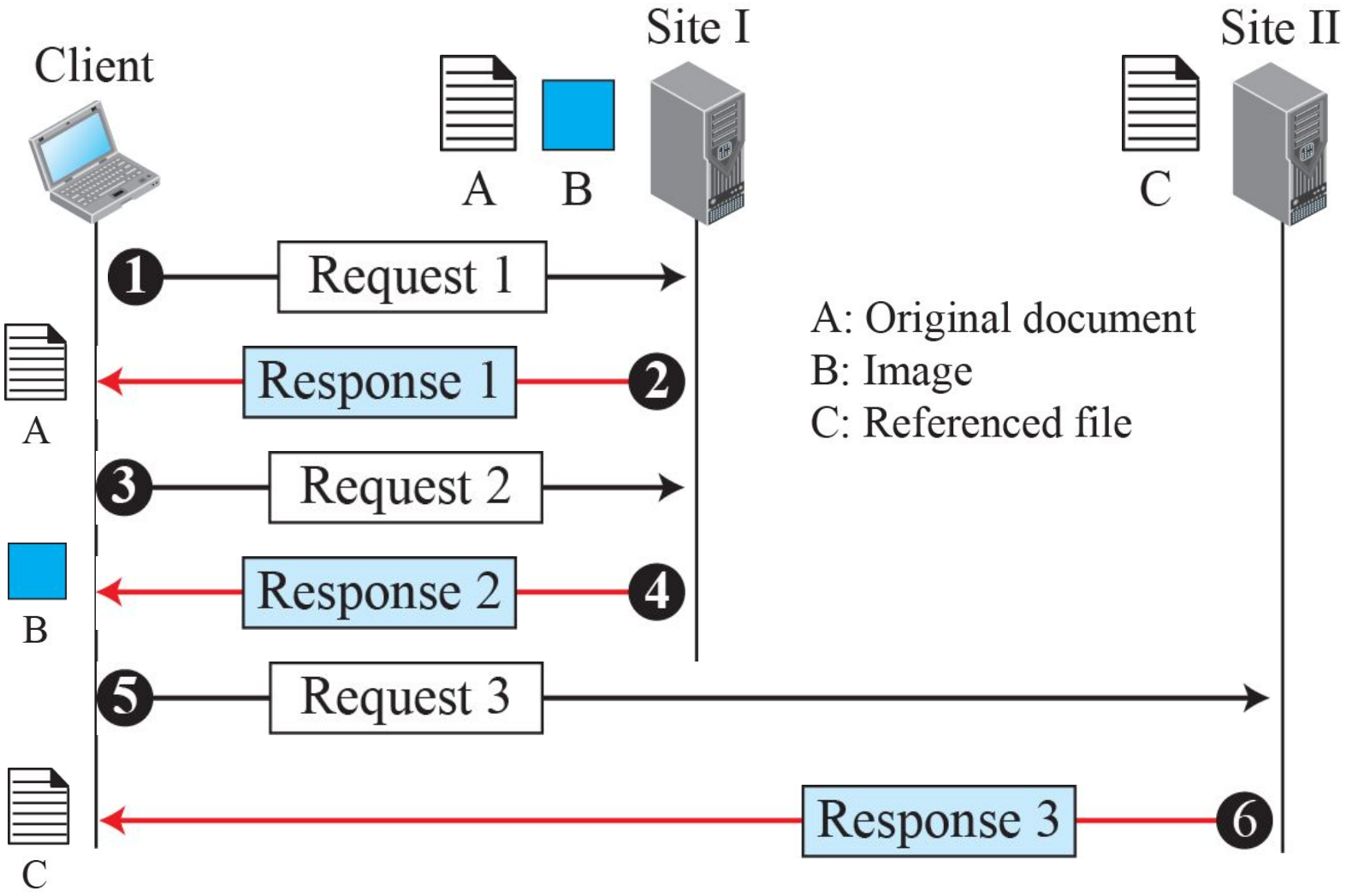
- **Web Caching: Proxy Server**
  - Proxy Server Location
  - Cache Update
- **HTTP Security**

Example 2.2

Assume we need to retrieve a scientific document that contains one reference to another text file and one reference to a large image. Figure 2.8 shows the situation.

The main document and the image are stored in two separate files in the same site (file A and file B); the referenced text file is stored in another site (file C). Since we are dealing with three different files, we need three transactions if we want to see the whole document.

Figure 2.8: Example 2.2 (Retrieving two files and one image



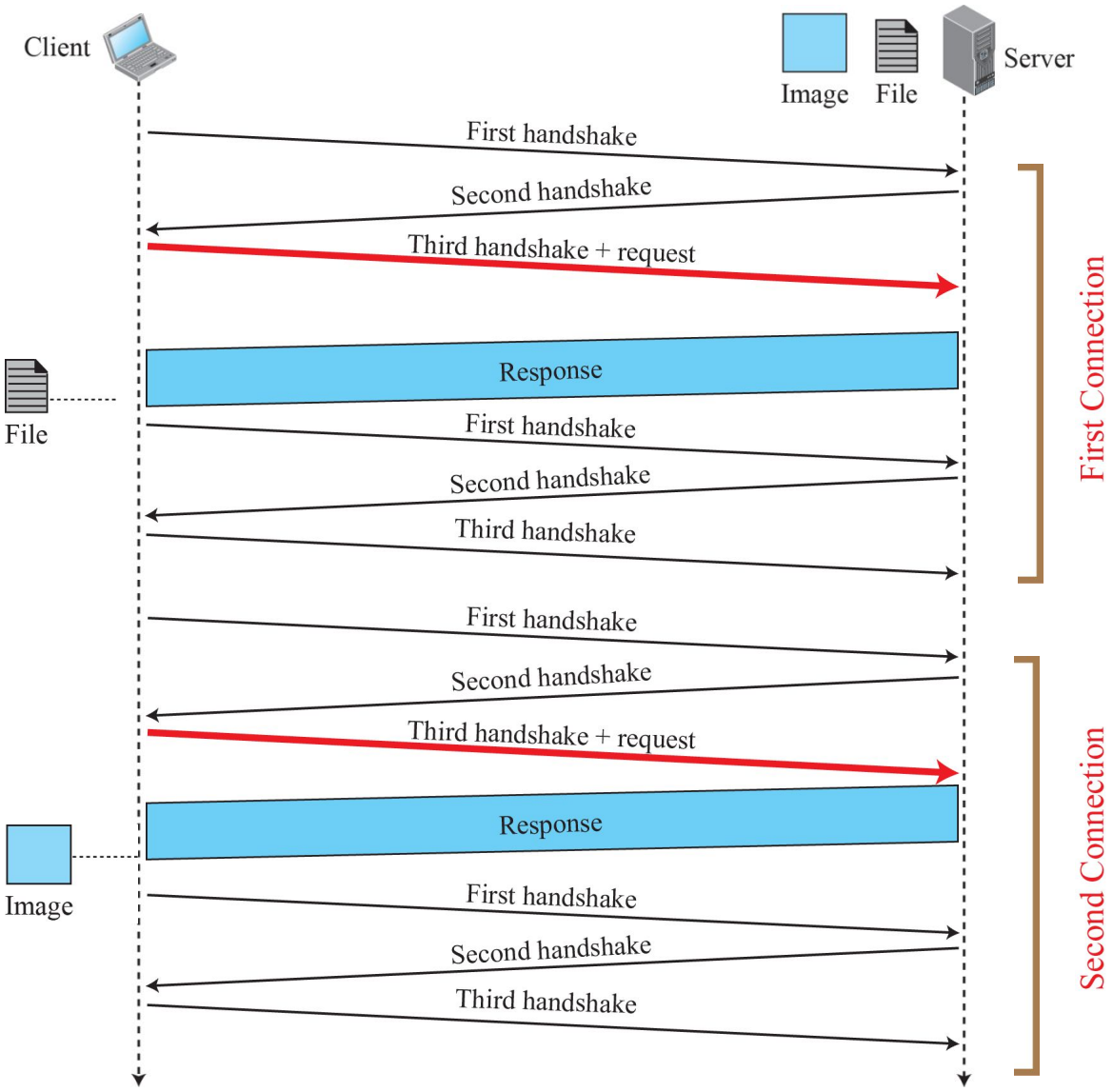
Example 2.3

The URL **http://www.mhhe.com/compsci/forouzan/** defines the web page related to one of the of the computer in the McGraw-Hill company (the three letters www are part of the host name and are added to the commercial host). The path is *compsci/forouzan/*, which defines Forouzan's web page under the directory *compsci* (computer science).

Example 2.4

Figure 2.10 shows an example of a *non-persistent* connection. The client needs to access a file that contains one link to an image. The text file and image are located on the same server. Here we need two connections. For each connection, TCP requires at least three handshake messages to establish the connection, but the request can be sent with the third one. After the connection is established, the object can be transferred. After receiving an object, another three handshake messages are needed to terminate the connection, as we will see in Chapter 3.

Figure 2.10: Example 2.4



Example 2.5

Figure 2.11 shows the same scenario as in Example 2.4, but using a persistent connection. Only one connection establishment and connection termination is used, but the request for the image is sent separately.

Figure 2.11: Example 2.5

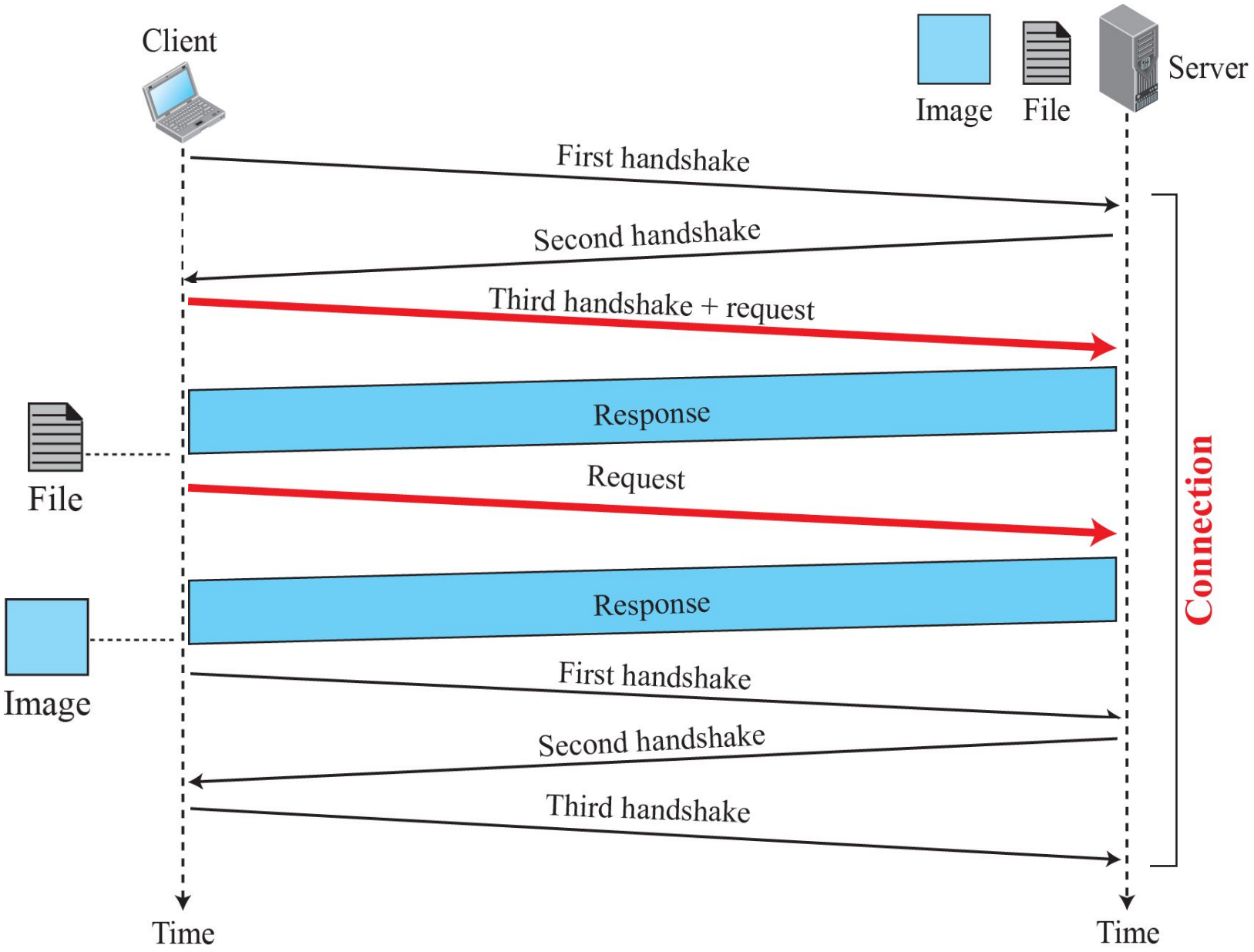


Figure 2.12: Formats of the request and response messages

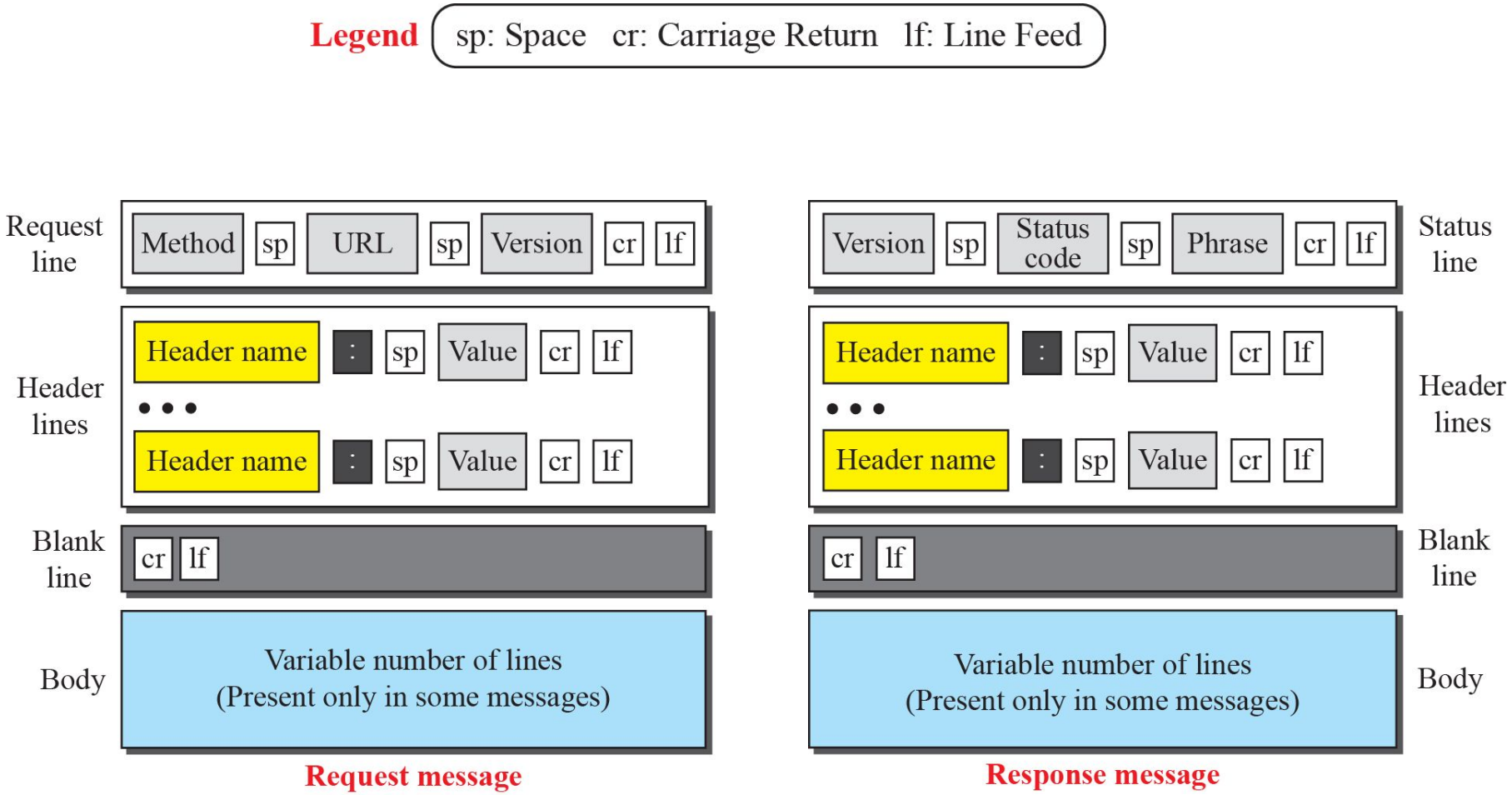


Table 2.1: Methods

Method	*Action*
GET	Requests a document from the server
HEAD	Requests information about a document but not the document itself
PUT	Sends a document from the client to the server
POST	Sends some information from the client to the server
TRACE	Echoes the incoming request
DELETE	Removes the web page
CONNECT	Reserved
OPTIONS	Inquires about available options

Table 2.2: Request Header Names

Header	*Description*
User-agent	Identifies the client program
Accept	Shows the media format the client can accept
Accept-charset	Shows the character set the client can handle
Accept-encoding	Shows the encoding scheme the client can handle
Accept-language	Shows the language the client can accept
Authorization	Shows what permissions the client has
Host	Shows the host and port number of the client
Date	Shows the current date
Upgrade	Specifies the preferred communication protocol
Cookie	Returns the cookie to the server (explained later)
If-Modified-Since	If the file is modified since a specific date

Table 2.3: Response Header Names

Header	*Description*
Date	Shows the current date
Upgrade	Specifies the preferred communication protocol
Server	Gives information about the server
Set-Cookie	The server asks the client to save a cookie
Content-Encoding	Specifies the encoding scheme
Content-Language	Specifies the language
Content-Length	Shows the length of the document
Content-Type	Specifies the media type
Location	To ask the client to send the request to another site
Accept-Ranges	The server will accept the requested byte-ranges
Last-modified	Gives the date and time of the last change

Example

This example retrieves a document (see Figure 2.13). We use the GET method to retrieve an image with the path **/usr/bin/image1**. The request line shows the method (GET), the URL, and the HTTP version (1.1). The header has two lines that show that the client can accept images in the GIF or JPEG format. The request does not have a body. The response message contains the status line and four lines of header. The header lines define the date, server, content encoding (MIME version, which will be described in electronic mail), and length of the document. The body of the document follows the header..

Figure 2.13: Example 2.6

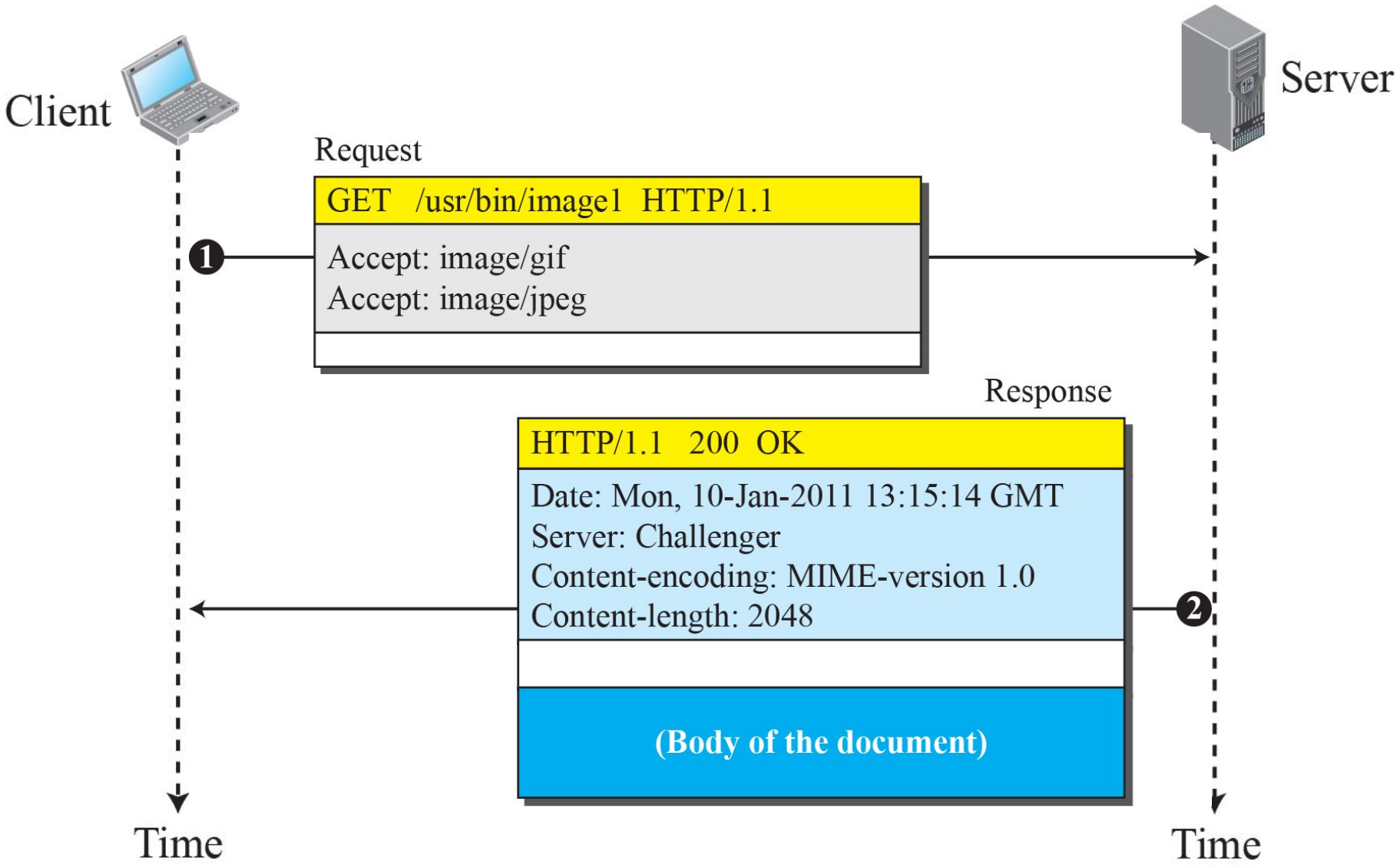
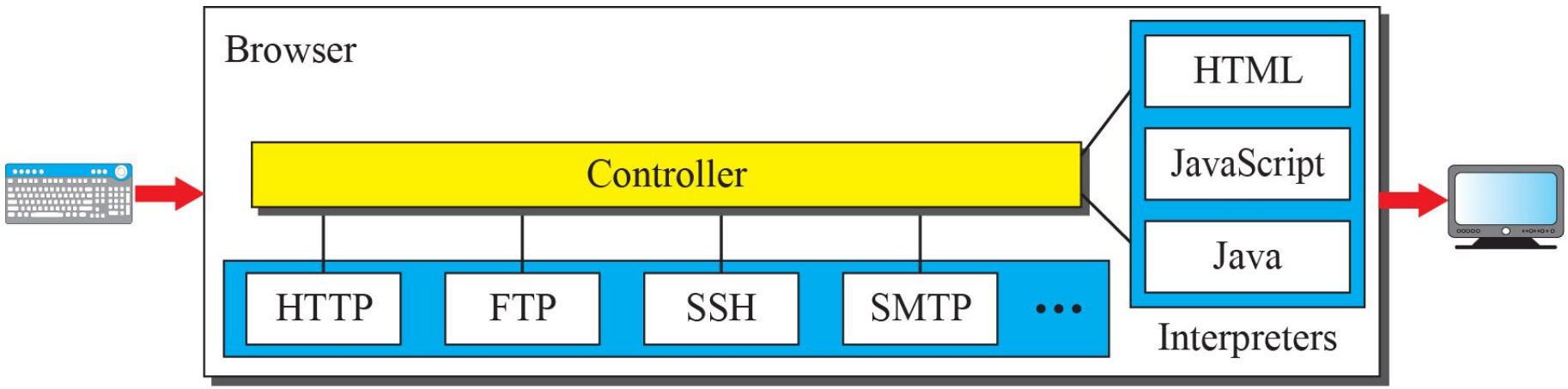


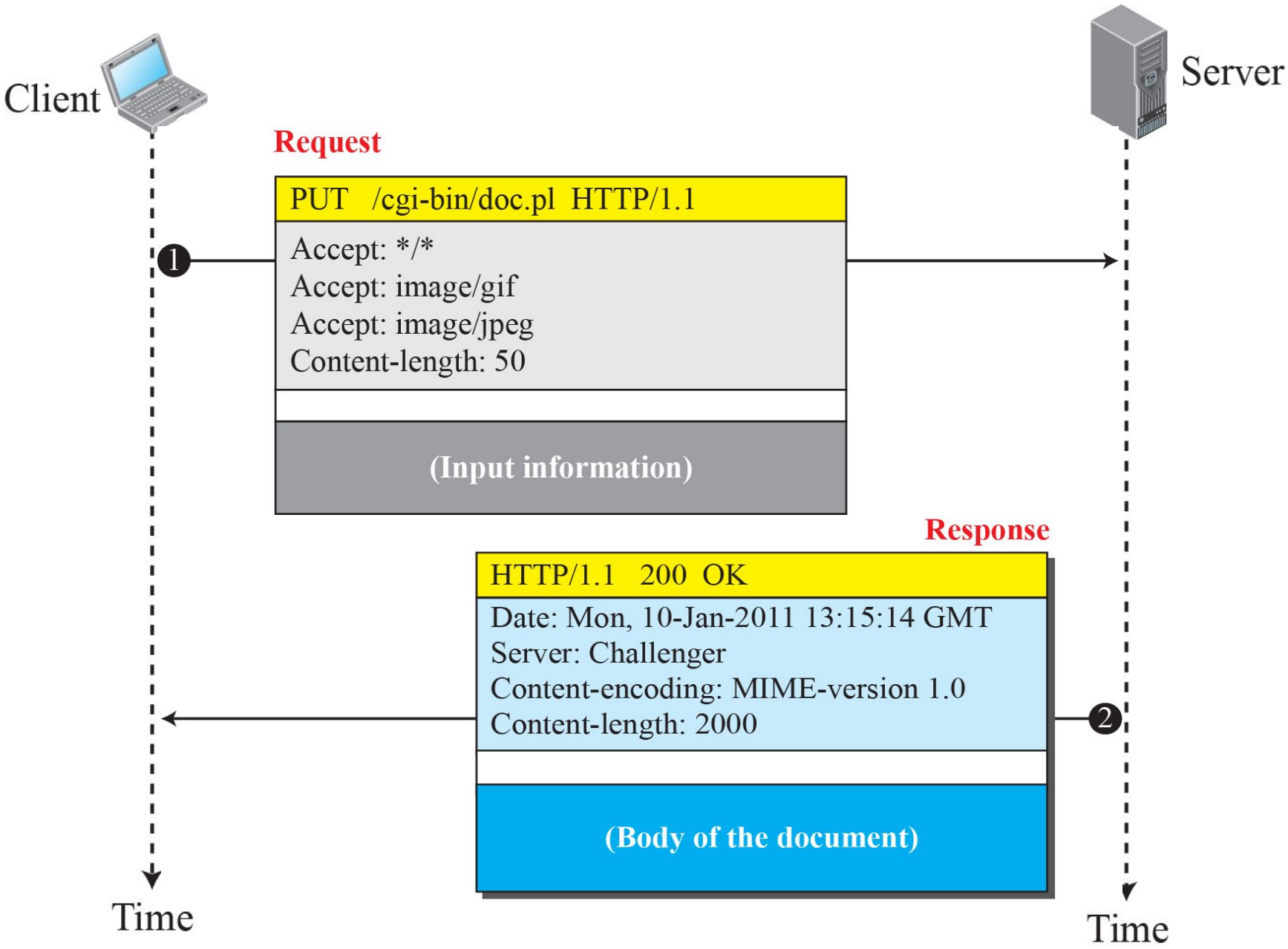
Figure 2.9: ***Browser***



Example 2.7

In this example, the client wants to send a web page to be posted on the server. We use the PUT method. The request line shows the method (PUT), URL, and HTTP version (1.1). There are four lines of headers. The request body contains the web page to be posted. The response message contains the status line and four lines of headers. The created document, which is a CGI document, is included as the body (see Figure 2.14).

Figure 2.14: Example 2.7



Example 2.8

The following shows how a client imposes the modification on data and time condition on a request.

GET http://www.commonServer.com/information/file1 HTTP/1.1	Request line
If-Modified-Since: Thu, Sept 04 00:00:00 GMT	Header line
	Blank line

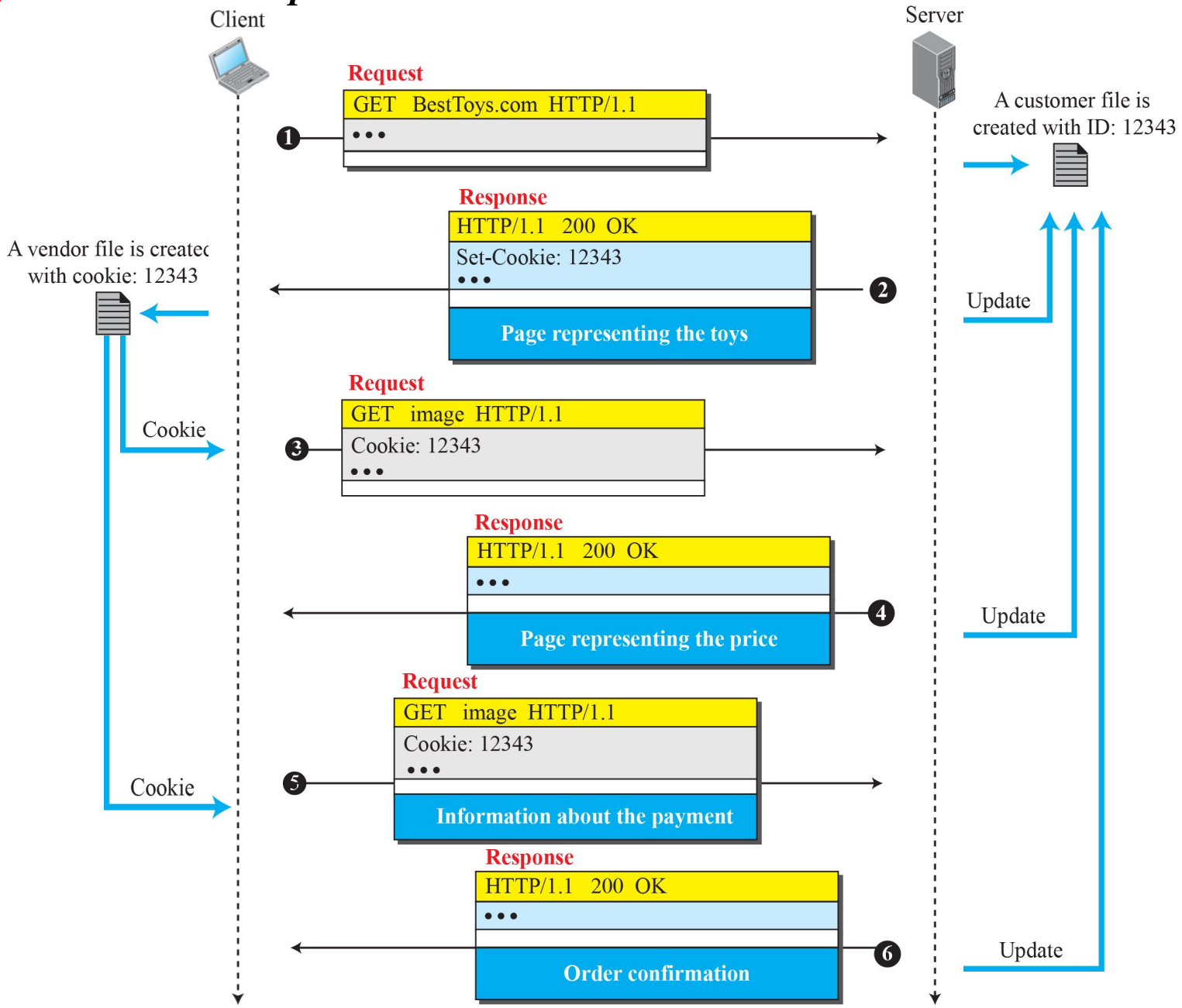
The status line in the response shows the file was not modified after the defined point in time. The body of the response message is also empty.

HTTP/1.1 304 Not Modified	Status line
Date: Sat, Sept 06 08 16:22:46 GMT	First header line
Server: commonServer.com	Second header line
	Blank line
(Empty Body)	Empty body

Example 2.9

Figure 2.15 shows a scenario in which an electronic store can benefit from the use of cookies. Assume a shopper wants to buy a toy from an electronic store named BestToys. The shopper browser (client) sends a request to the BestToys server. The server creates an empty shopping cart (a list) for the client and assigns an ID to the cart (for example, 12343). The server then sends a response message, which contains the images of all toys available, with a link under each toy that selects the toy if it is being clicked. This response message also includes the Set-Cookie header line whose value is 12343. The client displays the images and stores the cookie value in a file named BestToys.

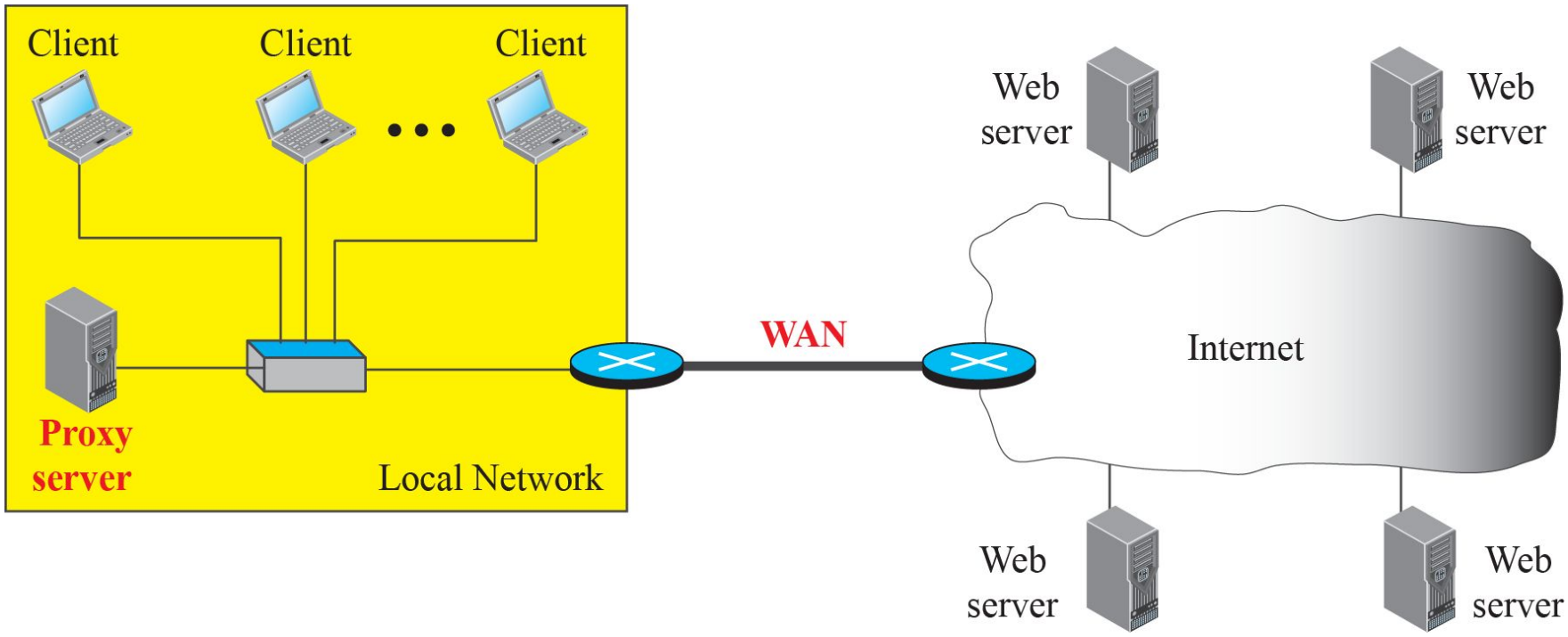
Figure 2.15: Example 2.9



Example 2.10

Figure 2.16 shows an example of a use of a proxy server in a local network, such as the network on a campus or in a company. The proxy server is installed in the local network. When an HTTP request is created by any of the clients (browsers), the request is first directed to the proxy server If the proxy server already has the corresponding web page, it sends the response to the client. Otherwise, the proxy server acts as a client and sends the request to the web server in the Internet. When the response is returned, the proxy server makes a copy and stores it in its cache before sending it to the requesting client.

Figure 2.16: Example of a proxy server



2.3.2 FTP

File Transfer Protocol (FTP) is the standard protocol provided by TCP/IP for copying a file from one host to another. Although transferring files from one system to another seems simple and straightforward, some problems must be dealt with first. For example, two systems may use different file name conventions. Two systems may have different ways to represent data. All of these problems have been solved by FTP in a very simple and elegant approach.

2.3.2 (continued)

- *Lifetimes of Two Connections*
- *Control Connection*
- *Data Connection*
  - *Communication over Data Connection*
  - *File Transfer*
- *Security for FTP*

Figure 2.17: FTP

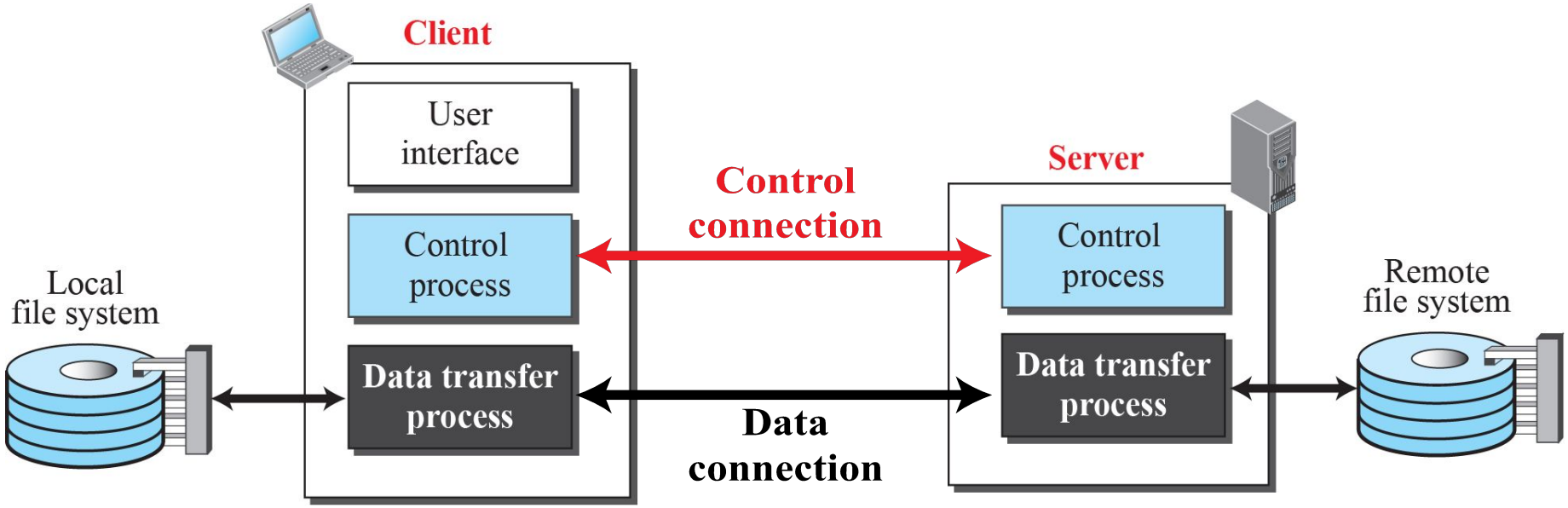


Table 2.4: Some FTP commands

Command	*Argument(s)*	*Description*
ABOR		Abort the previous command
CDUP		Change to parent directory
CWD	Directory name	Change to another directory
DELE	File name	Delete a file
LIST	Directory name	List subdirectories or files
MKD	Directory name	Create a new directory
PASS	User password	Password
PASV		Server chooses a port
PORT	port identifier	Client chooses a port
PWD		Display name of current directory
QUIT		Log out of the system
RETR	File name(s)	Retrieve files; files are transferred from server to client
RMD	Directory name	Delete a directory
RNFR	File name (old)	Identify a file to be renamed

Table 2.4: Some FTP commands (continued)

Command	*Argument(s)*	*Description*
RNTO	File name (new)	Rename the file
STOR	File name(s)	Store files; file(s) are transferred from client to server
STRU	**F**, **R**, or **P**	Define data organization (**F**: file, **R**: record, or **P**: page)
TYPE	**A**, **E**, **I**	Default file type (**A**: ASCII, **E**: EBCDIC, **I**: image)
USER	User ID	User information
MODE	**S**, **B**, or **C**	Define transmission mode (**S**: stream, **B**: block, or **C**: compressed

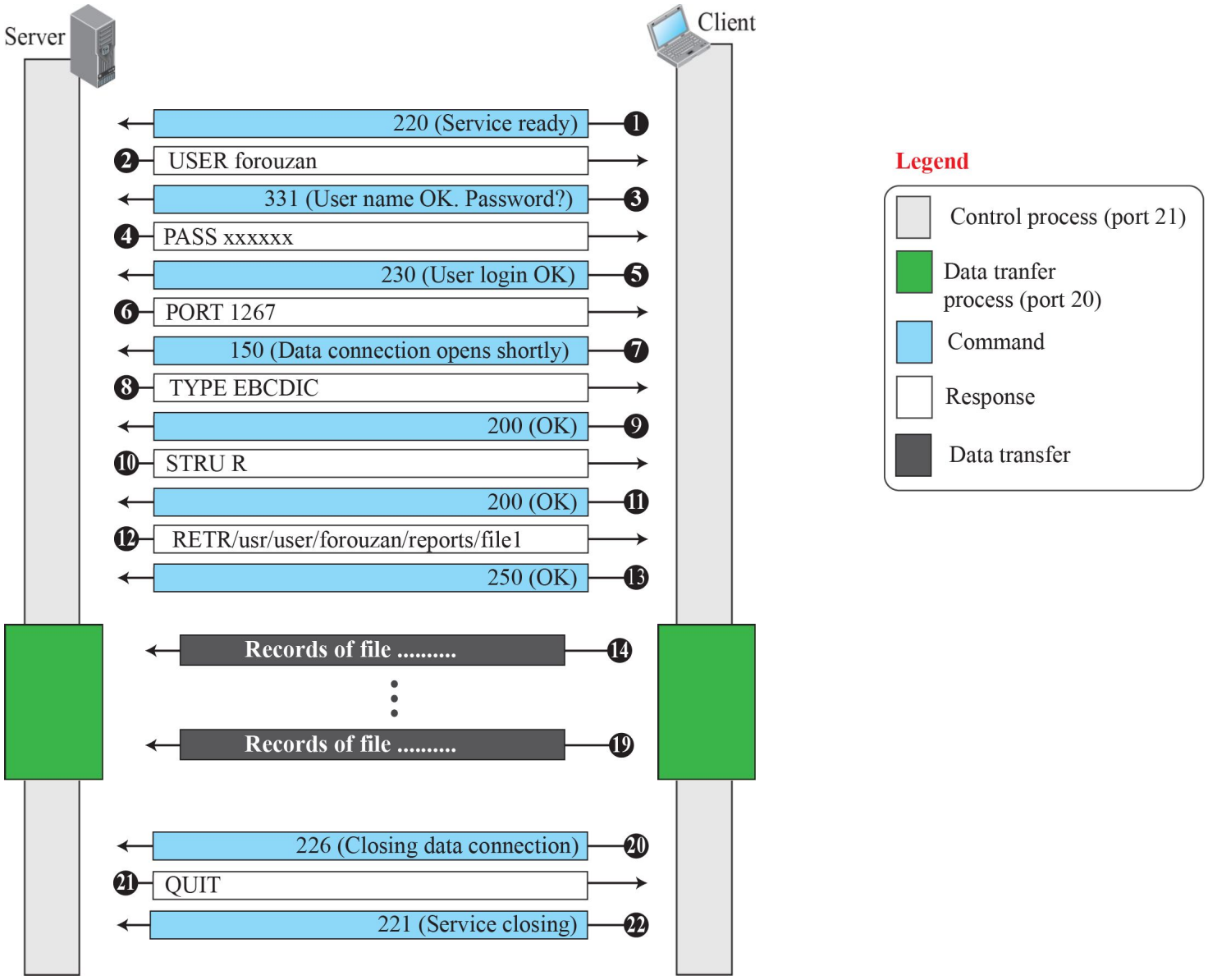
Table 2.5: Some responses in FTP

Code	Description	Code	Description
125	Data connection open	250	Request file action OK
150	File status OK	331	User name OK; password is needed
200	Command OK	425	Cannot open data connection
220	Service ready	450	File action not taken; file not available
221	Service closing	452	Action aborted; insufficient storage
225	Data connection open	500	Syntax error; unrecognized command
226	Closing data connection	501	Syntax error in parameters or arguments
230	User login OK	530	User not logged in

Example 2.11

Figure 2.18 shows an example of using FTP for retrieving a file. The figure shows only one file to be transferred. The control connection remains open all the time, but the data connection is opened and closed repeatedly. We assume the file is transferred in six sections. After all records have been transferred, the server control process announces that the file transfer is done. Since the client control process has no file to retrieve, it issues the QUIT command, which causes the service connection to be closed.

Figure 2.18: Example 2.11



Example 2.12

The following shows an actual FTP session that lists the directories.

```
$ ftp voyager.deanza.fhda.edu
Connected to voyager.deanza.fhda.edu.
220 (vsFTPd 1.2.1)
530 Please login with USER and PASS.
Name (voyager.deanza.fhda.edu:forouzan): forouzan
331 Please specify the password.
Password:**********
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
227 Entering Passive Mode (153,18,17,11,238,169)
150 Here comes the directory listing.
drwxr-xr-x    2    3027    411    4096    Sep 24    2002    business
drwxr-xr-x    2    3027    411    4096    Sep 24    2002    personal
drwxr-xr-x    2    3027    411    4096    Sep 24    2002    school
226 Directory send OK.
ftp> quit
221 Goodbye.
```

2.3.3 Electronic Mail

Electronic mail (or e-mail) allows users to exchange messages. The nature of this application, however, is different from other applications discussed so far. In an application such as HTTP or FTP, the server program is running all the time, waiting for a request from a client. When the request arrives, the server provides the service. In the case of electronic mail, the situation is different.

2.3.3 Continued

First, e-mail is considered a one-way transaction. When Alice sends an e-mail to Bob, she may expect a response, but this is not a mandate. Bob may or may not respond. If he does respond, it is another one-way transaction. Second, it is neither feasible nor logical for Bob to run a server program and wait until someone sends an e-mail to him. Bob may turn off his computer when he is not using it. This means that the idea of client/ server programming should be implemented in another way: using some intermediate computers (servers).

2.3.3 (continued)

- *Architecture*

- *User Agent*
  - *Sending Mail*
  - *Receiving Mail*
  - *Addresses*
  - *Mailing List or Group List*

2.3.1 (continued)

- *MIME*
  - *MIME Headers*
- *Web-Based Mail*
  - *Case I*
  - *Case II*
- *E-Mail Security*

2.3.1 (continued)

- ***Message Transfer Agent: SMTP***
  - ***Commands and Responses***
  - ***Mail Transfer Phases***
- ***Message Access Agent: POP and IMAP***
  - ***POP3***
  - ***IMAP4***

Figure 2.19: Common scenario

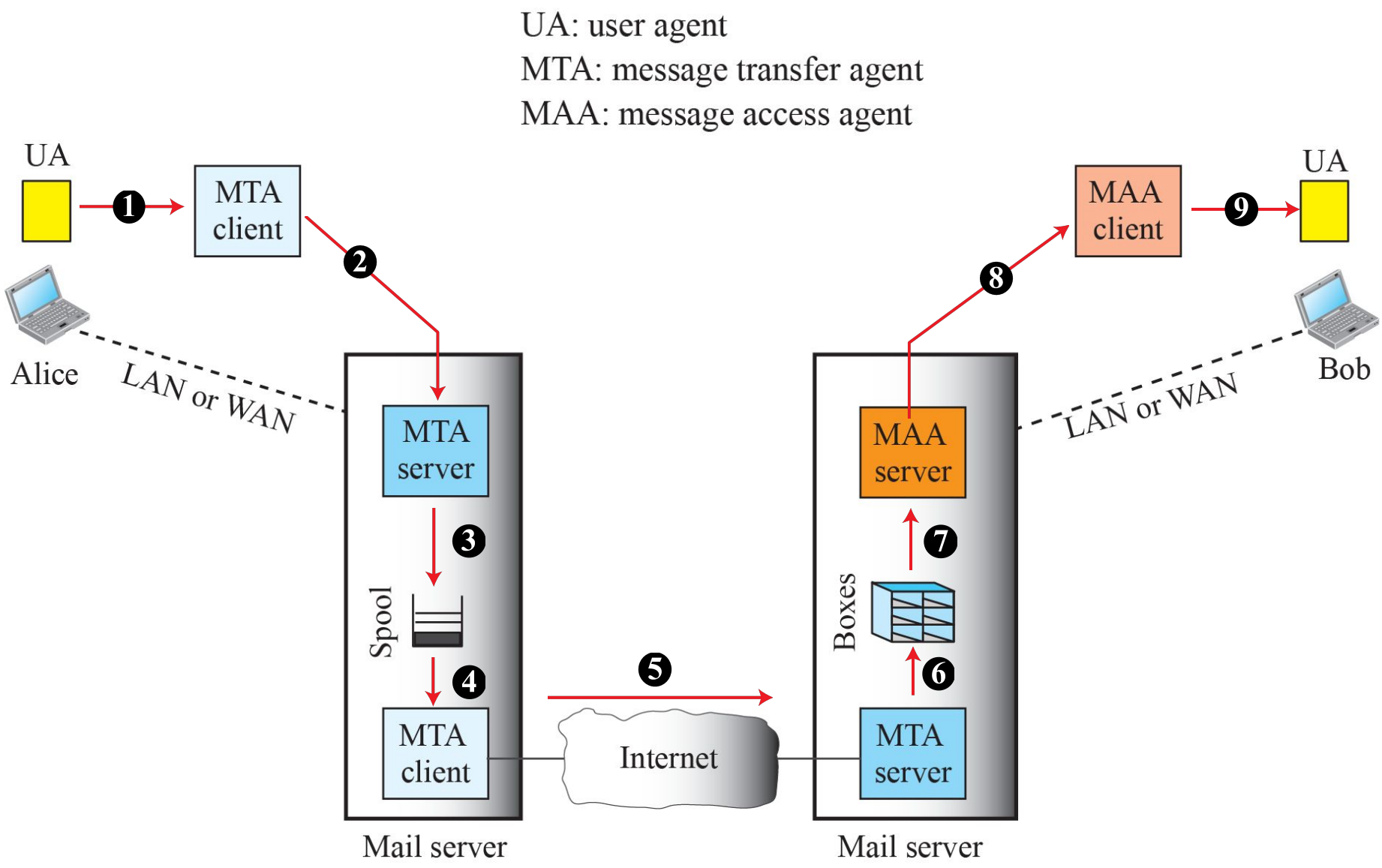


Figure 2.20: Format of an e-mail

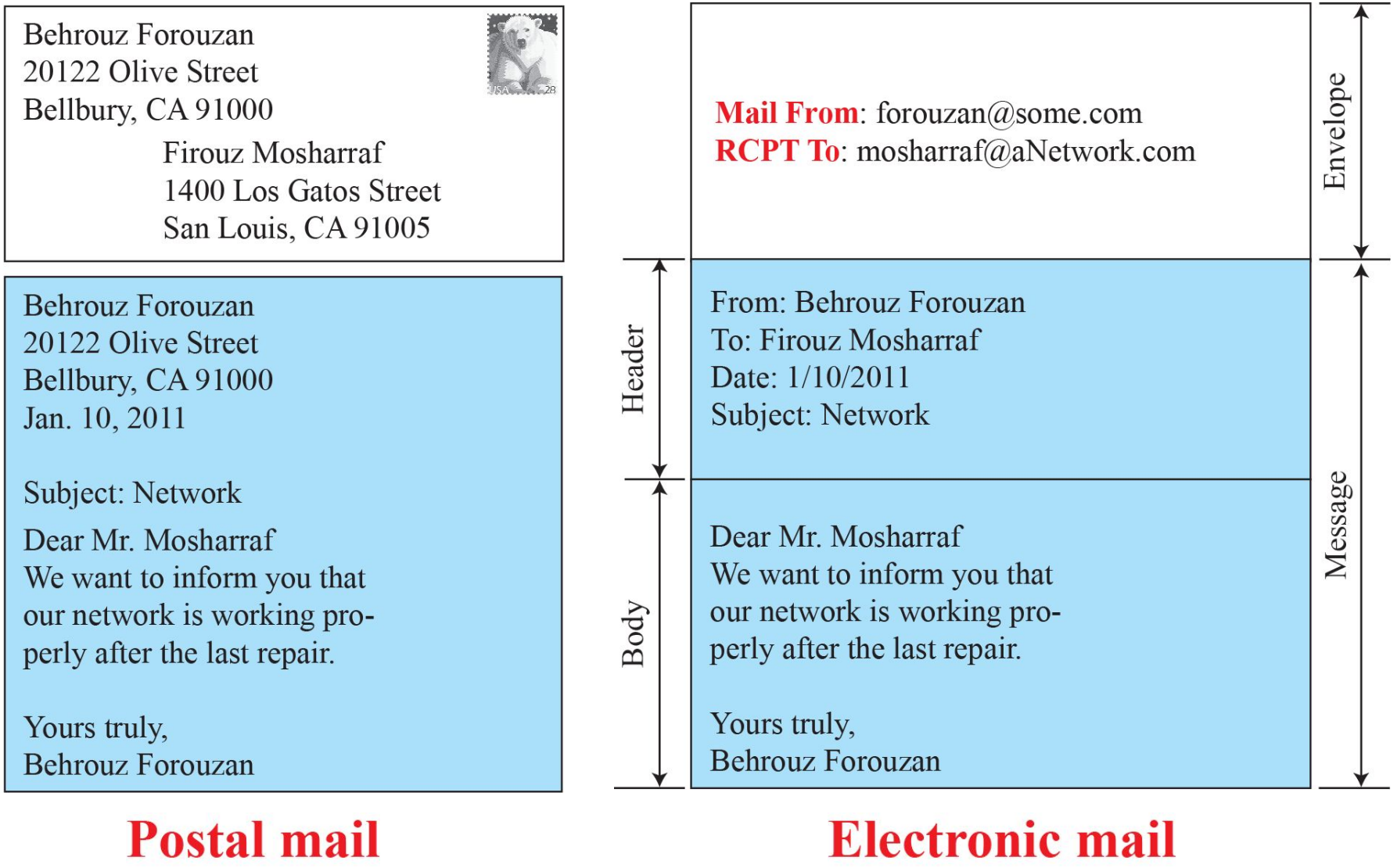


Figure 2.21: E-mail address

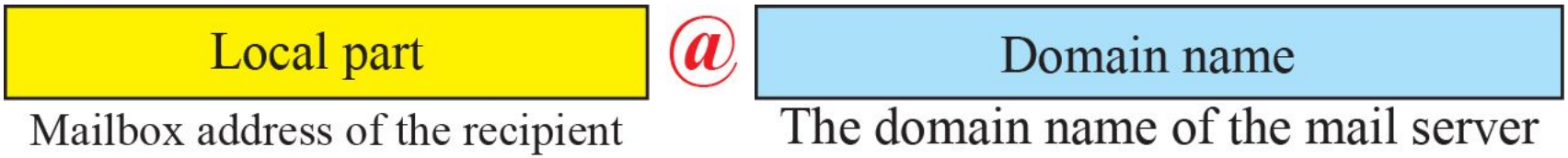


Figure 2.22: Protocols used in electronic mail

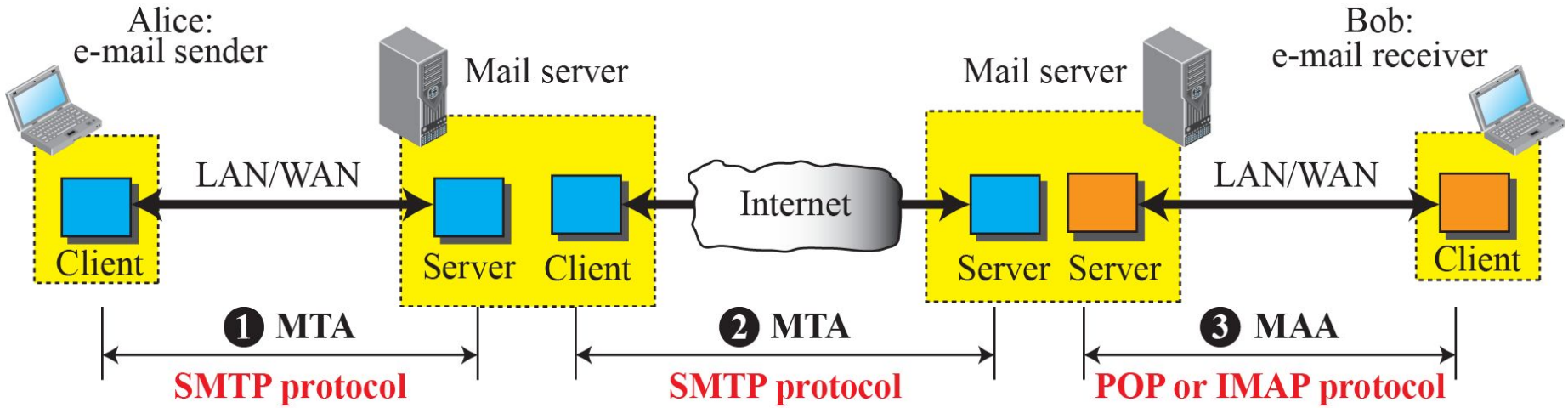


Table 2.7: SMTP responses

Code	*Description*
	Positive Completion Reply
211	System status or help reply
214	Help message
220	Service ready
221	Service closing transmission channel
250	Request command completed
251	User not local; the message will be forwarded
	Positive Intermediate Reply
354	Start mail input
	Transient Negative Completion Reply
421	Service not available
450	Mailbox not available
451	Command aborted: local error
452	Command aborted; insufficient storage

Table 2.6: SMTP Commands

Keyword	*Argument(s)*	*Description*
HELO	Sender's host name	Identifies itself
MAIL FROM	Sender of the message	Identifies the sender of the message
RCPT TO	Intended recipient	Identifies the recipient of the message
DATA	Body of the mail	Sends the actual message
QUIT		Terminates the message
RSET		Aborts the current mail transaction
VRFY	Name of recipient	Verifies the address of the recipient
NOOP		Checks the status of the recipient
TURN		Switches the sender and the recipient
EXPN	Mailing list	Asks the recipient to expand the mailing list.
HELP	Command name	Asks the recipient to send information about the command sent as the argument
SEND FROM	Intended recipient	Specifies that the mail be delivered only to the terminal of the recipient, and not to the mailbox
SMOL FROM	Intended recipient	Specifies that the mail be delivered to the terminal *or* the mailbox of the recipient
SMAL FROM	Intended recipient	Specifies that the mail be delivered to the terminal *and* the mailbox of the recipient

Table 2.7: SMTP responses (continued)

Permanent Negative Completion Reply	
500	Syntax error; unrecognized command
501	Syntax error in parameters or arguments
502	Command not implemented
503	Bad sequence of commands
504	Command temporarily not implemented
550	Command is not executed; mailbox unavailable
551	User not local
552	Requested action aborted; exceeded storage location
553	Requested action not taken; mailbox name not allowed
554	Transaction failed

Example 2.13

To show the three mail transfer phases, we show all of the steps described above using the information depicted in Figure 2.23. In the figure, we have separated the messages related to the envelope, header, and body in the data transfer section. Note that the steps in this figure are repeated two times in each e-mail transfer: once from the e-mail sender to the local mail server and once from the local mail server to the remote mail server. The local mail server, after receiving the whole e-mail message, may spool it and send it to the remote mail server at another time.

Figure 2.23: Example 2.13

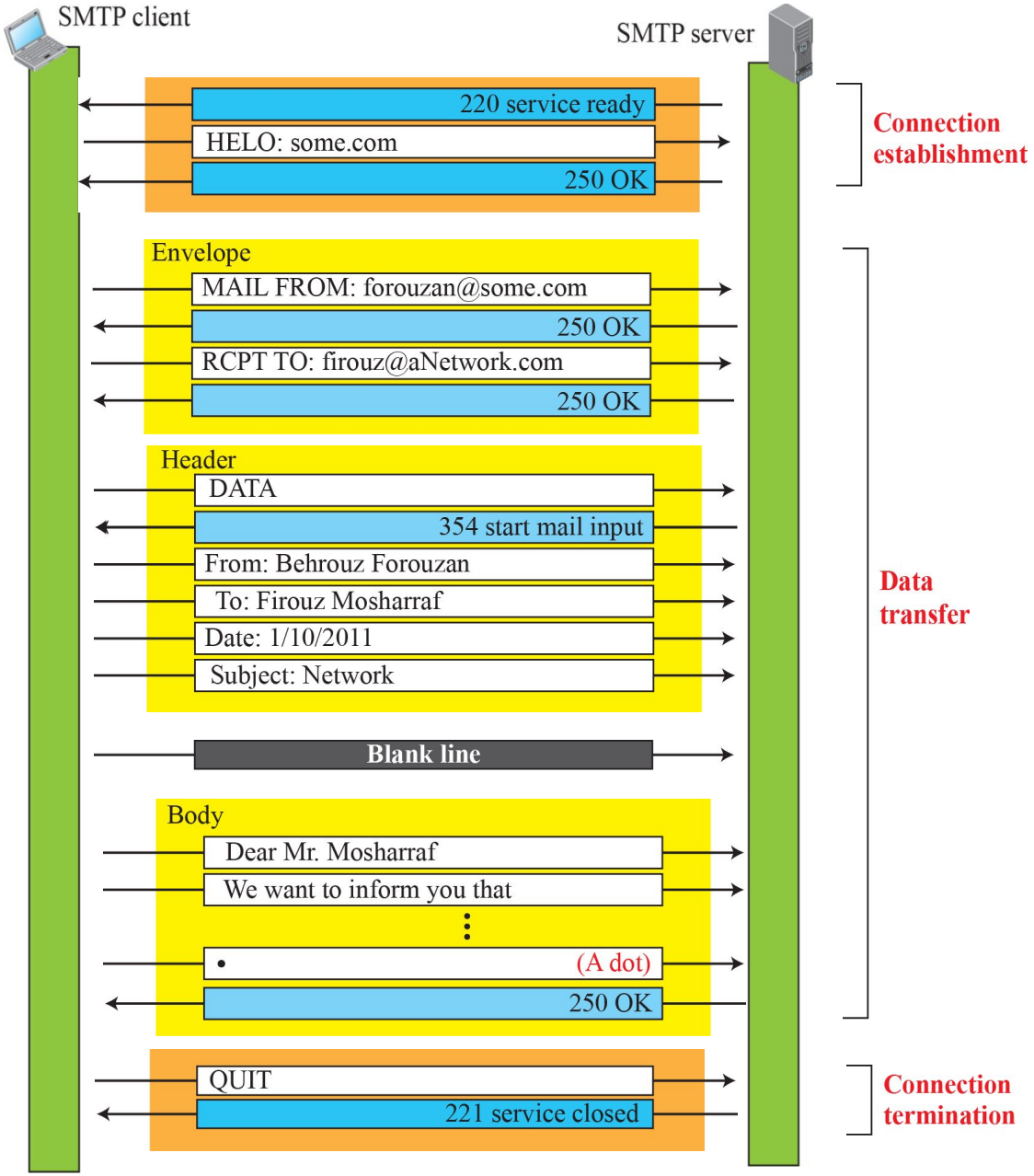


Figure 2.24: POP3

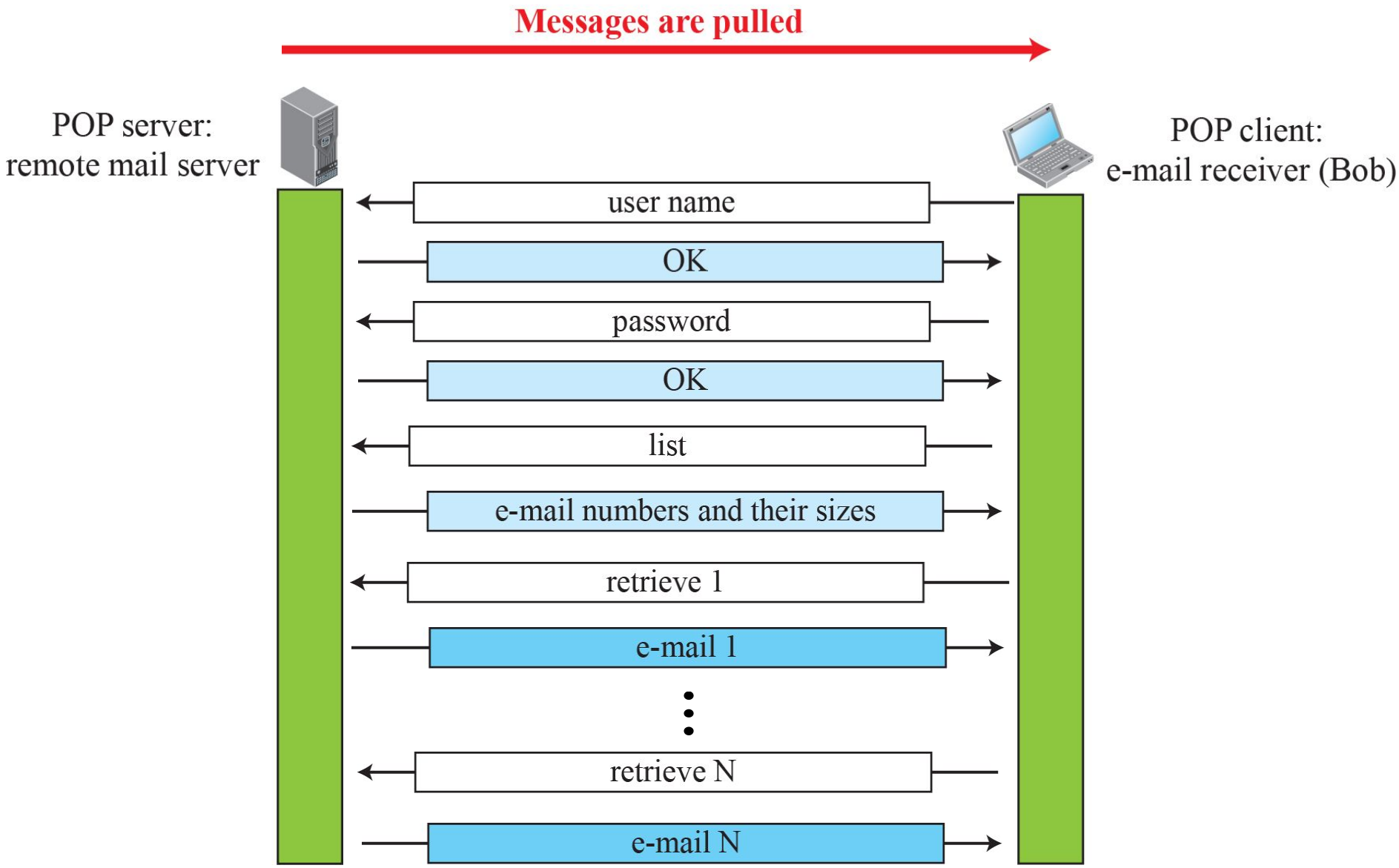


Figure 2.25: MIME

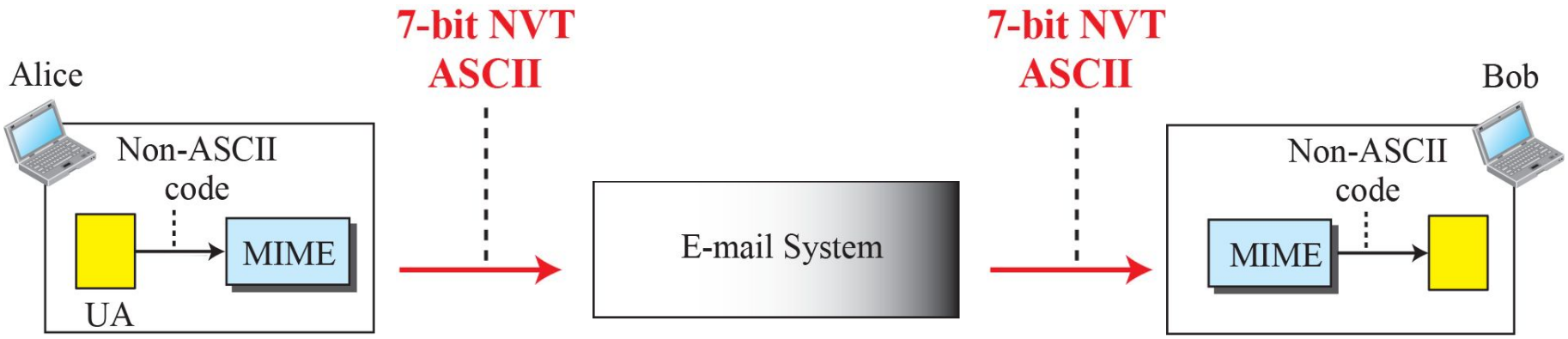


Figure 2.26: MIME header

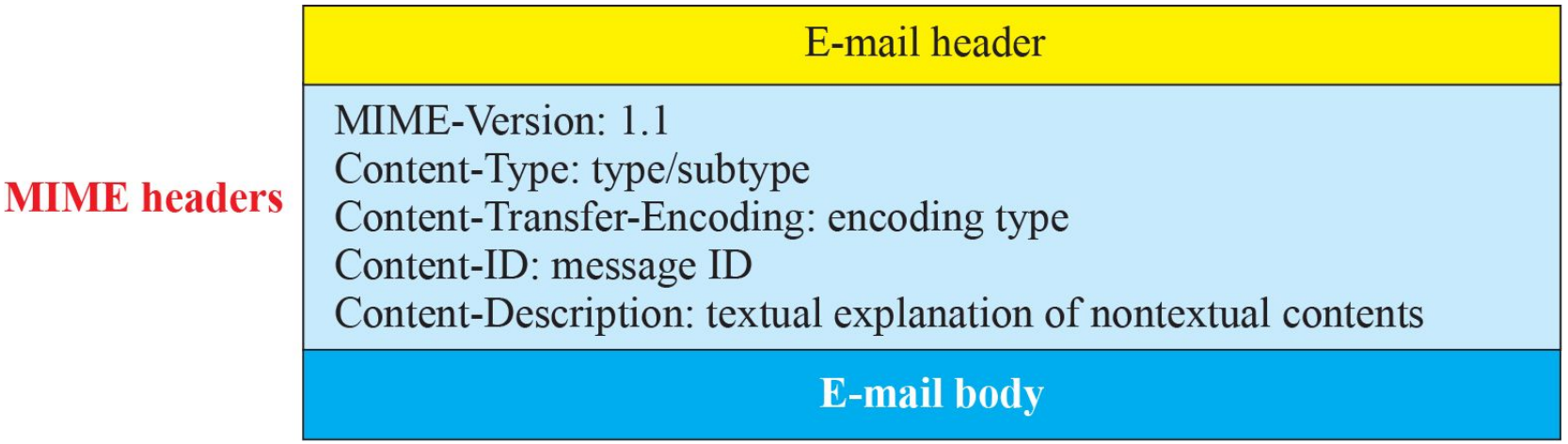


Table 2.8: Data Types and Subtypes in MIME

Type	*Subtype*	*Description*
Text	Plain	Unformatted
	HTML	HTML format (see Appendix C)
Multipart	Mixed	Body contains ordered parts of different data types
	Parallel	Same as above, but no order
	Digest	Similar to Mixed, but the default is message/RFC822
	Alternative	Parts are different versions of the same message
Message	RFC822	Body is an encapsulated message
	Partial	Body is a fragment of a bigger message
	External-Body	Body is a reference to another message
Image	JPEG	Image is in JPEG format
	GIF	Image is in GIF format
Video	MPEG	Video is in MPEG format
Audio	Basic	Single channel encoding of voice at 8 KHz
Application	PostScript	Adobe PostScript
	Octet-stream	General binary data (eight-bit bytes)

Table 2.9: Methods for Content-Transfer-Encoding

Type	*Description*
7-bit	NVT ASCII characters with each line less than 1000 characters
8-bit	Non-ASCII characters with each line less than 1000 characters
Binary	Non-ASCII characters with unlimited-length lines
Base64	6-bit blocks of data encoded into 8-bit ASCII characters
Quoted-printable	Non-ASCII characters encoded as an equal sign plus an ASCII code

Figure 2.27: ***Base64 conversion***

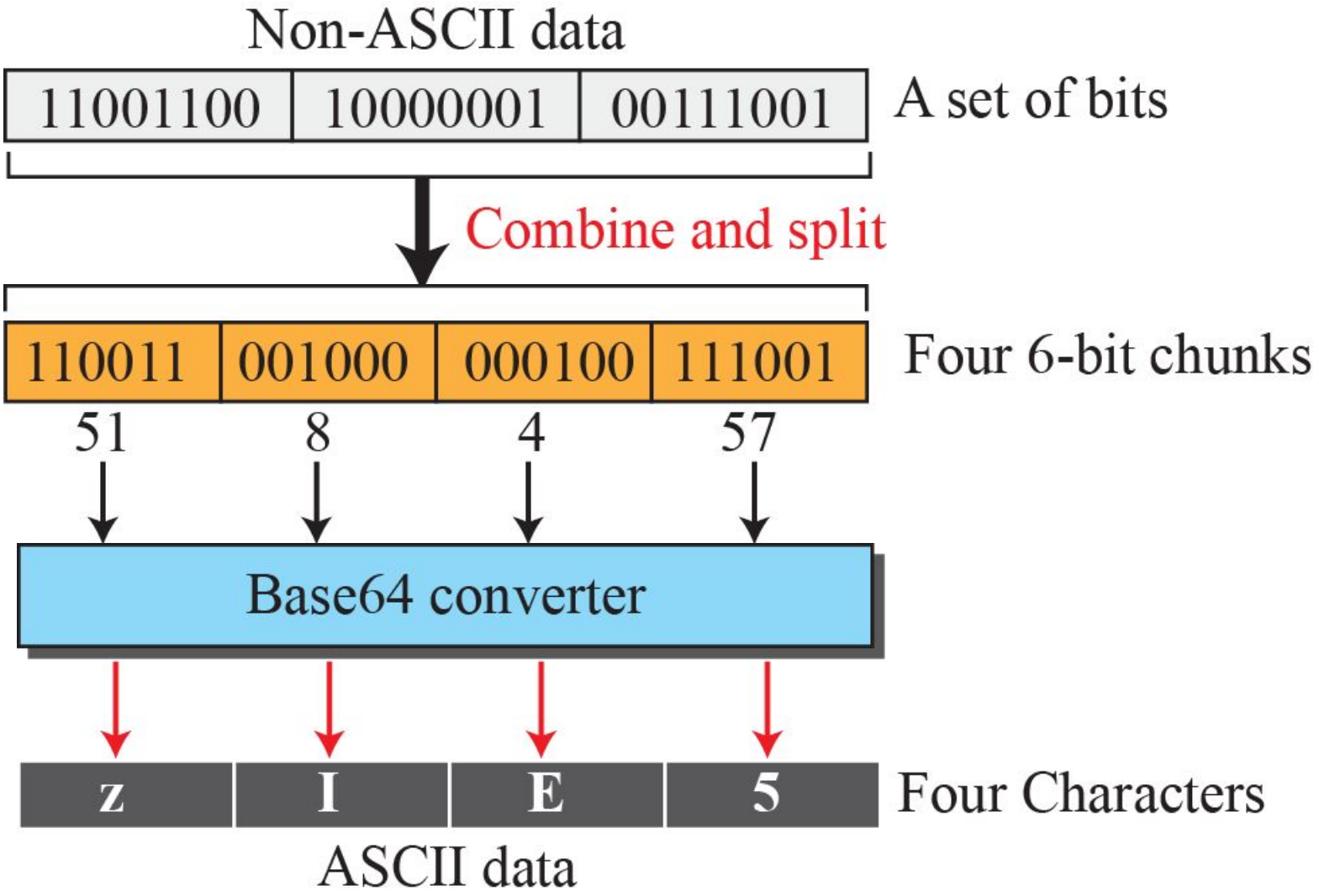


Table 2.10: Base64 Converting Table

Value	*Code*	*Value*	*Code*	*Value*	*Code*	*Value*	*Code*	*Value*	*Code*	*Value*	*Code*
0	**A**	11	**L**	22	**W**	33	**h**	44	**s**	55	**3**
1	**B**	12	**M**	23	**X**	34	**i**	45	**t**	56	**4**
2	**C**	13	**N**	24	**Y**	35	**j**	46	**u**	57	**5**
3	**D**	14	**O**	25	**Z**	36	**k**	47	**v**	58	**6**
4	**E**	15	**P**	26	**a**	37	**l**	48	**w**	59	**7**
5	**F**	16	**Q**	27	**b**	38	**m**	49	**x**	60	**8**
6	**G**	17	**R**	28	**c**	39	**n**	50	**y**	61	**9**
7	**H**	18	**S**	29	**d**	40	**o**	51	**z**	62	+
8	**I**	19	**T**	30	**e**	41	**p**	52	**0**	63	/
9	**J**	20	**U**	31	**f**	42	**q**	53	**1**		
10	**K**	21	**V**	32	**g**	43	**r**	54	**2**		

Figure 2.28: Quoted-printable

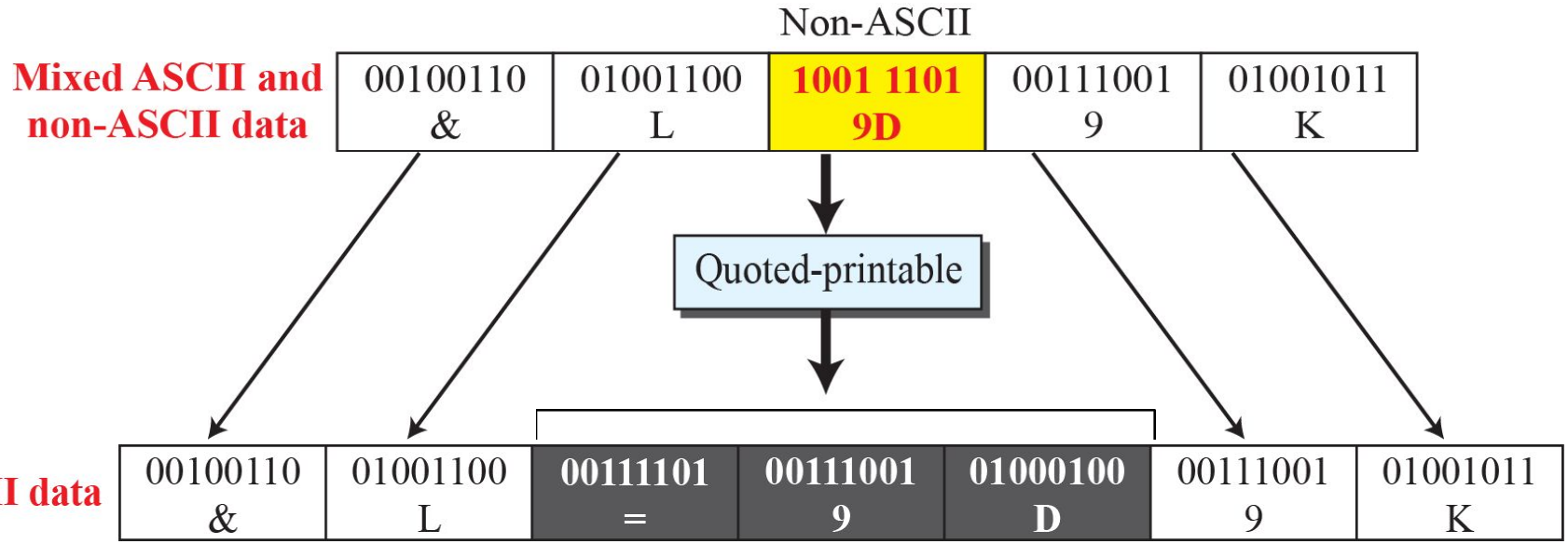
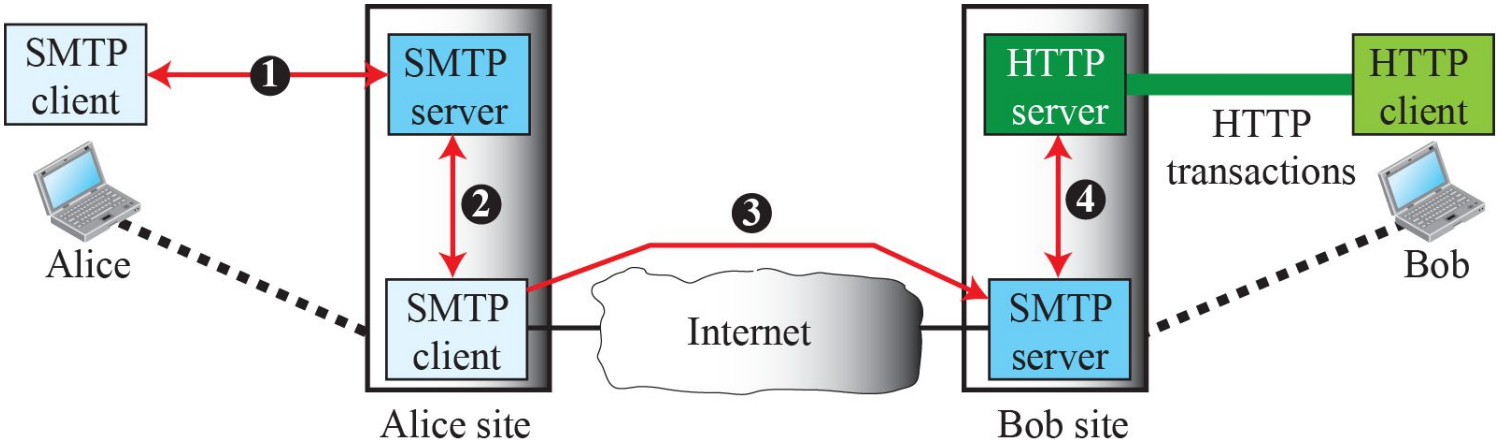
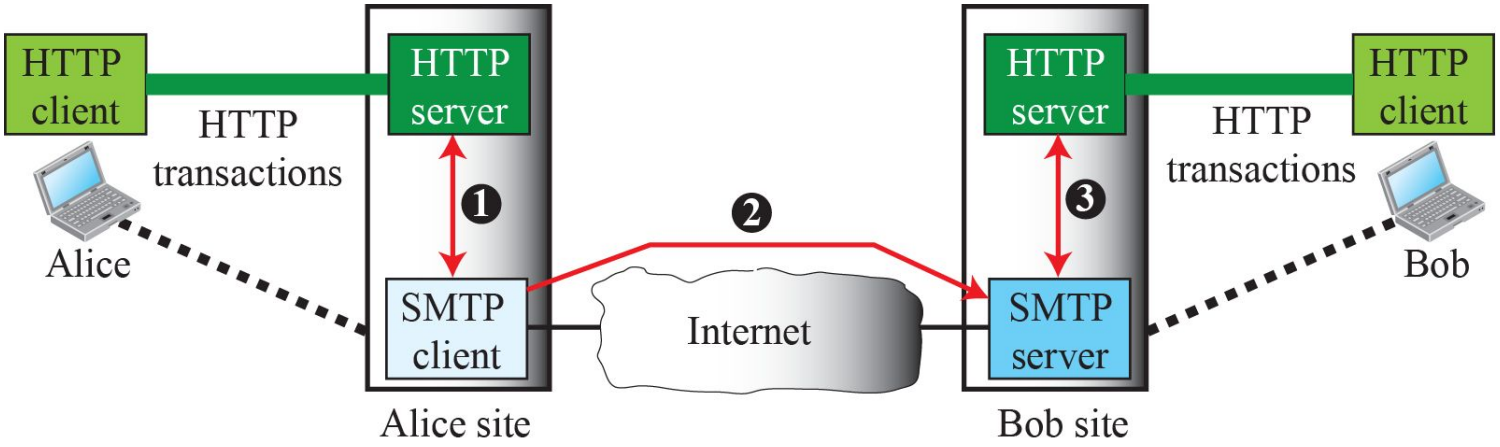


Figure 2.29: Web-based e-mail, cases I and II



Case 1: Only receiver uses HTTP



Case 2: Both sender and receiver use HTTP

2.3.4 TELNET

A server program can provide a specific service to its corresponding client program. However, it is impossible to have a client/server pair for each type of service we need. Another solution is to have a specific client/server program for a set of common scenarios, but to have some generic client/server programs that allow a user on the client site to log into the computer at the server site and use the services available there. We refer to these generic client/server pairs as remote logging applications. One of the original remote logging protocols is ***TELNET****.*

2.3.4 (continued)

- *Local versus Remote Logging*
- *Network Virtual Terminal (NVT)*
- *Options*
- *User Interface*

Figure 2.30: Local versus remote logging

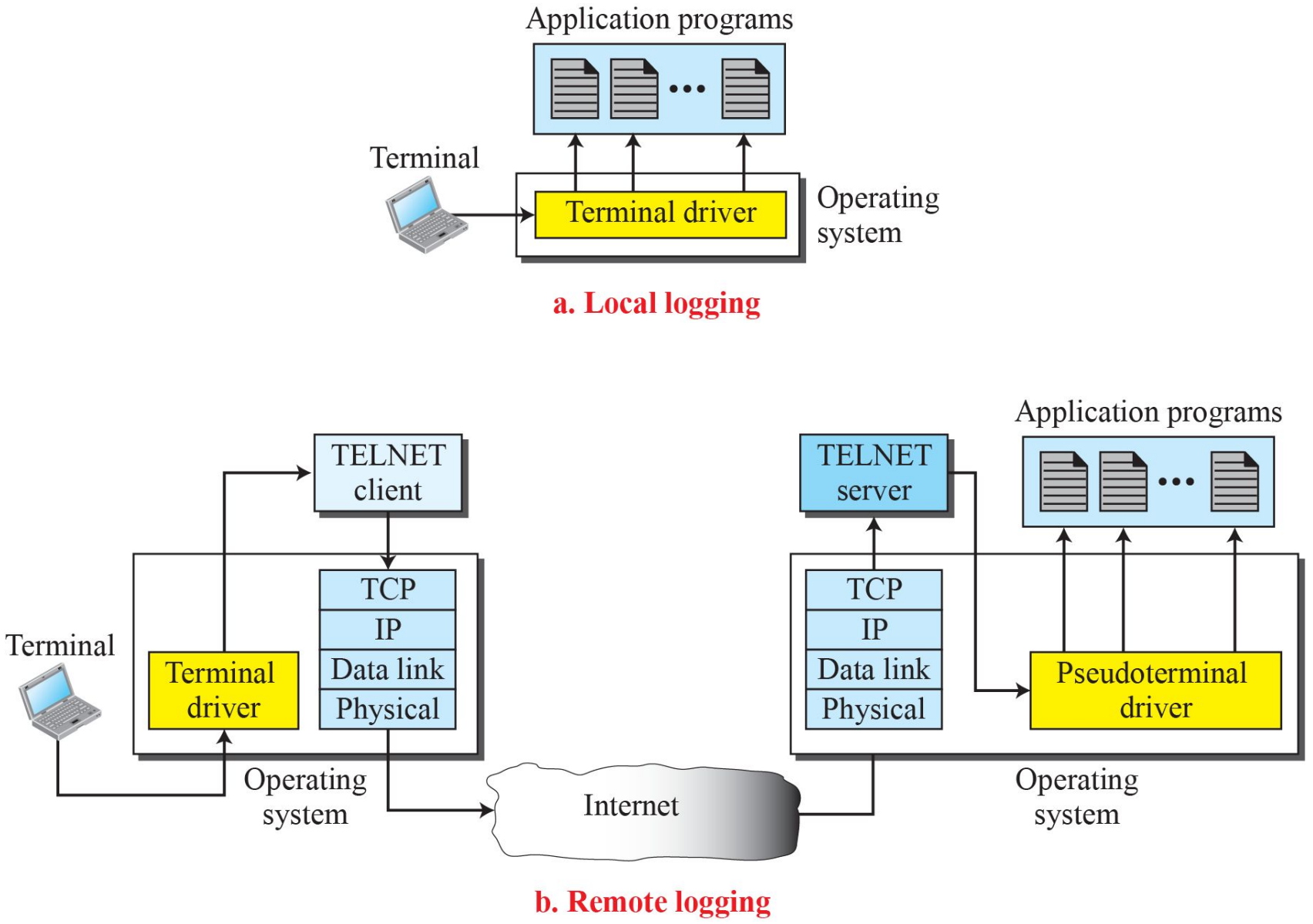
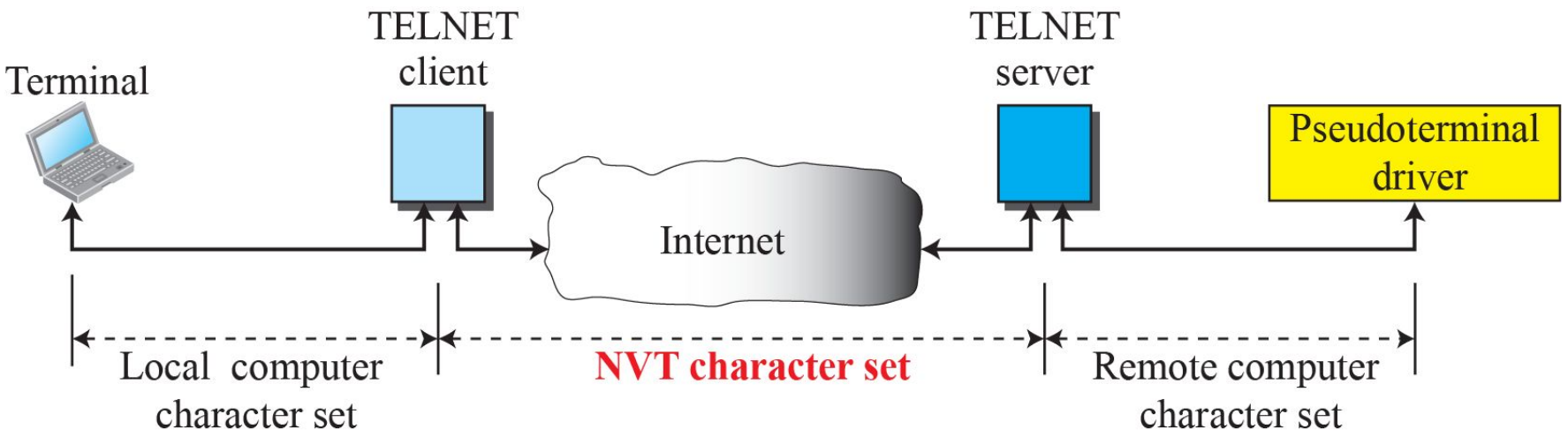


Figure 2.31: Concept of NVT



NVT character format

Table 2.11: Examples of interface commands

Command	*Meaning*	*Command*	*Meaning*
open	Connect to a remote computer	**set**	Set the operating parameters
close	Close the connection	**status**	Display the status information
display	Show the operating parameters	**send**	Send special characters
mode	Change to line or character mode	**quit**	Exit TELNET

2.3.5 Secure Shell (SSH)

Although Secure Shell (SSH) is a secure application program that can be used today for several purposes such as remote logging and file transfer, it was originally designed to replace TELNET. There are two versions of SSH: SSH-1 and SSH-2, which are totally incompatible. The first version, SSH-1, is now deprecated because of security flaws in it. In this section, we discuss only SSH-2.

2.3.5 (continued)

- **Components**
  - SSH Transport-Layer Protocol (SSH-TRANS)
  - SSH Authentication Protocol (SSH-AUTH)
  - SSH Connection Protocol (SSH-CONN)
- **Applications**
  - SSH for Remote Logging
  - SSH for File Transfer
- **Port Forwarding**
- **Format of the SSH Packets**

Figure 2.32: Components of SSH

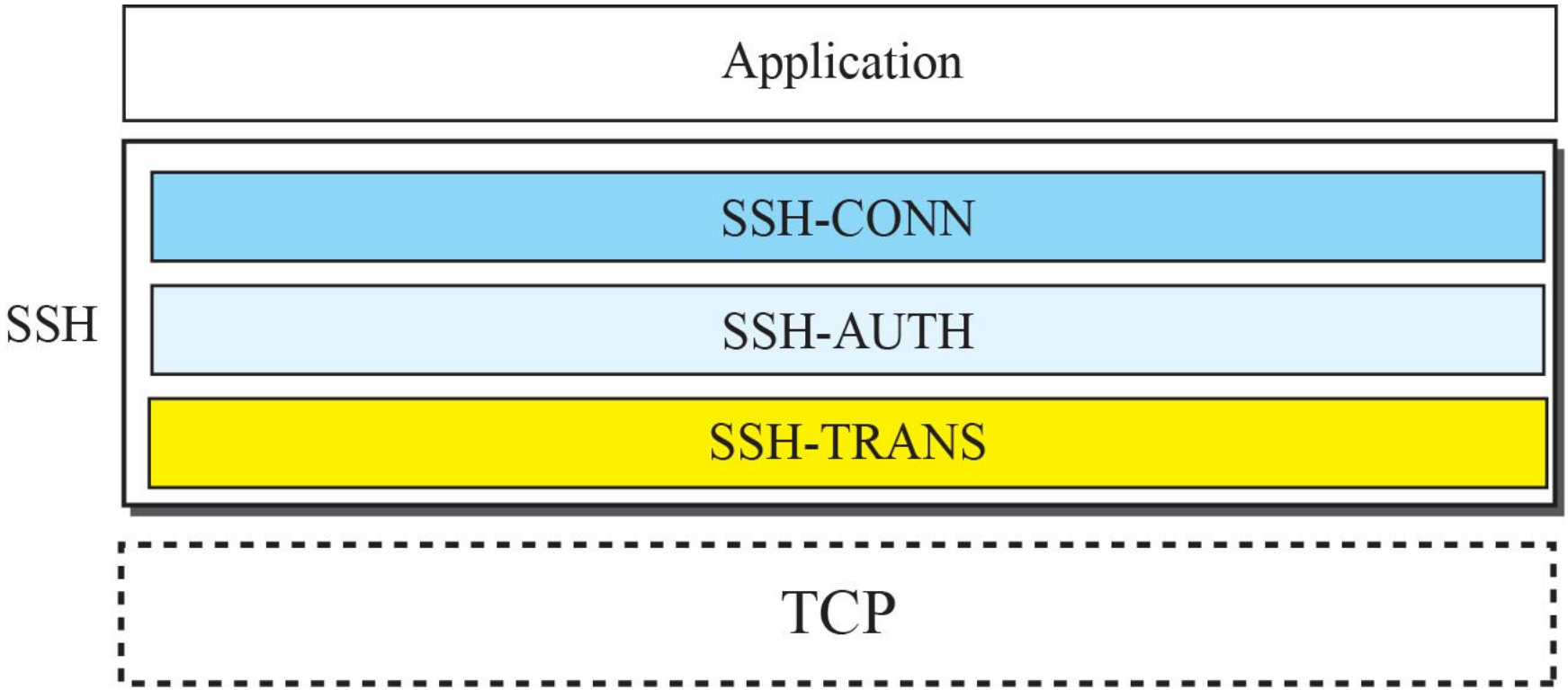


Figure 2.33: ***Port Forwarding***

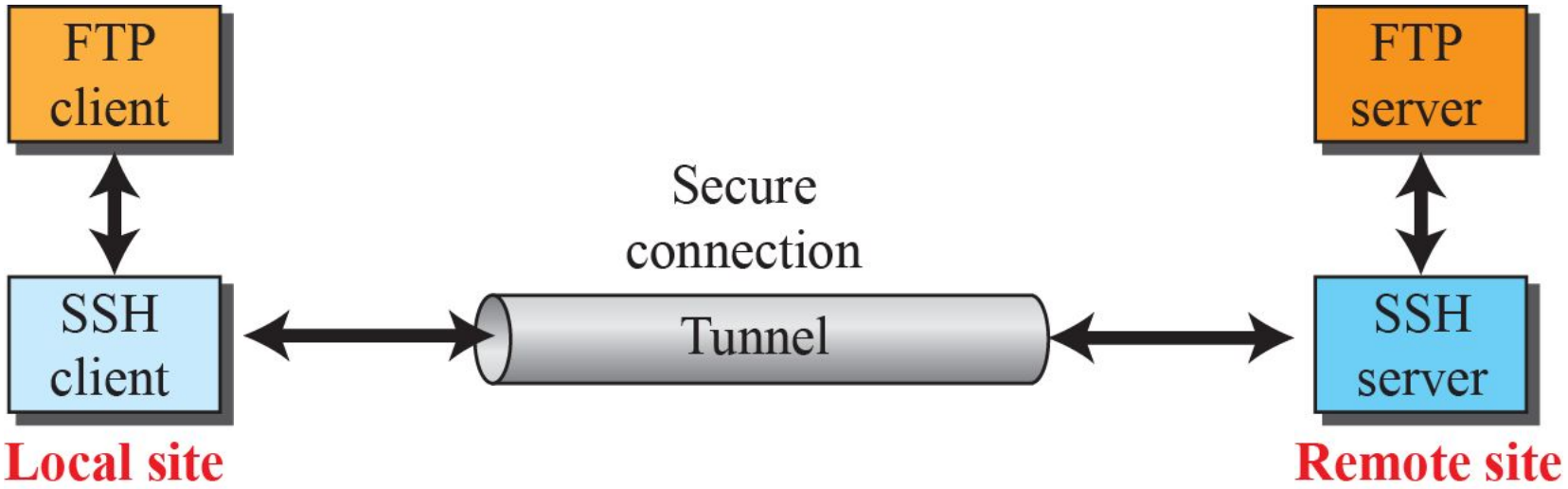
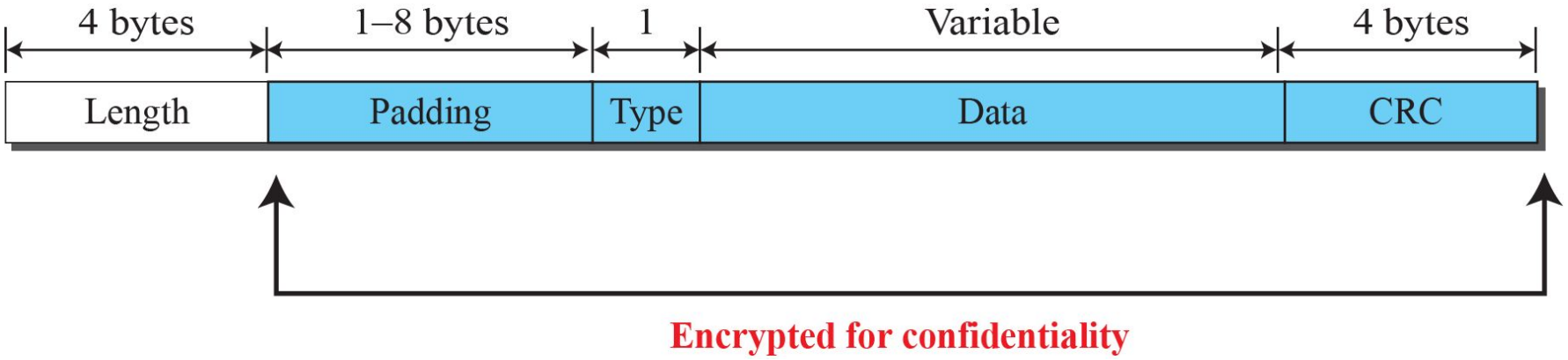


Figure 2.34: SSH Packet Format



2.3.6 Domain Name System (DNS)

To identify an entity, TCP/IP protocols use the IP address, which uniquely identifies the connection of a host to the Internet. However, people prefer to use names instead of numeric addresses. Therefore, the Internet needs to have a directory system that can map a name to an address. This is analogous to the telephone network. A telephone network is designed to use telephone numbers, not names. People can either keep a private file to map a name to the corresponding telephone number or can call the telephone directory to do so.

2.3.6 (continued)

- **Name Space**
  - Domain Name Space
  - Domain
  - Distribution of Name Space
  - Zone
  - Root Server
- **DNS in the Internet**
  - Generic Domains
  - Country Domains

2.3.1 (continued)

- Resolution
  - Recursive Resolution
  - Iterative Resolution
  - Caching
- Resource Records
- DNS Messages
- Encapsulation
- Registrars
- DDNS
- Security of DNS

Figure 2.35: Purpose of DNS

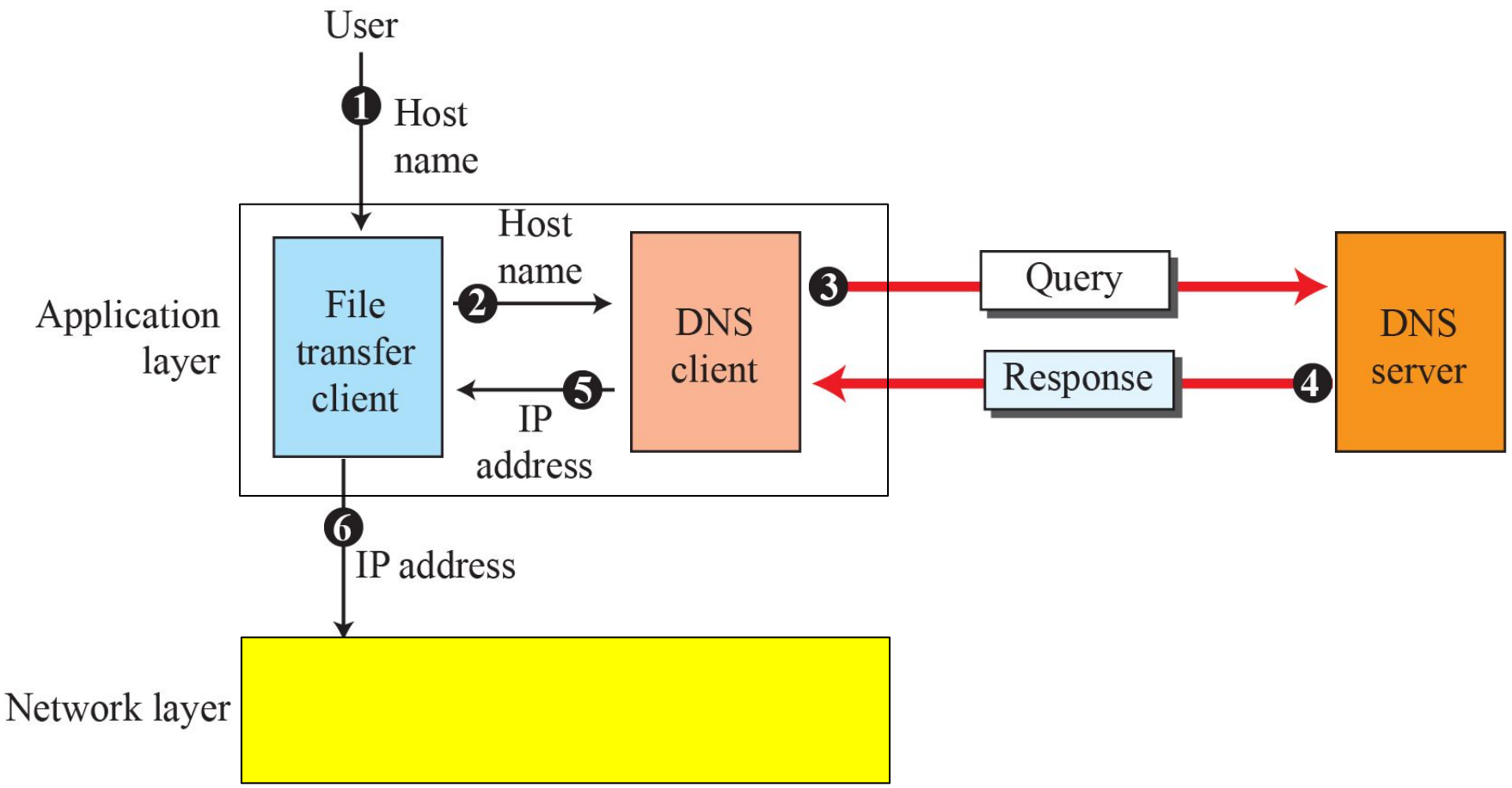


Figure 2.36: ***Domain name space***

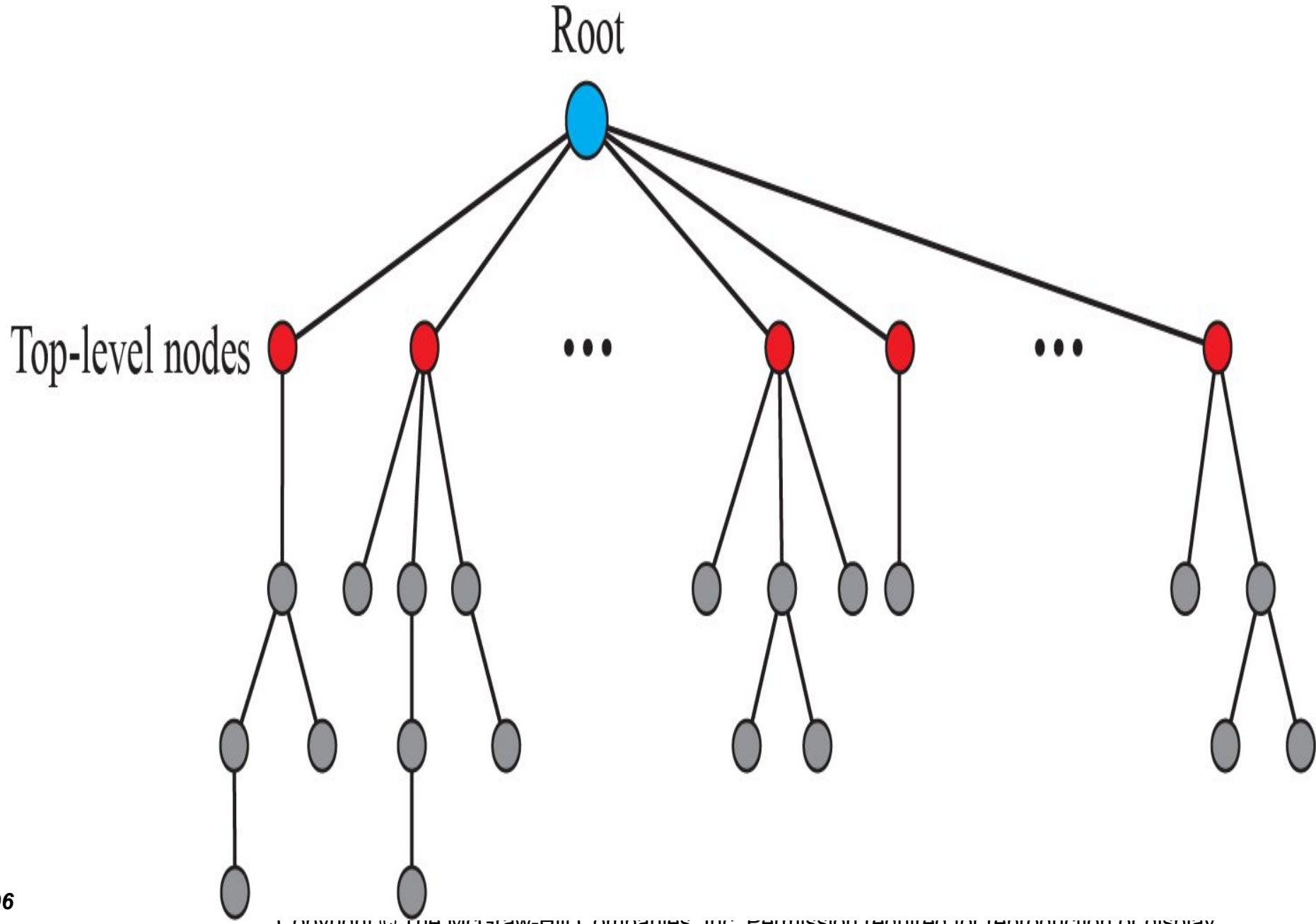


Figure 2.37: ***Domain names and labels***

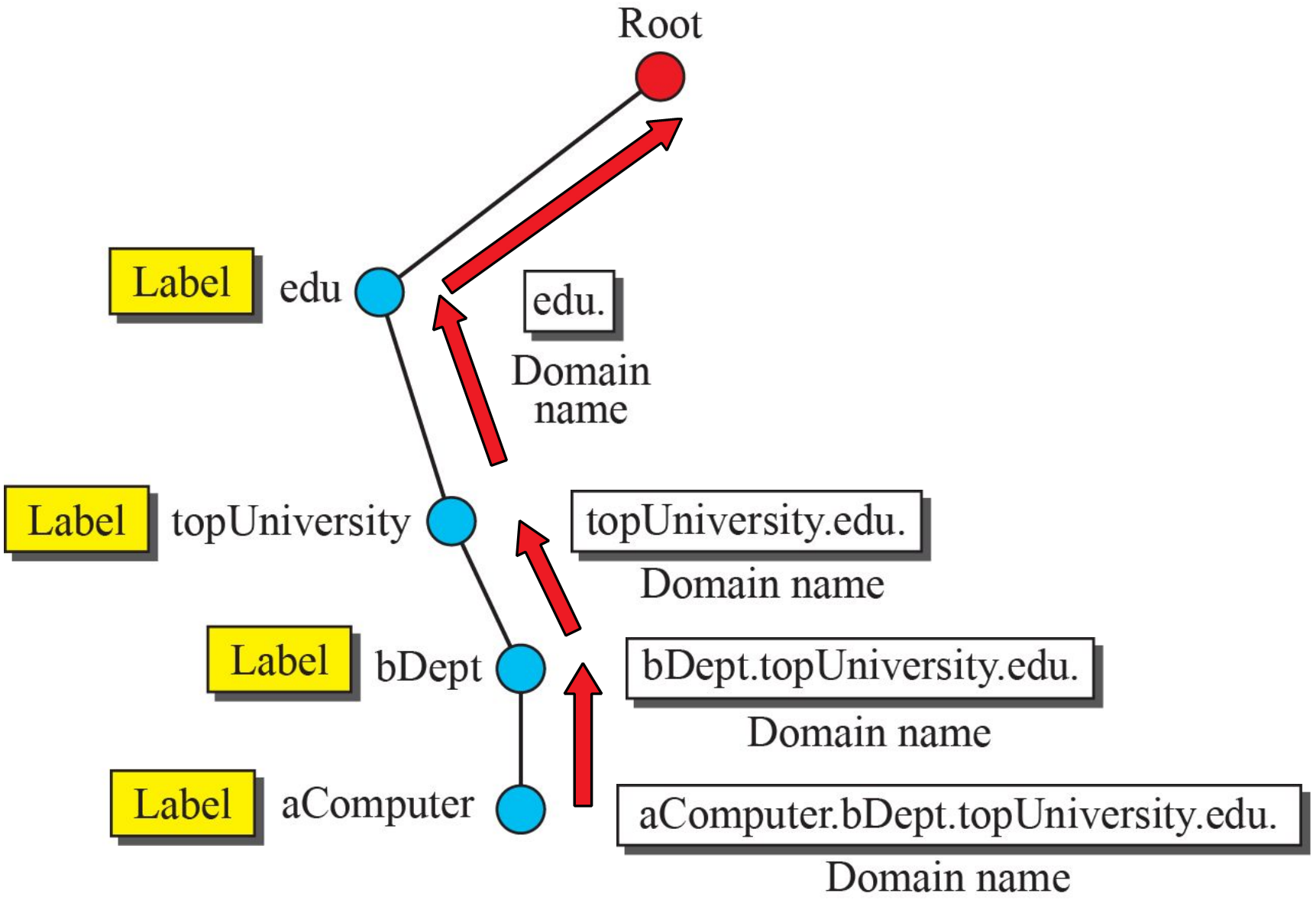


Figure 2.38: Domains

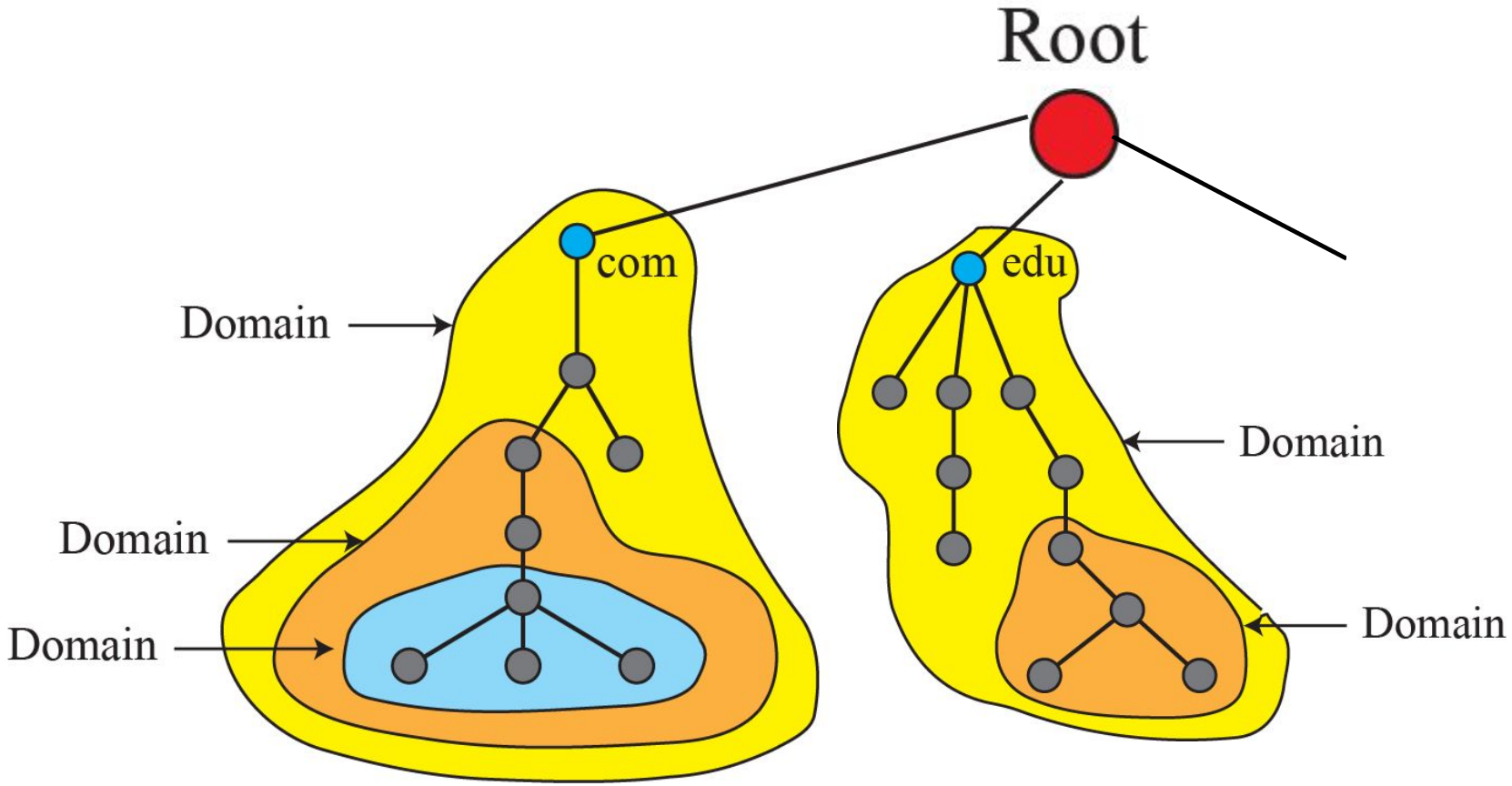


Figure 2.39: Hierarchy of name servers

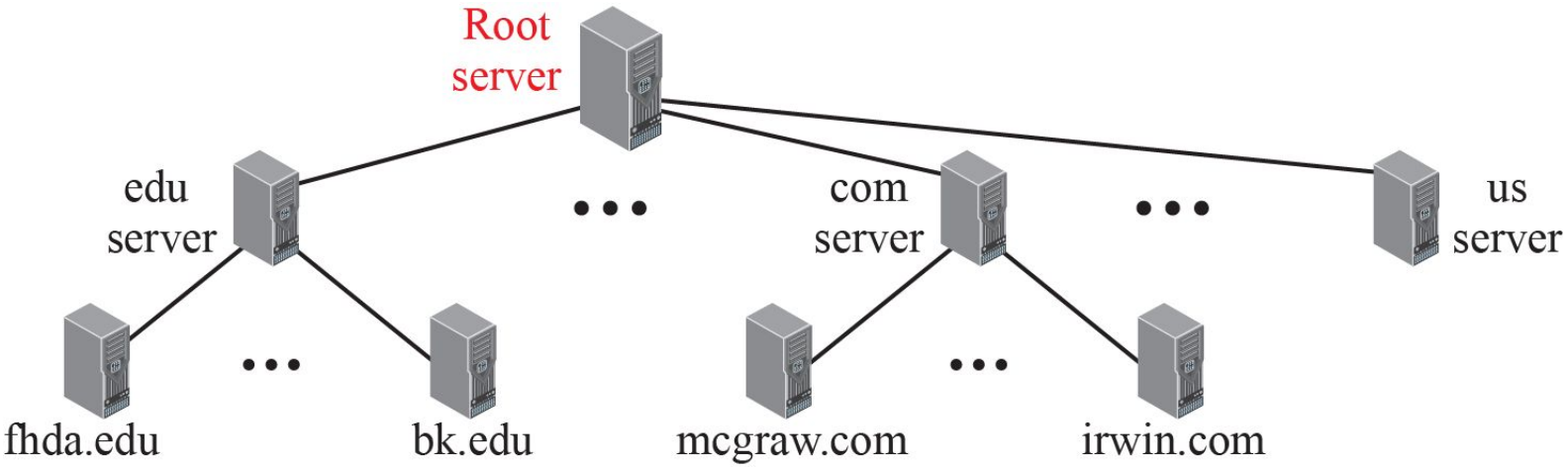


Figure 2.40: Zone

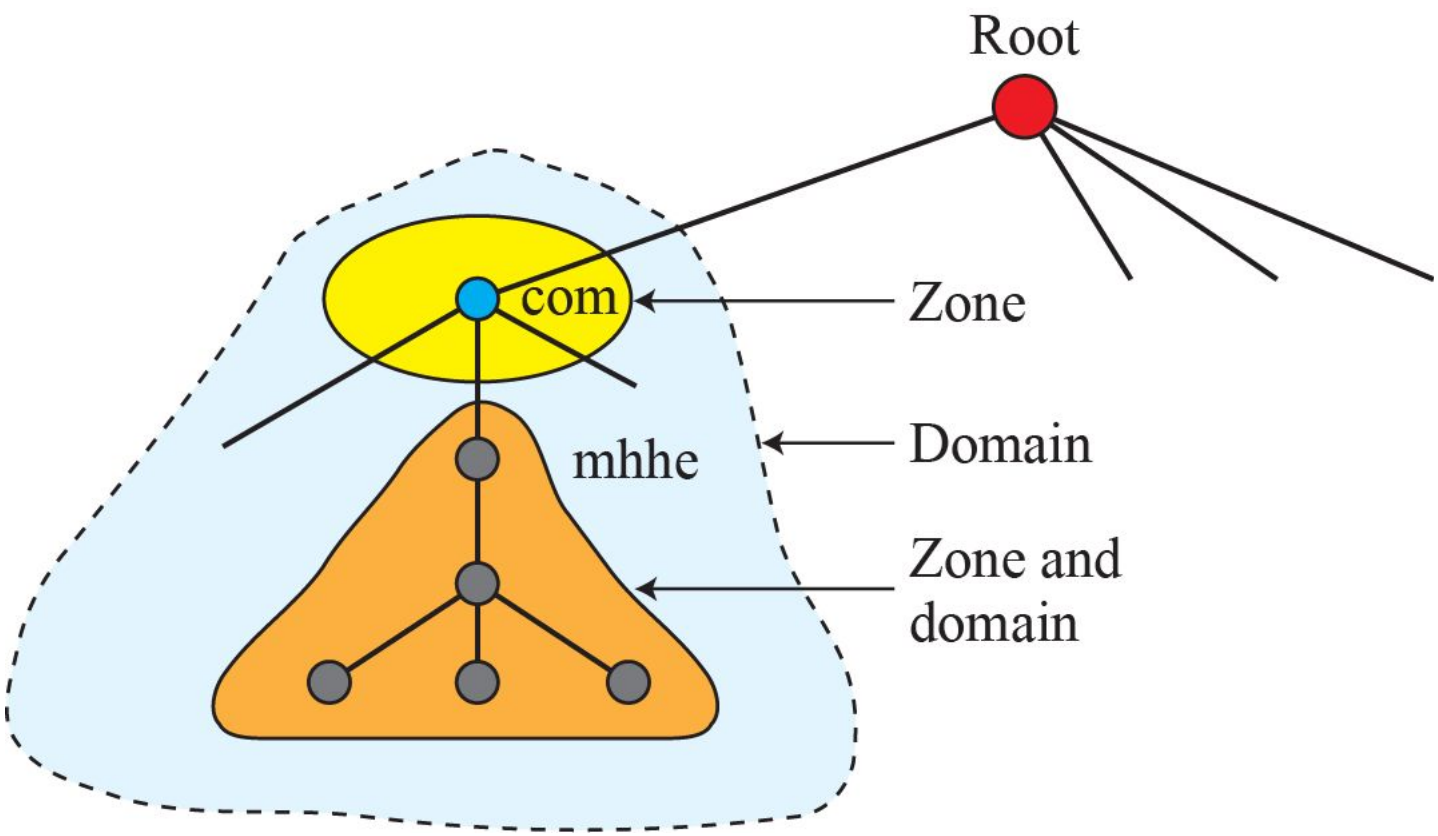


Figure 2.41: Generic domains

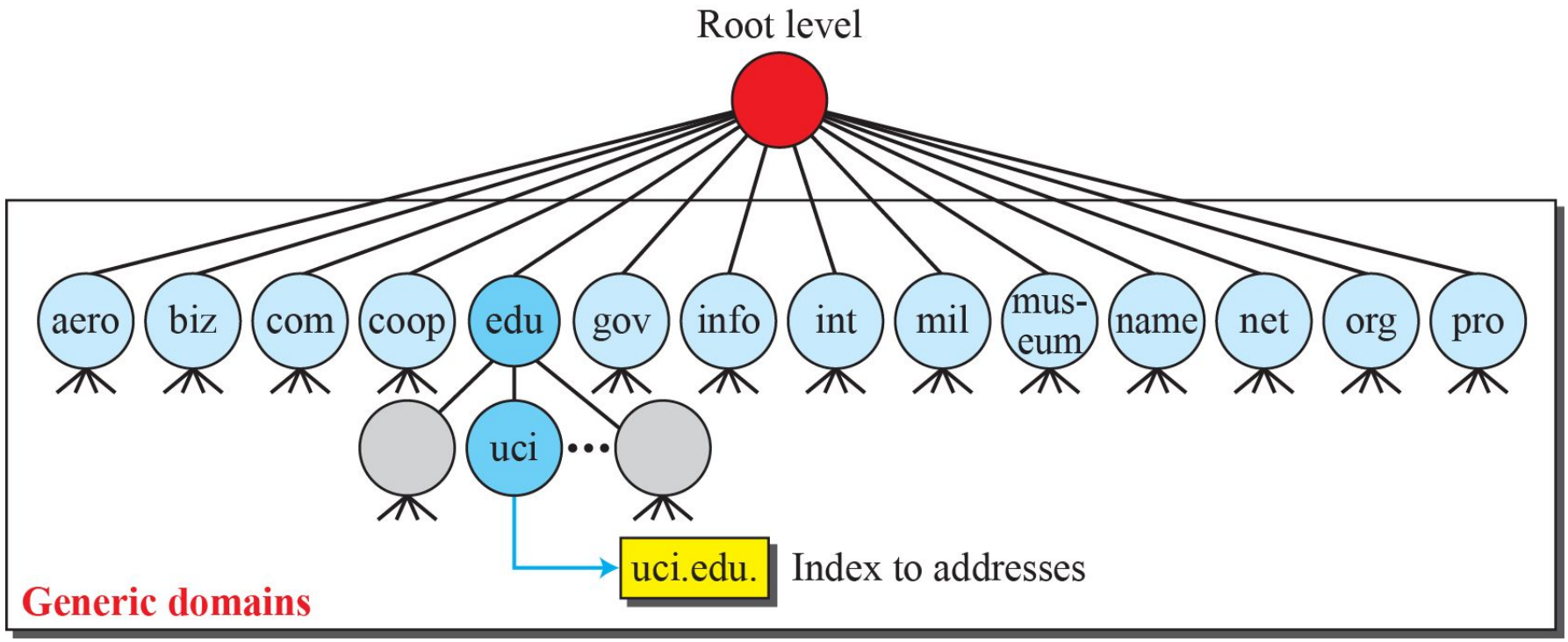


Table 2.12: Generic domain labels

Label	*Description*	*Label*	*Description*
aero	Airlines and aerospace	**int**	International organizations
biz	Businesses or firms	**mil**	Military groups
com	Commercial organizations	**museum**	Museums
coop	Cooperative organizations	**name**	Personal names (individuals)
edu	Educational institutions	**net**	Network support centers
gov	Government institutions	**org**	Nonprofit organizations
info	Information service providers	**pro**	Professional organizations

Figure 2.42: Country domains

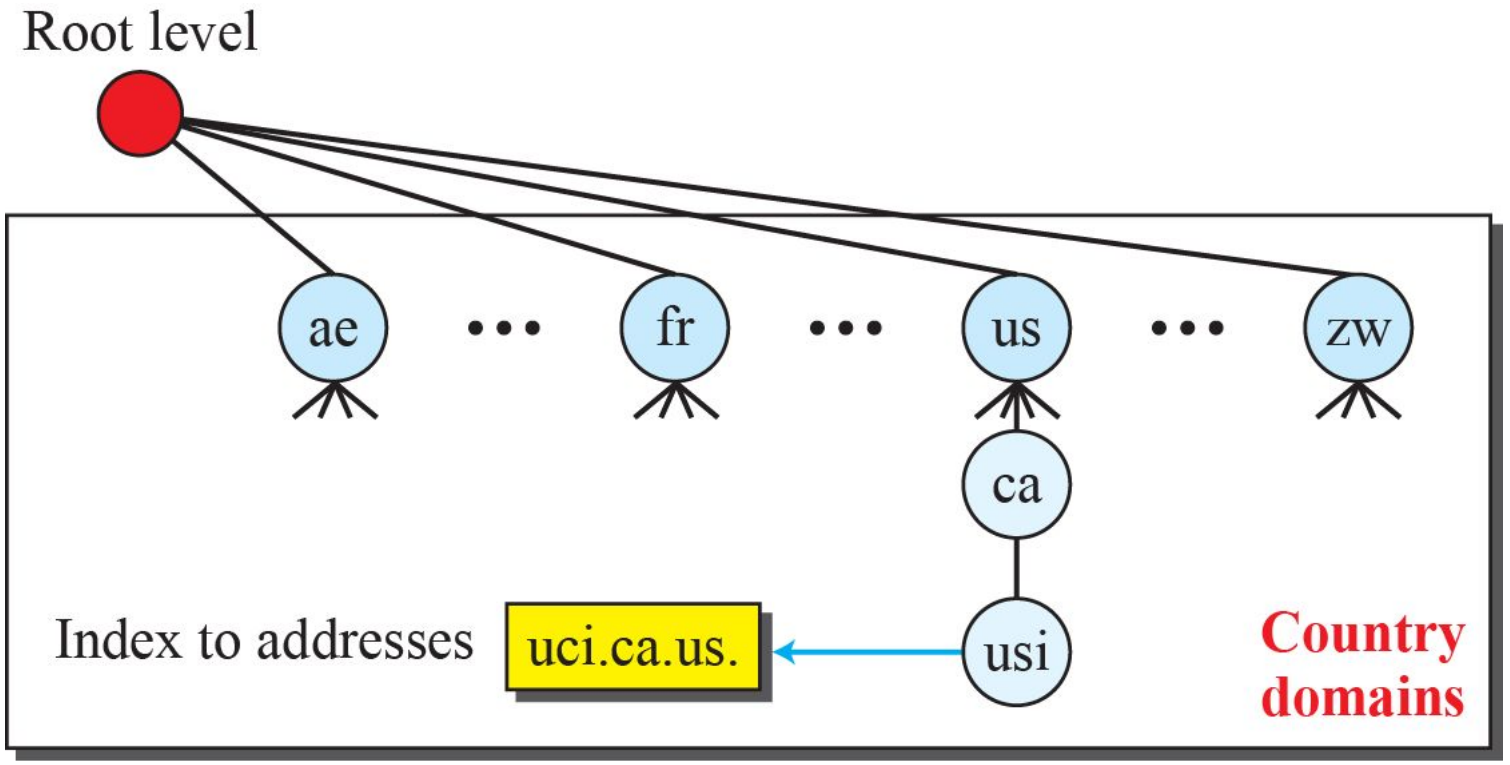


Figure 2.43: Recursive resolution

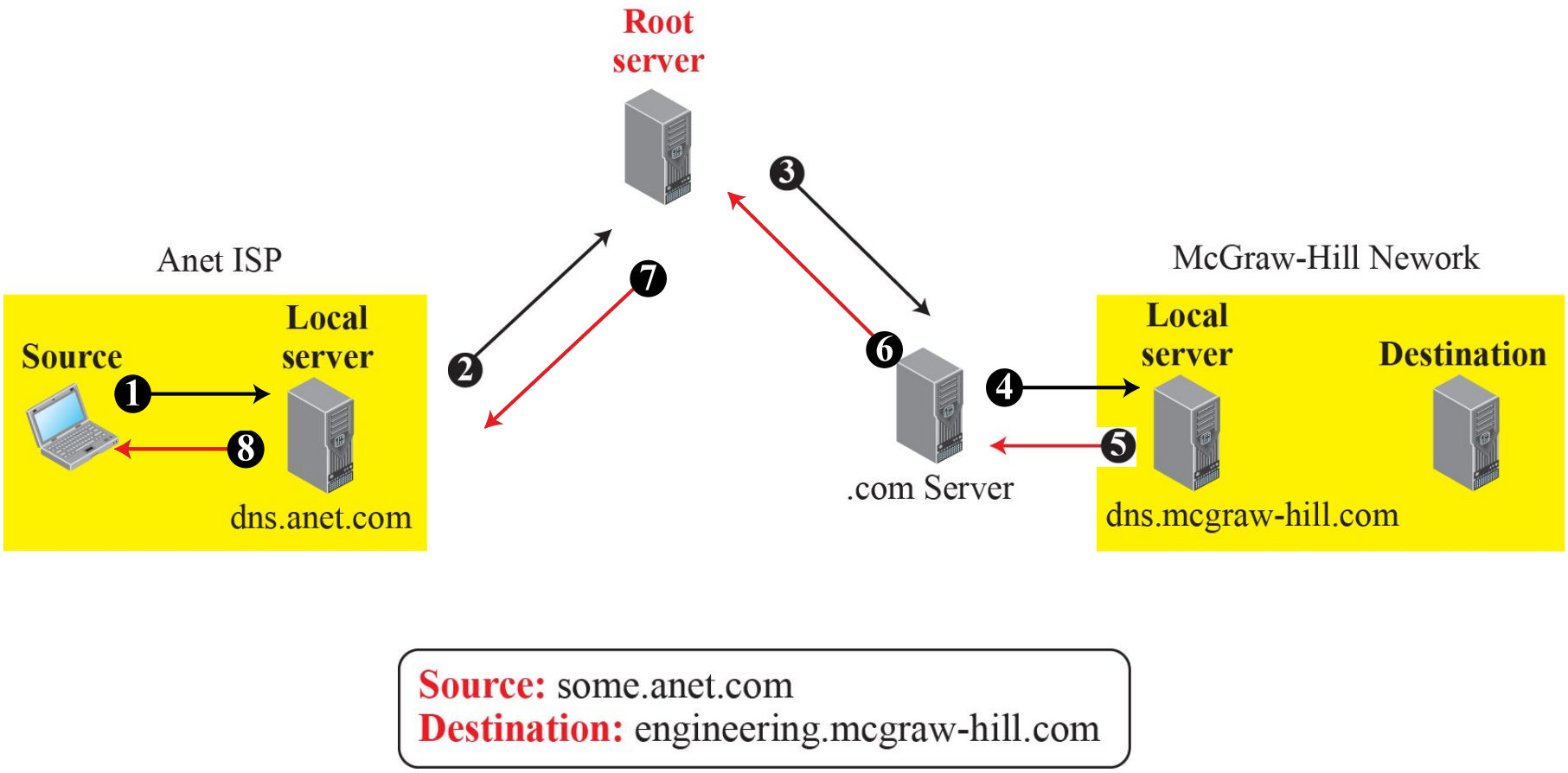


Figure 2.44: Iterative resolution

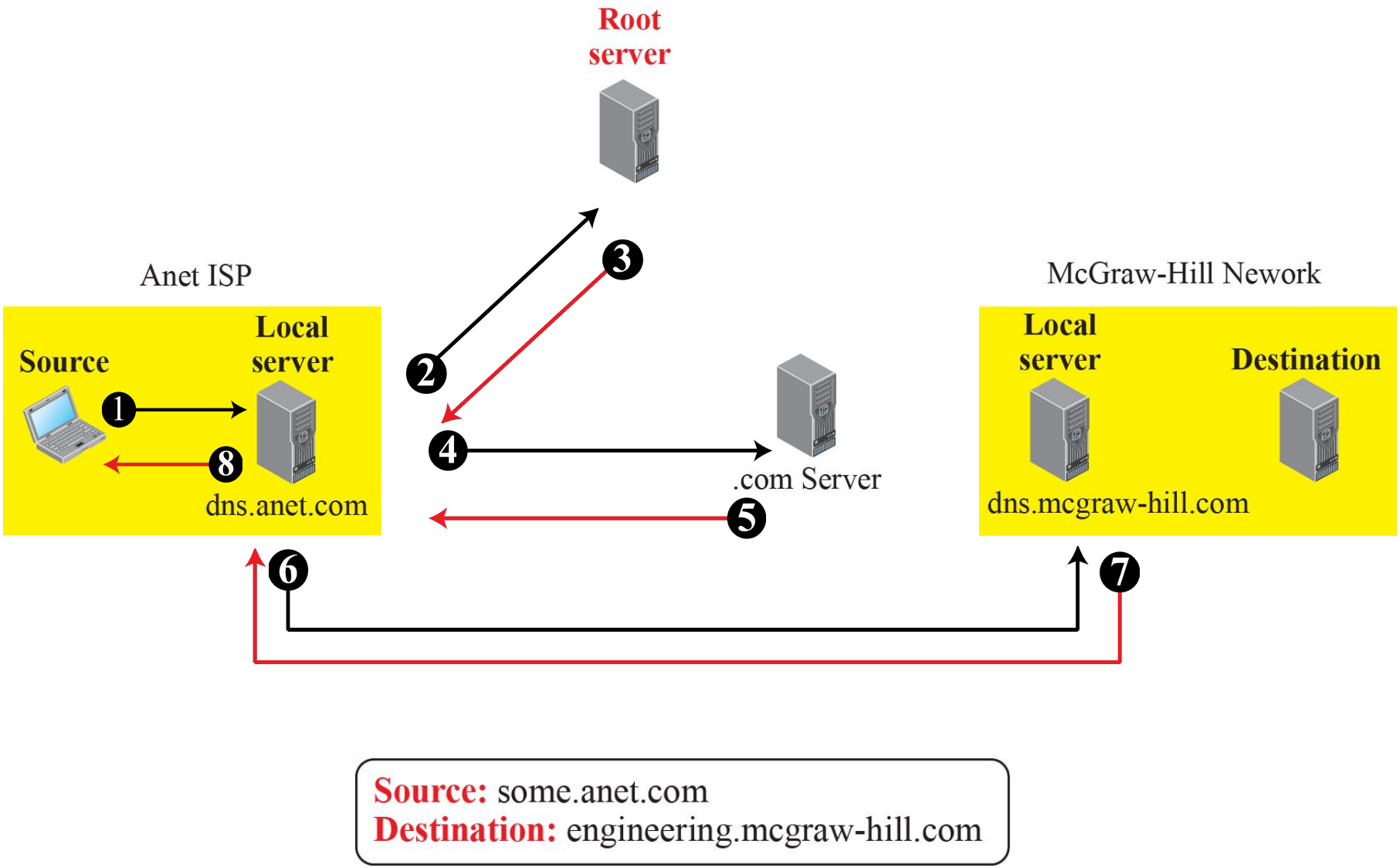
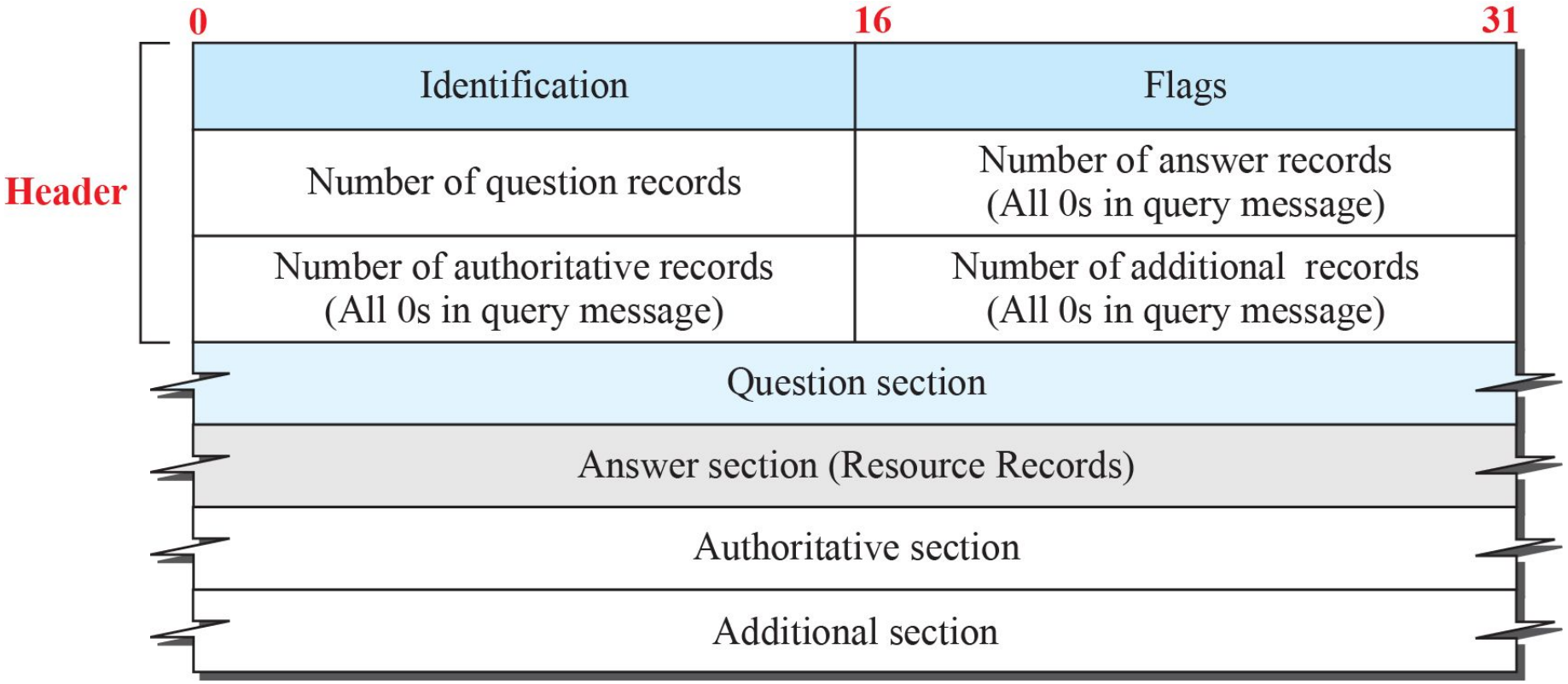


Table 2.13: DNS types

Type	*Interpretation of value*
A	A 32-bit IPv4 address (see Chapter 4)
NS	Identifies the authoritative servers for a zone
CNAME	Defines an alias for the official name of a host
SOA	Marks the beginning of a zone
MX	Redirects mail to a mail server
AAAA	An IPv6 address (see Chapter 4)

Figure 2.45: DNS message



Note:

The query message contains only the question section. The response message includes the question section, the answer section, and possibly two other sections.

Example 2.14

In UNIX and Windows, the nslookup utility can be used to retrieve address/name mapping. The following shows how we can retrieve an address when the domain name is given.

```
$nslookup www.forouzan.biz
Name:   www.forouzan.biz
Address: 198.170.240.179
```

2-4 PEER-TO-PEER PARADIGM

In this section, we discuss the peer-to peer paradigm. Peer-to-peer gained popularity with Napster, an online music file. Napster paved the way for peer-to-peer file-distribution models that came later. Gnutella was followed by Fast-
Track, BitTorrent, WinMX, and GNUnet.

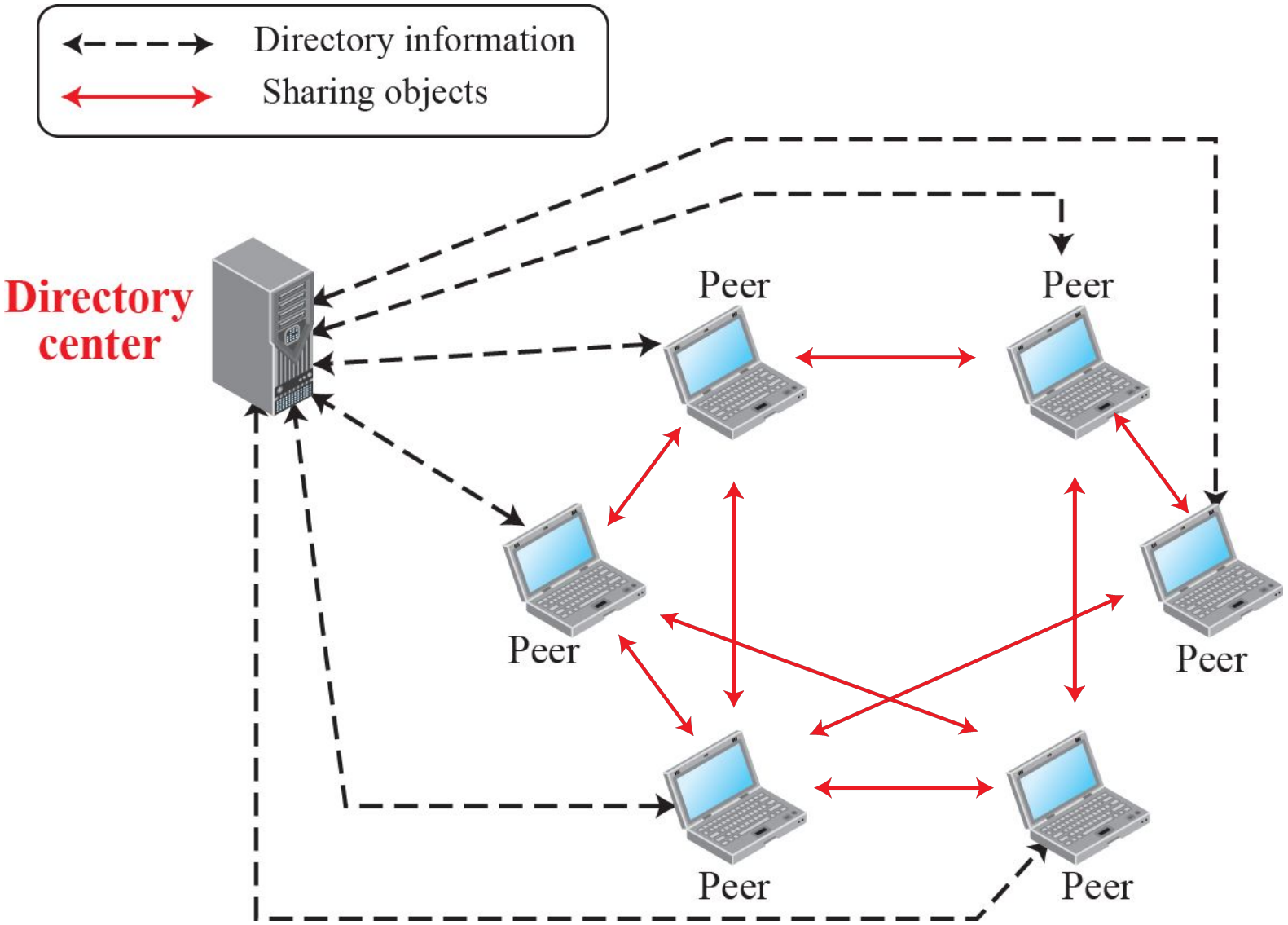
2.4.1 P2P Networks

Internet users that are ready to share their resources become peers and form a network. When a peer in the network has a file) to share, it makes it available to the rest of the peers. An interested peer can connect itself to the computer where the file is stored and download it. After a peer downloads a file, it can make it available for other peers to download. As more peers join and download that file, more copies of the file become available to the group.

2.4.1 (continued)

- *Centralized Networks*
- *Decentralized Network*
  - *Unstructured Networks*
  - *Structured Networks*

Figure 2.46: ***Centralized network***



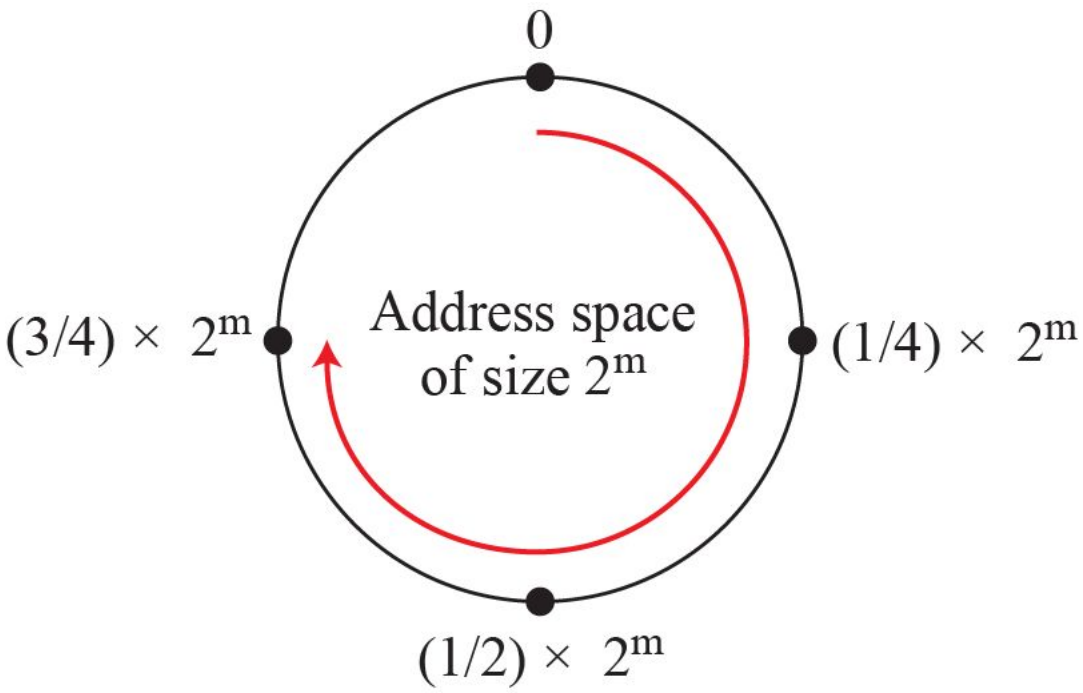
2.4.2 Distributed Hash Function

A Distributed Hash Table (DHT) distributes data among a set of nodes according to some predefined rules. Each peer in a DHT-based network becomes responsible for a range of data items. To avoid the flooding overhead that we discussed for unstructured P2P networks, DHT-based networks allow each peer to have a partial knowledge about the whole network. This knowledge can be used to route the queries about the data items to the responsible nodes using effective and scalable procedures.

2.4.2 (continued)

- ***Address Space***
  - ***Hashing Peer Identifier***
  - ***Hashing Object Identifier***
  - ***Storing the Object***
  - ***Routing***
  - ***Arrival and Departure of Nodes***

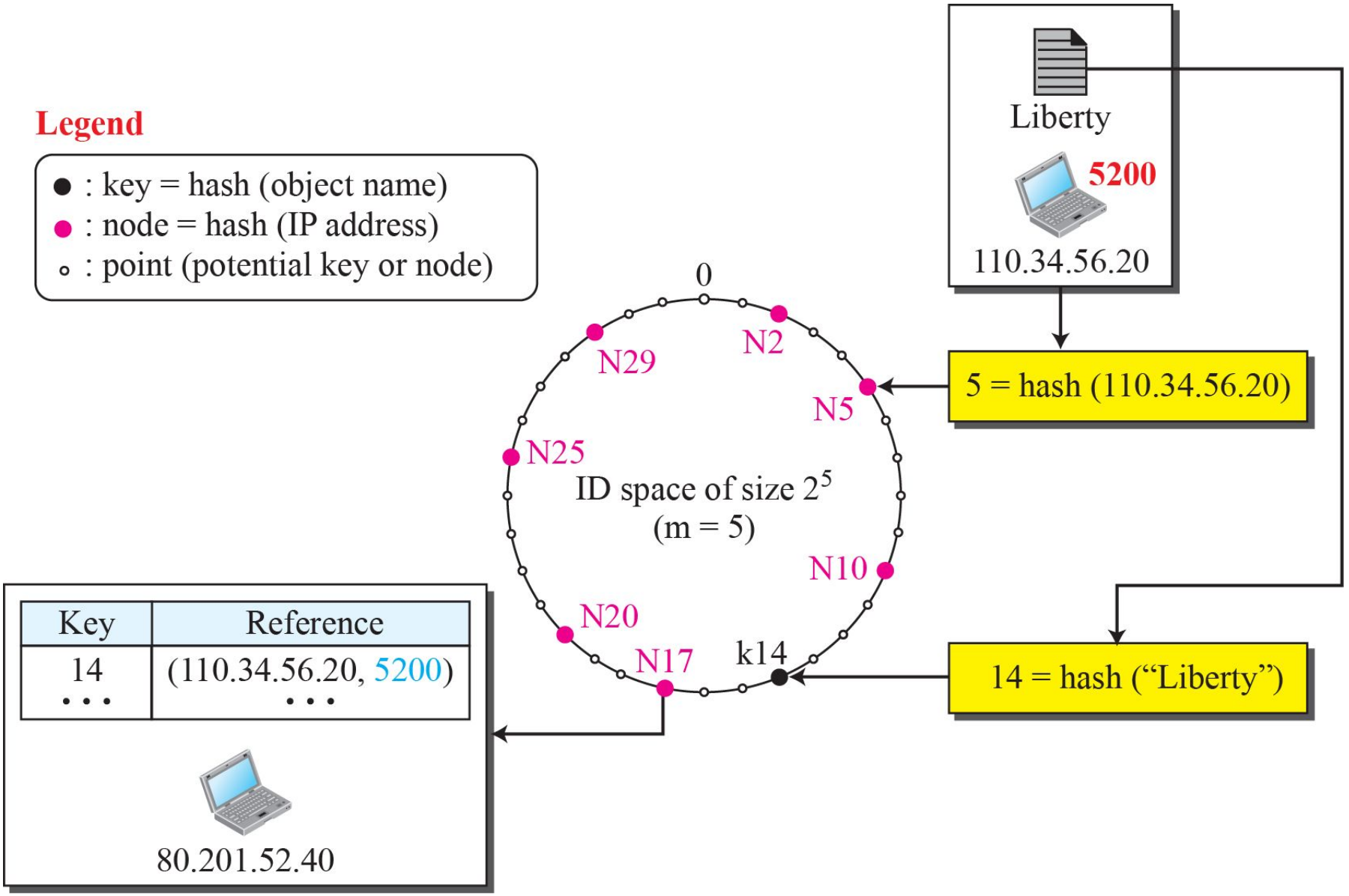
Figure 2.47: Address space



Example 2.15

Although the normal value of m is 160, for the purpose of demonstration, we use $m = 5$ to make our examples tractable. In Figure 2.48, we assume that several peers have already joined the group. The node N5 with IP address 110.34.56.20 has a file named Liberty that wants to share with its peers. The node makes a hash of the file name, "Liberty," to get the key = 14. Since the closest node to key 14 is node N17, N5 creates a reference to file name (key), its IP address, and the port number (and possibly some other information about the file) and sends this reference to be stored in node N17. In other words, the file is stored in N5, the key of the file is k14 (a point in the DHT ring), but the reference to the file is stored in node N17.

Figure 2.48: Example 2.15



2.4.3 Chord

There are several protocols that implement DHT systems. In this section, we introduce the Chord protocol for its simplicity and elegant approach to routing queries. Chord was published by Stoica et al in 2001. We briefly discuss the main feature of this algorithm here.

2.4.3 (continued)

- *Identifier Space*
- *Finger Table*
- *Interface*
  - *Lookup*
  - *Stabilize*
  - *Fix_Finger*
  - *Join*
  - *Leave or Fail*

Table 2.14: Finger table

i	*Target Key*	*Successor of Target Key*	*Information about Successor*
1	N + 1	Successor of N + 1	IP address and port of successor
2	N + 2	Successor of N + 2	IP address and port of successor
⋮	⋮	⋮	⋮
m	$N + 2^{m-1}$	Successor of $N + 2^{m-1}$	IP address and port of successor

Figure 2.49: An example of a ring in Chord

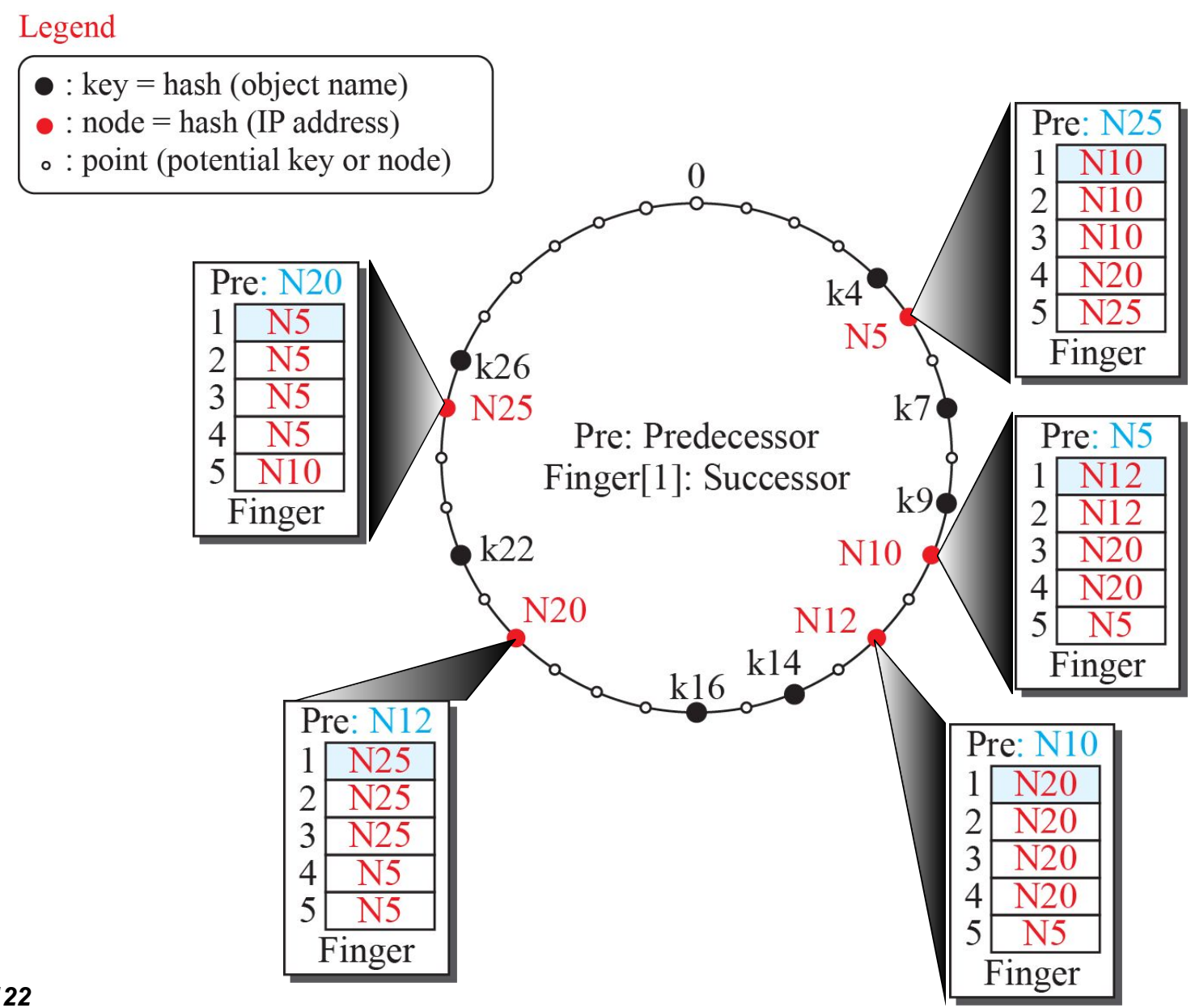


Table 2.15: Lookup

```
Lookup (key)
{
        if (node is responsible for the key)
                return (node's ID)
        else
                 return find_succesor (key)
}

find_successor (id)
{
        x = find_ predecessor (id)
        return x.finger[1]
}
```

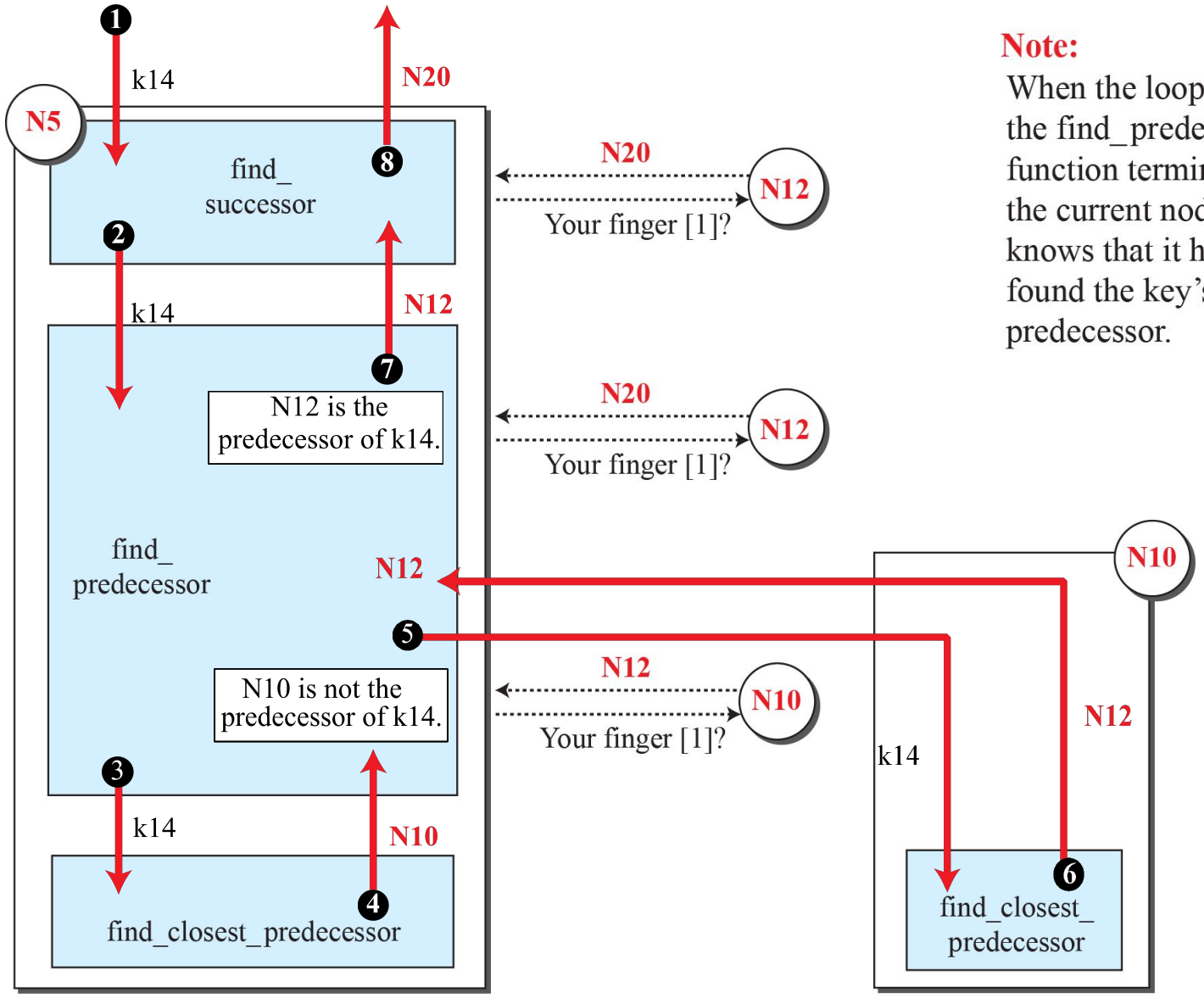
Table 2.15: Lookup (continued)

```
find_predecessor (id)
{
        x = N                                              // N is the current node
        while (id ∉ (x, x.finger[1]]
        {
                x = x.find_closest_predecessor (id)        // Let x find it
        }
        return x
}

find_closest_predecessor (id)
{
        for (i = m downto 1)
        {
                if (finger [i] ∈ (N, id))                  //N is the current node
                        return (finger [i])
        }
        return N                                           //The node itself is closest predecessor
}
```

Example 2.16

Assume node N5 in Figure 2.49 needs to find the responsible node for key k14. Figure 2.50 shows the sequence of 8 events to do so.

Figure 2.50: Example 2.16



Note:
When the loop in the find_predecessor function terminates, the current node knows that it has found the key's predecessor.

Table 2.16: Stabilize

```
Stabilize ()
{
        P = finger[1].Pre                       //Ask the successor to return its predecessor
        if(P∈ (N, finger[1]))   finger[1] = P       // P is the possible successor of N
        finger[1].notify (N)                        // Notify P to change its predecessor
}
Notify (x)
{
            if (Pre = null or x ∈ (Pre, N))      Pre = x
}
```

Table 2.17: Fix_Finger

```
Fix_Finger ()
{
        Generate (i ∈ (1, m])                    //Randomly generate i such as 1< i ≤ m
        finger[i] = find_successor (N + 2^(i − 1))        // Find value of finger[i]
}
```

Table 2.18: Join

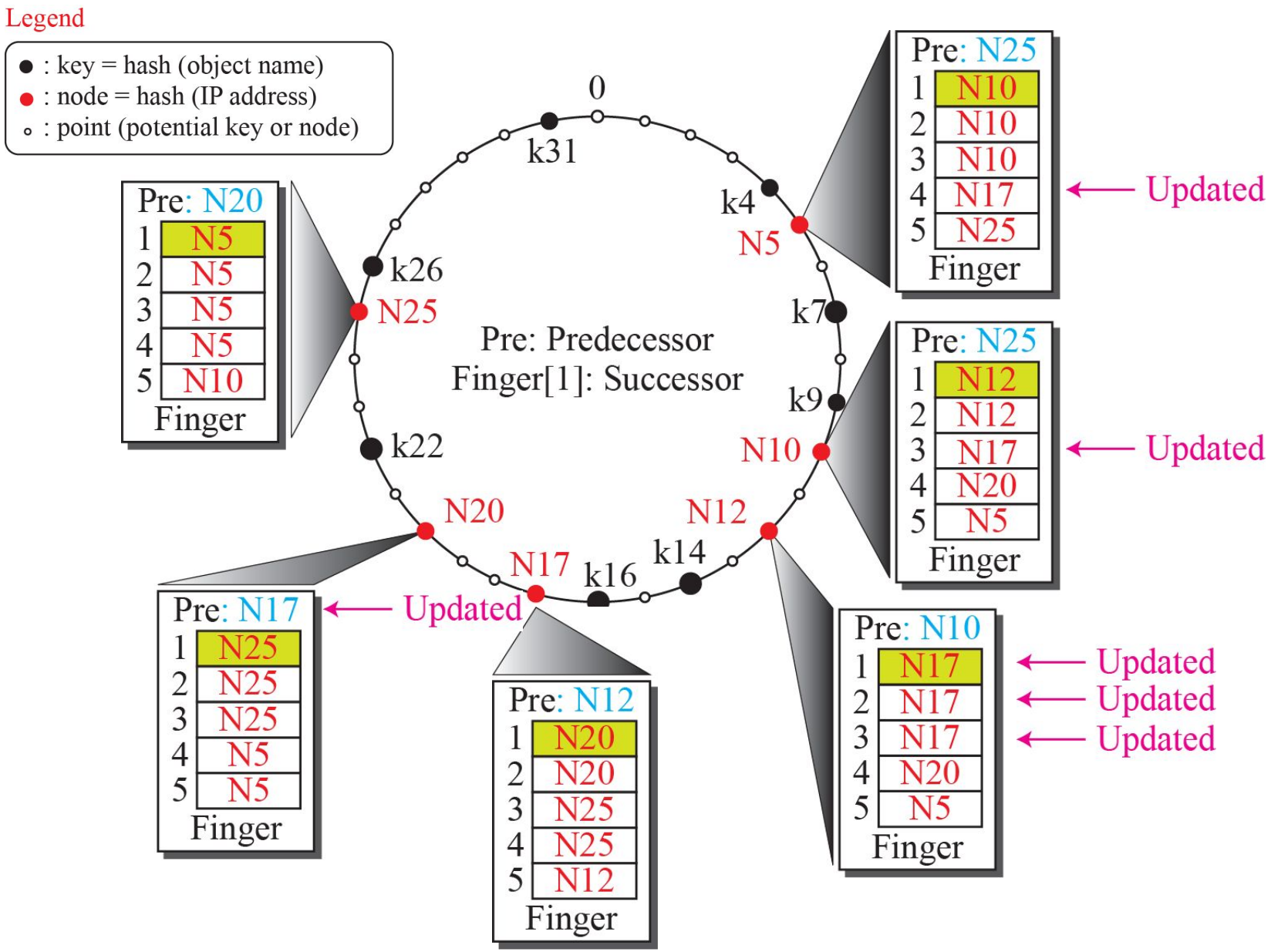
```
Join (x)
{
        Initialize (x)
        finger[1].Move_Keys (N)
}

Initialize (x)
{
        Pre = null
        if (x = null) finger[1] = N
        else finger[1] = x. Find_Successor (N)
}

Move_Keys (x)
{
        for (each key k)
        {
                if (x ∈ [k, N)) move (k to node x)          // N is the current node
        }
}
```

Example 2.17

We assume that node N17 joins the ring in Figure 2.49 with the help of N5. Figure 2.51 shows the ring after the ring has been stabilized. The following five steps shows the process:

1. N17 set its predecessor to null and its successor to N20.
2. N17 then asks N20 to send k14 and k16 to N17.
3. N17 validates its own successor and asks N20 to change its predecessor to N17
4. The predecessor of N17 is updated to N12.
5. The finger table of nodes N17, N10, N5, and N12 is changed.

Figure 2.51: Example 2.17

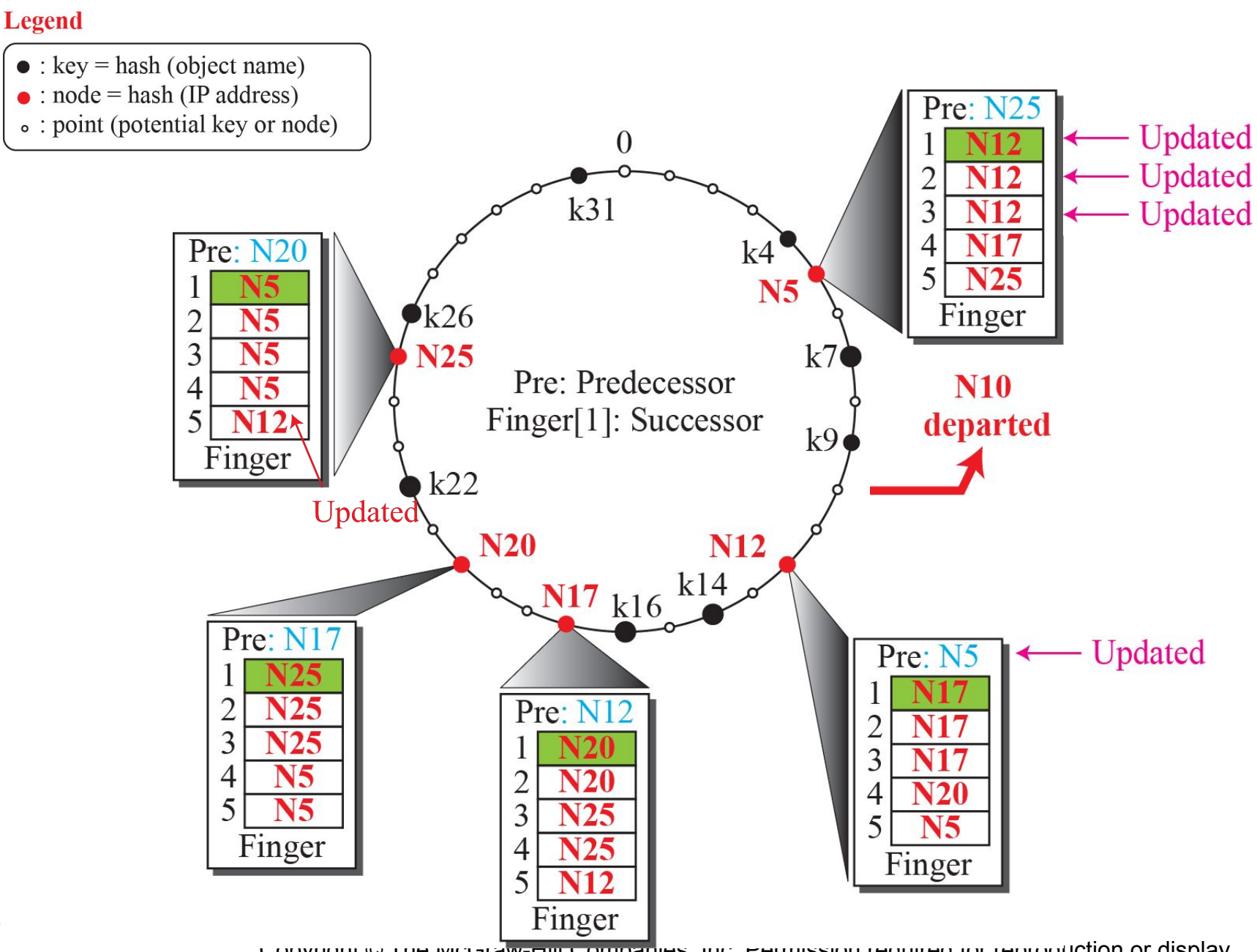


Example 2.18

We assume that a node, N10, leaves the ring in Figure 2.51. Figure 2.52 shows the ring after it has been stabilized. The following shows the process:

1. Node N5 finds out about N10's departure when it does not receive a pong message to its ping message. Node N5 changes its successor to N12 in the list of successors.
2. Node N5 immediately launches the *stabilize* function and asks N12 to change its predecessor to N5.
3. Hopefully, k7 and k9, which were under the responsibility of N10, have been duplicated in N12 before the departure of N10.
4. Nodes N5 and N25 update their finger tables.

Figure 2.52: Example 2.18



2.4.4 Pastry

Another popular protocol in the P2P paradigm is Pastry, designed by Rowstron and Druschel. Pastry uses DHT, as described before, but there are some fundamental differences between Pastry and Chord in the identifier space and routing process that we describe next.

2.4.4 (continued)

- *Identifier Space*
- *Routing*
  - *Routing Table*
  - *Leaf Set*
- *Lookup*
- *Join*
- *Leave or Fail*
- *Application*

Table 2.19: Routing table for a node in Pastry

Common prefix length	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*A*	*B*	*C*	*D*	*E*	*F*
0																
1																
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
31																

Example 2.19

Let us assume that $m = 8$ bits and $b = 2$. This means that we have up to $2^m = 256$ identifiers, and each identifier has m/b = 4 digits in base $2^b = 4$. Figure 2.53 shows the situation in which there are some live nodes and some keys mapped to these nodes. The key k1213 is stored in two nodes because it is equidistant from them.

Figure 2.53: An example of a Pastry ring

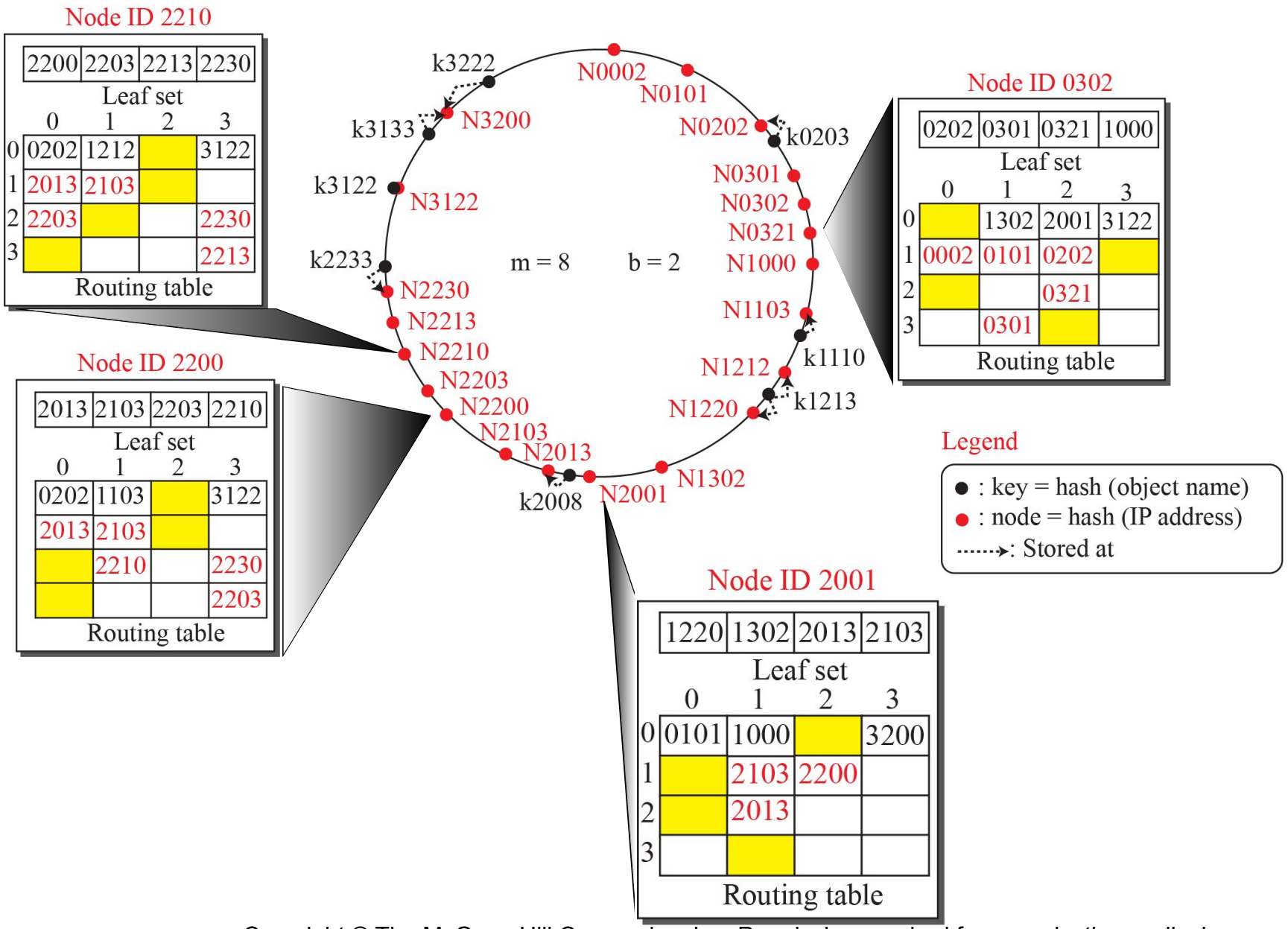


Table 2.20: Lookup (Pastry)

```
Lookup (key)
{
        if (key is in the range of N's leaf set)
                forward the message to the closest node in the leaf set
        else
                route (key, Table)
}
route (key, Table)
{
        p = length of shared prefix between key and N
        v = value of the digit at position p of the key          // Position starts from 0
        if (Table [p, v] exists)
                forward the message to the node in Table [p, v]
        else
                forward the message to a node sharing a prefix as long as the current node, but
                numerically closer to the key.
}
```

Example 2.20

In Figure 2.53, we assume that node N2210 receives a query to find the node responsible for key 2008. Since this node is not responsible for this key, it first checks its leaf set. The key 2008 is not in the range of the leaf set, so the node needs to use its routing table. Since the length of the common prefix is 1, p = 1. The value of the digit at position 1 in the key is v = 0. The node checks the identifier in Table [1, 0], which is 2013. The query is forwarded to node 2013, which is actually responsible for the key. This node sends its information to the requesting node.

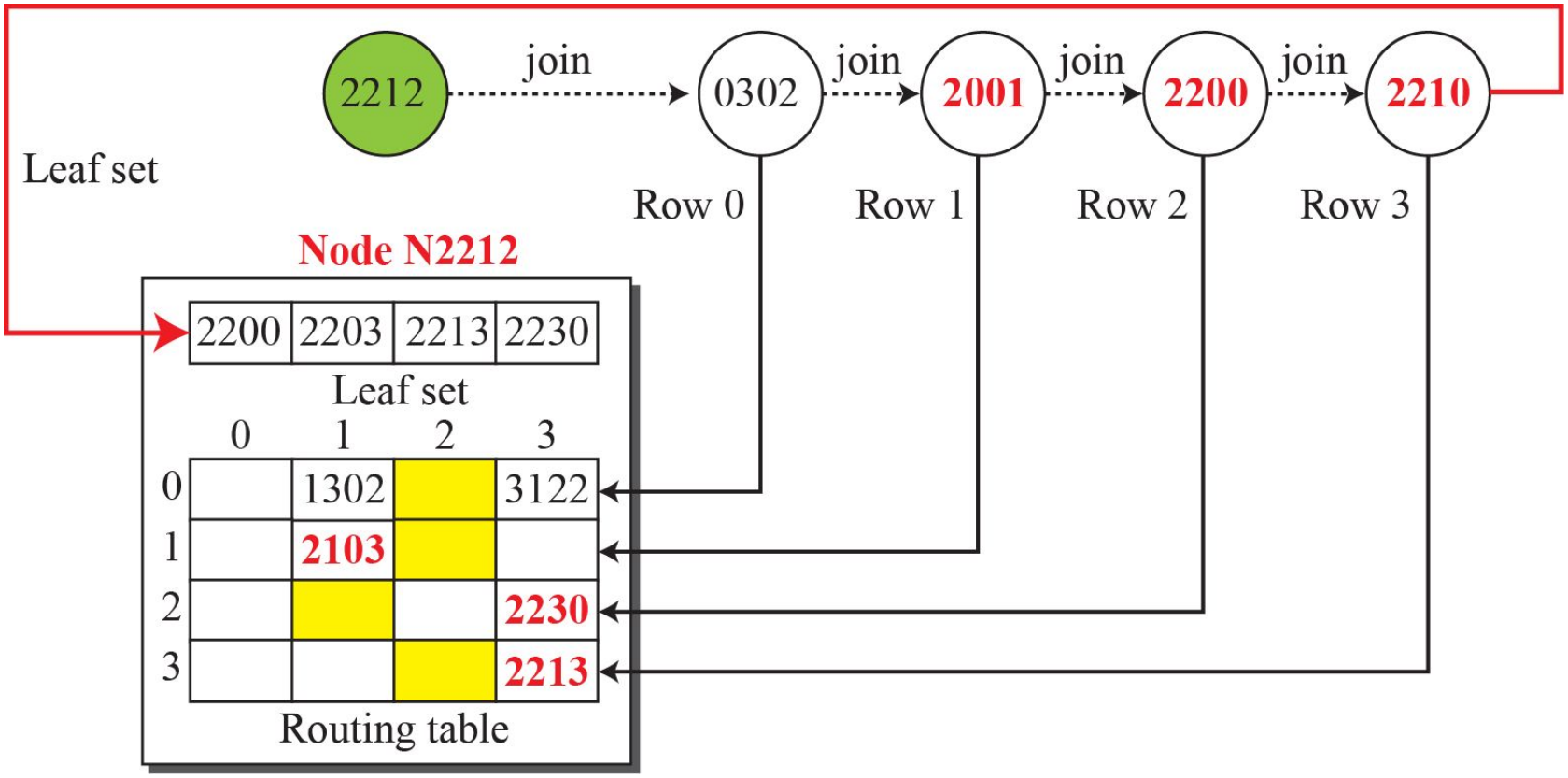
Example 2.21

In Figure 2.53, we assume that node N0302 receives a query to find the node responsible for the key 0203. This node is not responsible for this key, but the key is in the range of its leaf set. The closest node in this set is the node N0202. The query is sent to this node, which is actually responsible for this node. Node N0202 sends its information to the requesting node.

Example 2.22

Figure 2.54 shows how a new node X with node identifier N2212 uses the information in four nodes in Figure 2.53 to create its initial routing table and leaf set for joining the ring. Note that the contents of these two tables will become closer to what they should be in the updating process. In this example, we assume that node 0302 is a nearby node to node 2212 based on the proximity metric.

Figure 2.54: Example 2.22



2.4.5 Kademlia

Another DHT peer-to-peer network is Kademlia, designed by Maymounkov and Mazières. Kademlia, like Pastry, routes messages based on the distance between nodes, but the interpretation of the distance metric in Kademlia is different from the one in Pastry, as we describe below. In this network, the distance between the two identifiers (nodes or keys) is measured as the bitwise exclusive-or (XOR), between them.

2.4.5 (continued)

- *Identifier Space*
- *Routing Table*
- *K-Buckets*
  - *Parallel Query*
  - *Concurrent Updating*
- *Join*
- *Leave or Fail*

Example 2.23

For simplicity, let us assume that $m = 4$. In this space, we can have 16 identifiers distributed on the leaves of a binary tree. Figure 2.55 shows the case with only eight live nodes and five keys.

As the figure shows, the key k3 is stored in N3 because $3 \oplus 3 = 0$. Although the key k7 looks numerically equidistant from N6 and N8, it is stored only in N6 because $6 \oplus 7 = 1$ but $6 \oplus 8 = 14$. Another interesting point is that the key k12 is numerically closer to N11, but it is stored in N15 because $11 \oplus 12 = 7$, but $15 \oplus 12 = 3$.

Figure 2.55: ***Example 2.23***

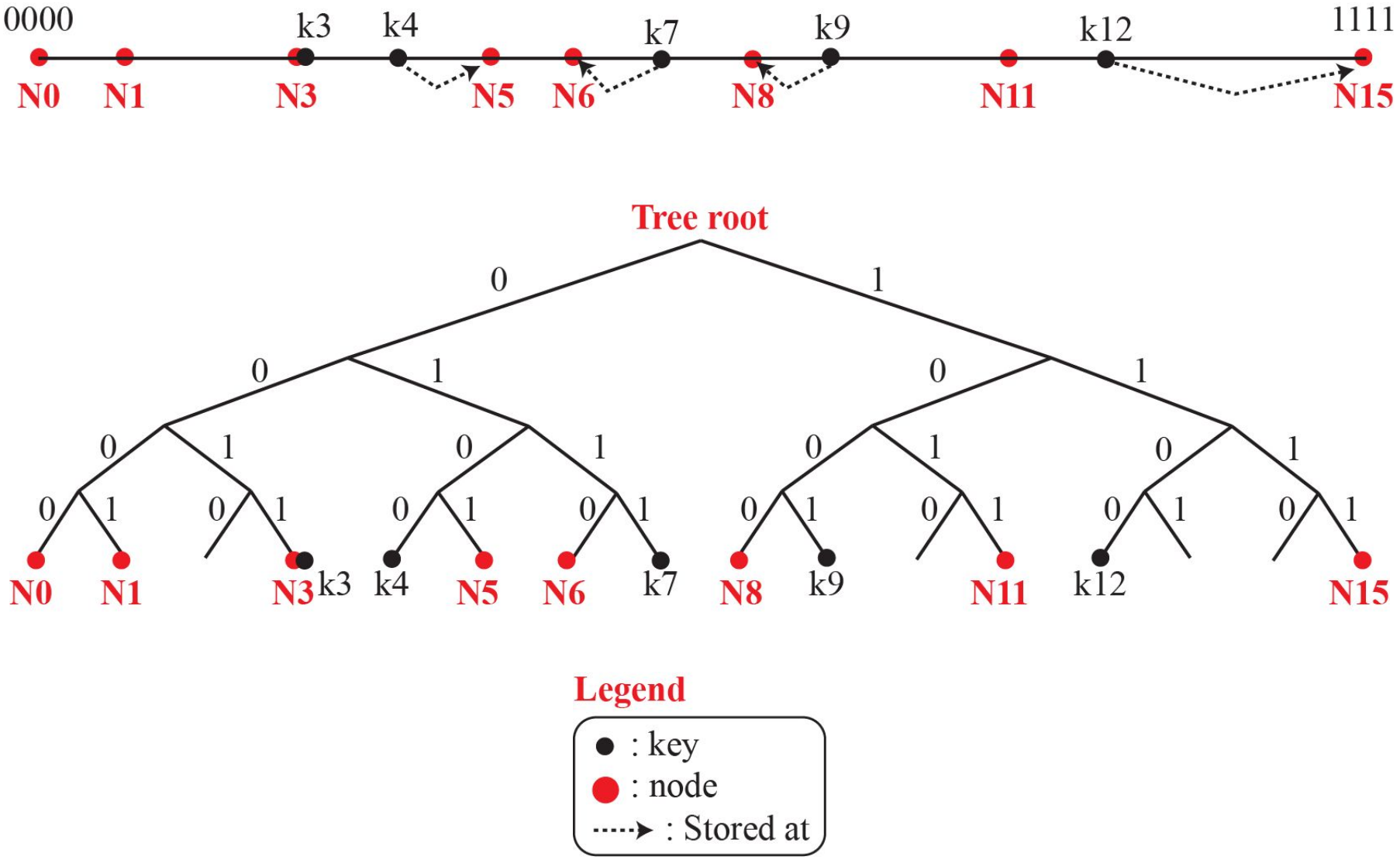


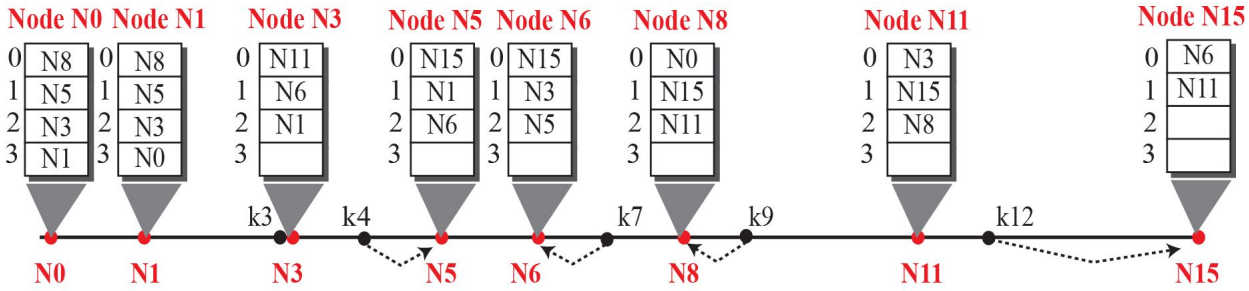
Table 2.21: Routing table for a node in Kademlia

Common prefix length	*Identifiers*
0	Closest node(s) in subtree with common prefix of length 0
1	Closest node(s) in subtree with common prefix of length 1
⋮	⋮
$m-1$	Closest node(s) in subtree with common prefix of length $\boldsymbol{m}-1$

Example 2.24

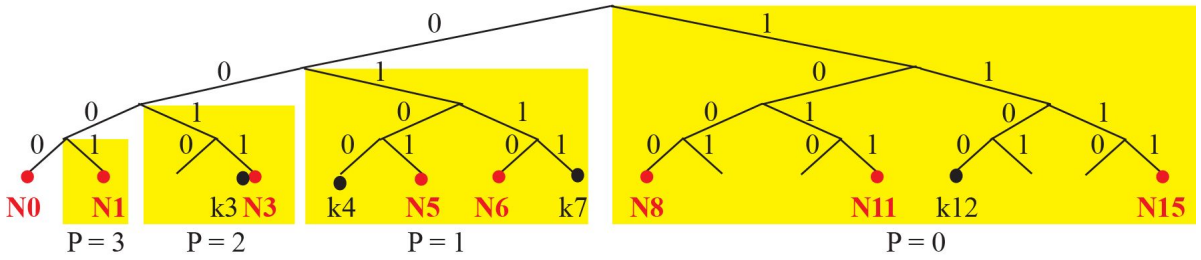
Let us find the routing table for Example 2.23. To make the example simple, we assume that each row uses only one identifier. Since m = 4, each node has four subtrees corresponding to four rows in the routing table. The identifier in each row represents the node that is closest to the current node in the corresponding subtree. Figure 2.56 shows all routing tables, but only three of the subtrees. We have chosen these three, out of eight, to make the figure smaller.

Figure 2.56: Example 2.24

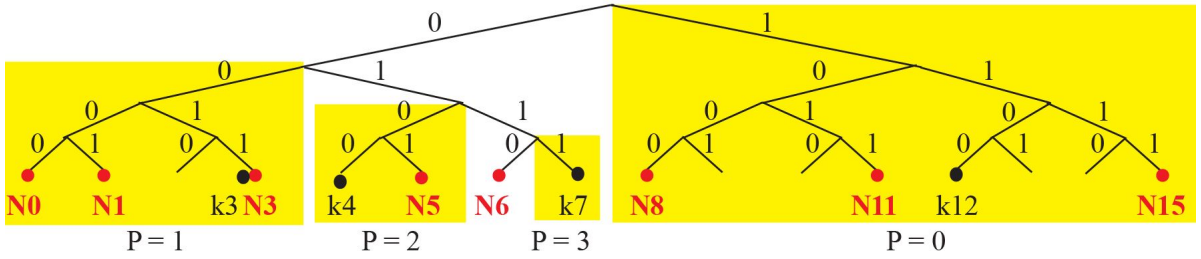


P : Prefix lengh

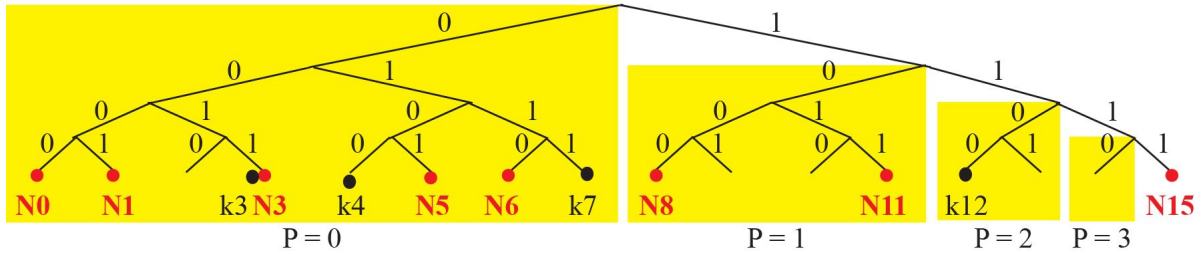
Subtrees for node N0



Subtrees for node N6



Subtrees for node N15



Example 2.25

In Figure 2.56, we assume node N0 $(0000)_2$ receives a lookup message to find the node responsible for k12 $(1100)_2$. The length of the common prefix between the two identifiers is 0. Node N0 sends the message to the node in row 0 of its routing table, node N8. Now node N8 $(1000)_2$ needs to look for the node closest to k12 $(1100)_2$. The length of the common prefix between the two identifiers is 1. Node N8 sends the message to the node in row 1 of its routing table, node N15, which is responsible for k12. The routing process is terminated. The route is N0 → N8 → N15. It is interesting to note that node N15, $(1111)_2$, and k12, $(1100)_2$, have a common prefix of length 2, but row 2 of N15 is empty, which means that N15 itself is responsible for k12.

Example 2.26

In Figure 2.56, we assume node N5 $(0101)_2$ receives a lookup message to find the node responsible for k7 $(0111)_2$. The length of the common prefix between the two identifiers is 2. Node N5 sends the message to the node in row 2 of its routing table, node N6, which is responsible for k7. The routing process is terminated. The route is N5 → N6.

Example 2.27

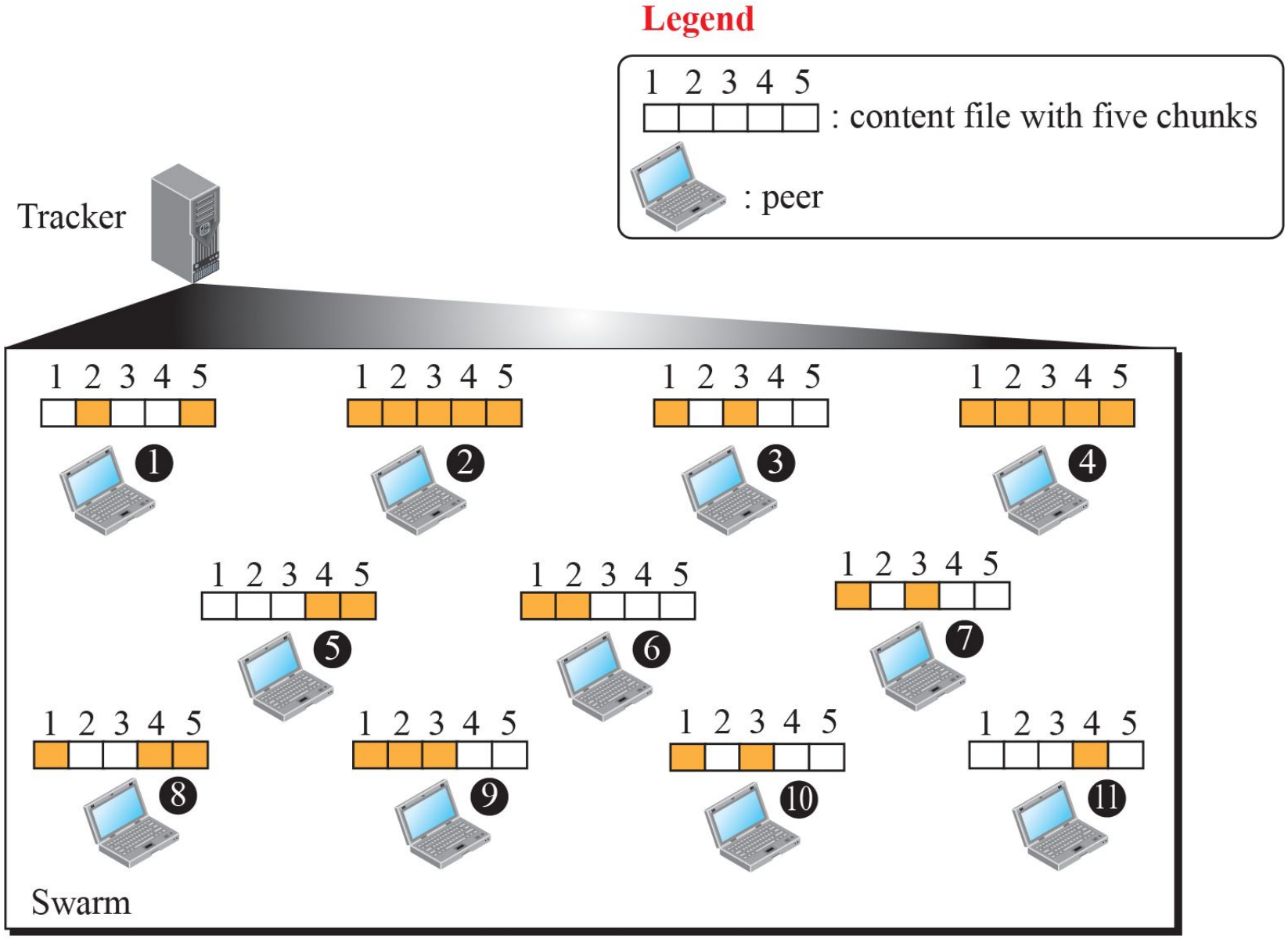
In Figure 2.56, we assume node N11 $(1011)_2$ receives a lookup message to find the node responsible for k4 $(0100)_2$. The length of the common prefix between the two identifiers is 0. Node N11 sends the message to the node in row 0 of its routing table, node N3. Now node N3 $(0011)_2$needs to look for the node closest to k4 $(0100)_2$. The length of the common prefix between the two identifiers is 1. Node N3 sends the message to the node in row 1 of its routing table, node N6. And so on. Theroute is N11 → N3→ N6 → N5.

2.4.6 BitTorrent

BitTorrent is a P2P protocol, designed by Bram Cohen, for sharing a large file among a set of peers. However, the term sharing in this context is different from other file sharing protocols. Instead of one peer allowing another peer to download the whole file, a group of peers takes part in the process to give all peers in the group a copy of the file. File sharing is done in a collaborating process called a torrent.

- *BitTorrent with A Tracker*
- *Trackerless BitTorrent*

Figure 2.57: Example of a torrent



Note: Peers 2 and 4 are seeds; others are leeches.

2-5 SOCKET-INTERFACE PROGRAMMING

In this section, we show how to write some simple client-server programs using C, a procedural programming language. We chose the C language in this section; In Chapter 11, we expand this idea in Java, which provides a more compact version.

2.5.1 Socket Interface in C

In this section, we show how this interface is implemented in the C language. The important issue in socket interface is to understand the role of a socket in communication. The socket has no buffer to store data to be sent or received. It is capable of neither sending nor receiving data. The socket just acts as a reference or a label. The buffers and necessary variables are created inside the operating system.

2.5.1 (continued)

- Data Structure for Socket
- Header Files
- Communication Using UDP
  - Sockets Used for UDP
  - Communication Flow Diagram
  - Programming Examples
- Communication Using TCP
  - Sockets Used in TCP
  - Communication Flow Diagram

Figure 2.58: ***Socket data structure***

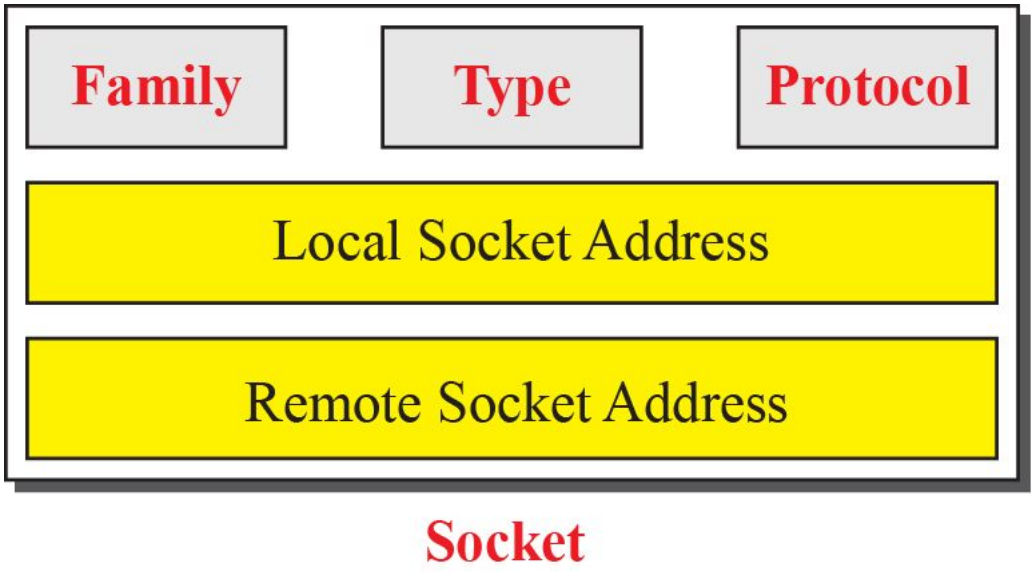


Figure 2.59: Sockets for UDP communication

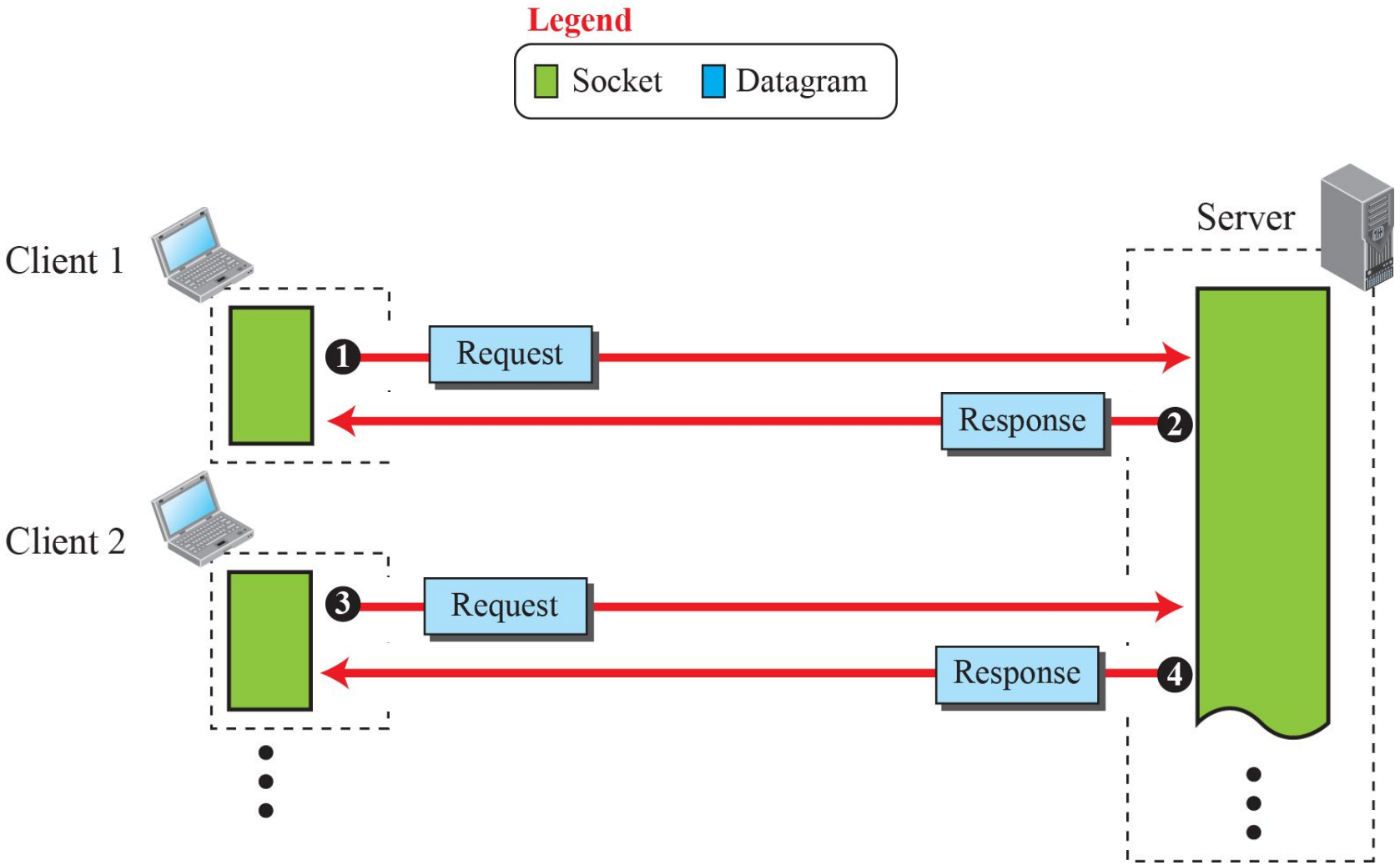


Figure 2.60: Flow diagram for iterative UDP communication

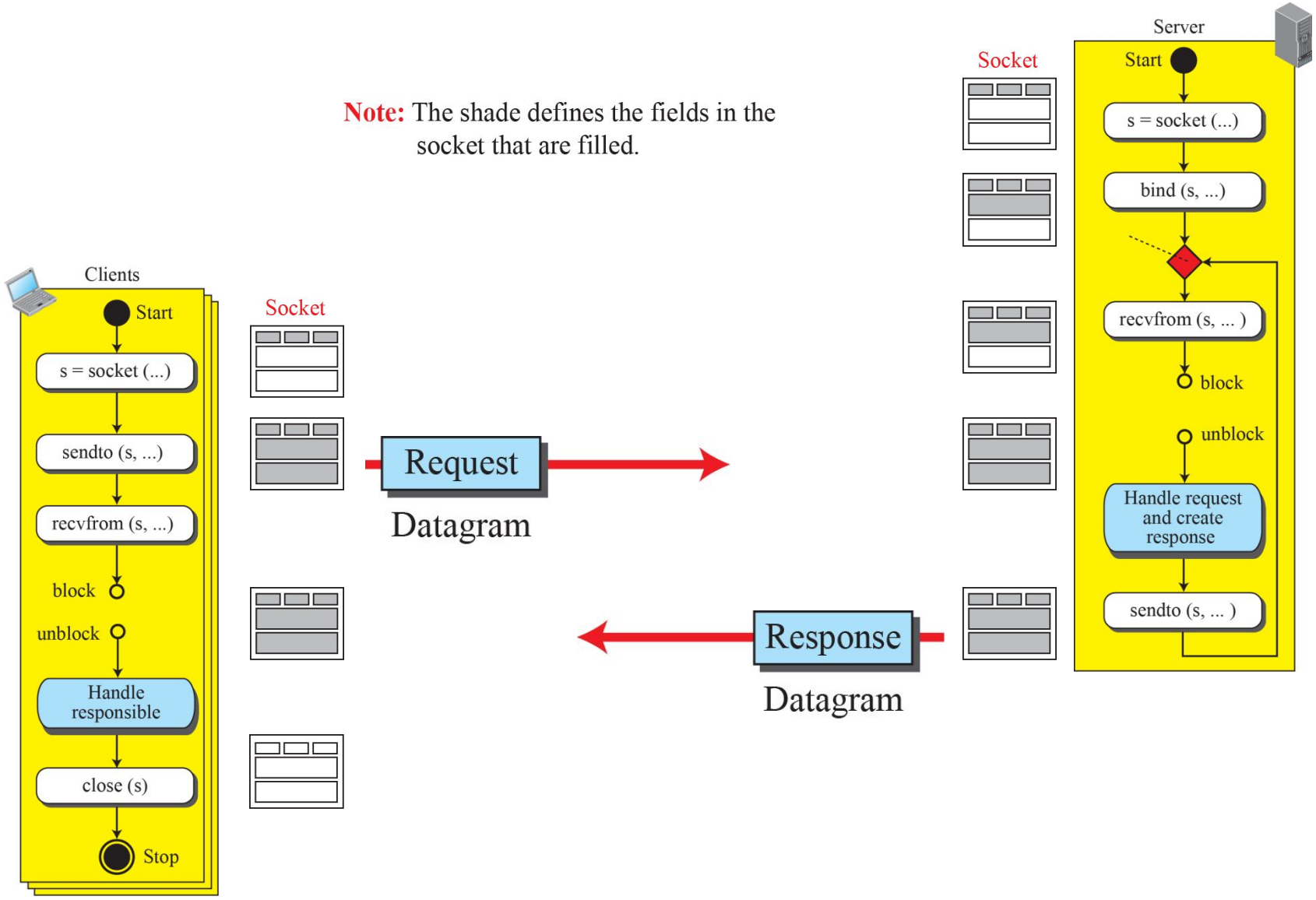


Table 2.22: Echo server program using UDP

```
1   // UDP echo server program
2   #include "headerFiles.h"
3   int main (void)
4   {
5       // Declare and define variables
6       int s;                                  // Socket descriptor (reference)
7       int len;                                // Length of string to be echoed
8       char   buffer [256];                    // Data buffer
9       struct sockaddr_in servAddr;            // Server (local) socket address
10      struct sockaddr_in clntAddr;            // Client (remote) socket address
11      int  clntAddrLen;                       // Length of client socket address
12      // Build local (server) socket address
13      memset (&servAddr, 0, sizeof (servAddr));          // Allocate memory
14      servAddr.sin_family =   AF_INET;                   // Family field
15      servAddr.sin_port = htons (SERVER_PORT)            // Default port number
16      servAddr.sin_addr.s_addr =  htonl (INADDR_ANY);    // Default IP address
17      // Create socket
18      if ((s = socket (PF_INET, SOCK_DGRAM, 0) < 0);
```

Table 2.22: Echo server program using UDP (continued)

```
19      {
20              perror ("Error: socket failed!");
21              exit (1);
22      }
23      // Bind socket to local address and port
24      if ((bind (s, (struct sockaddr*) &servAddr, sizeof (servAddr)) < 0);
25      {
26              perror ("Error: bind failed!");
27              exit (1);
28      }
29      for ( ; ; )         // Run forever
30      {
31              // Receive String
32              len = recvfrom (s, buffer, sizeof (buffer), 0,
33                      (struct sockaddr*)&clntAddr, &clntAddrLen);
34              // Send String
35              sendto (s, buffer, len, 0, (struct sockaddr*)&clntAddr, sizeof(clntAddr));
36      } // End of for loop
37  } // End of echo server program
```

Table 2.23: Echo client program using UDP

```
1   // UDP echo client program
2   #include "headerFiles.h"
3   int main (int argc, char* argv[ ])          // Three arguments to be checked later
4   {
5       // Declare and define variables
6       int   s;                                // Socket descriptor
7       int   len;                              // Length of string to be echoed
8       char*  servName;                        // Server name
9       int   servPort;                         // Server port
10      char*   string;                         // String to be echoed
11      char  buffer[256 + 1];                  // Data buffer
12      struct sockaddr_in servAddr;            // Server socket address
13      // Check and set program arguments
14      if (argc != 3)
15      {
16          printf ("Error: three arguments are needed!");
17          exit(1);
18      }
```

Table 2.23: Echo client program using UDP (continued)

```
19      servName = argv[1];
20      servPort = atoi (argv[2]);
21      string =  argv[3];
22      // Build server socket address
23      memset (&servAddr, 0, sizeof (servAddr));
24      servAddr.sin_family = AF_INET;
25      inet_pton (AF_INET, servName, &servAddr.sin_addr);
26      servAddr.sin_port = htons (servPort);
27      // Create socket
28      if ((s = socket (PF_INET, SOCK_DGRAM, 0) < 0);
29      {
30          perror ("Error: Socket failed!");
31          exit (1);
32      }
33      // Send echo string
34      len =  sendto (s, string, strlen (string), 0, (struct sockaddr)&servAddr, sizeof (servAddr));
35      // Receive echo string
36      recvfrom (s, buffer, len, 0, NULL, NULL);
37      // Print and verify echoed string
```

Table 2.23: Echo client program using UDP (continued)

```
38          buffer [len] = '\0';
39          printf ("Echo string received: ";
40          fputs (buffer, stdout);
41          // Close the socket
42          close (s);
43          // Stop the program
44          exit (0);
45  } // End of echo client program
```

Figure 2.61: Sockets used in TCP communication

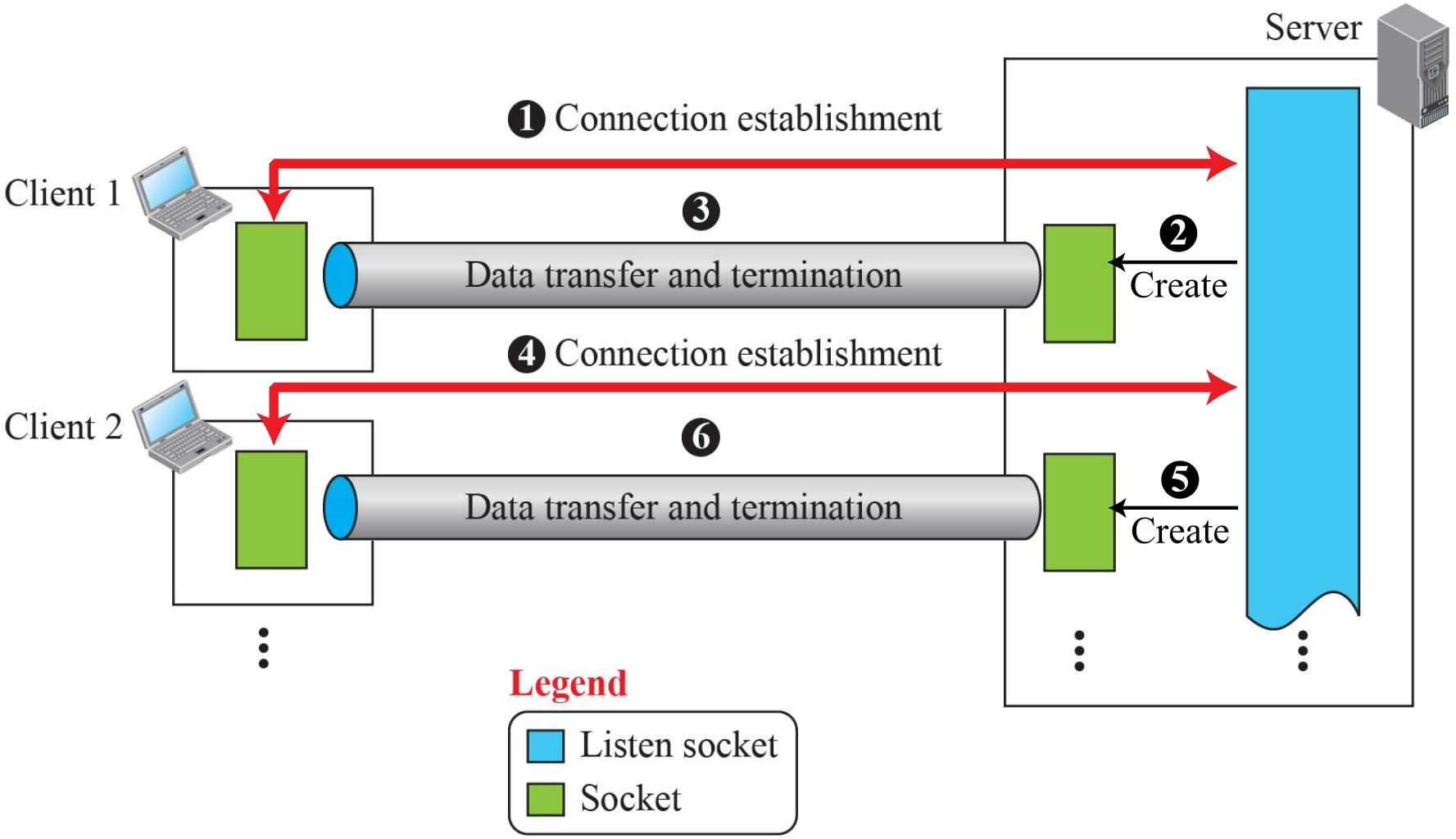


Figure 2.62: Flow diagram for iterative TCP communication

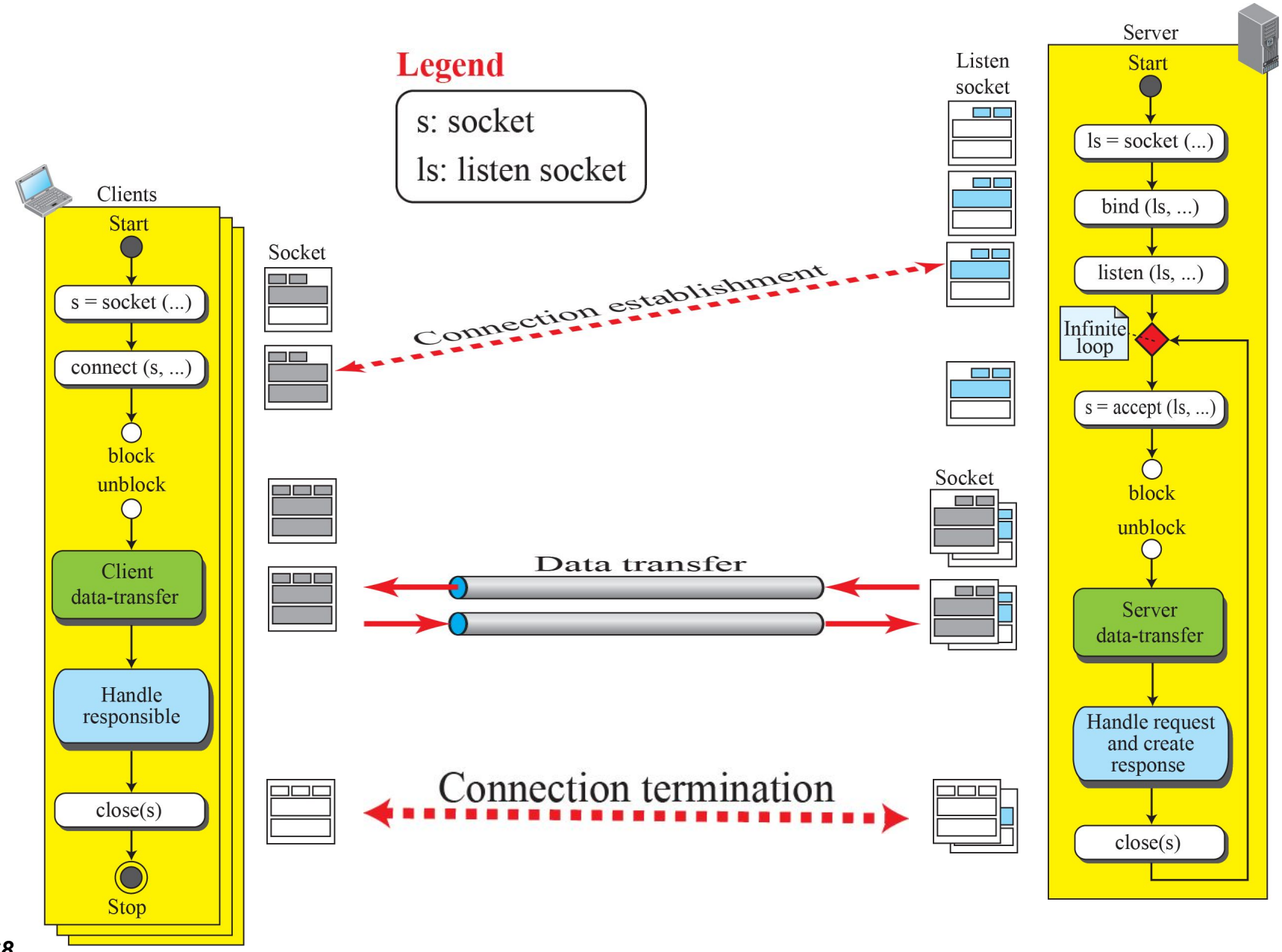


Figure 2.63: Flow diagram for data-transfer boxes

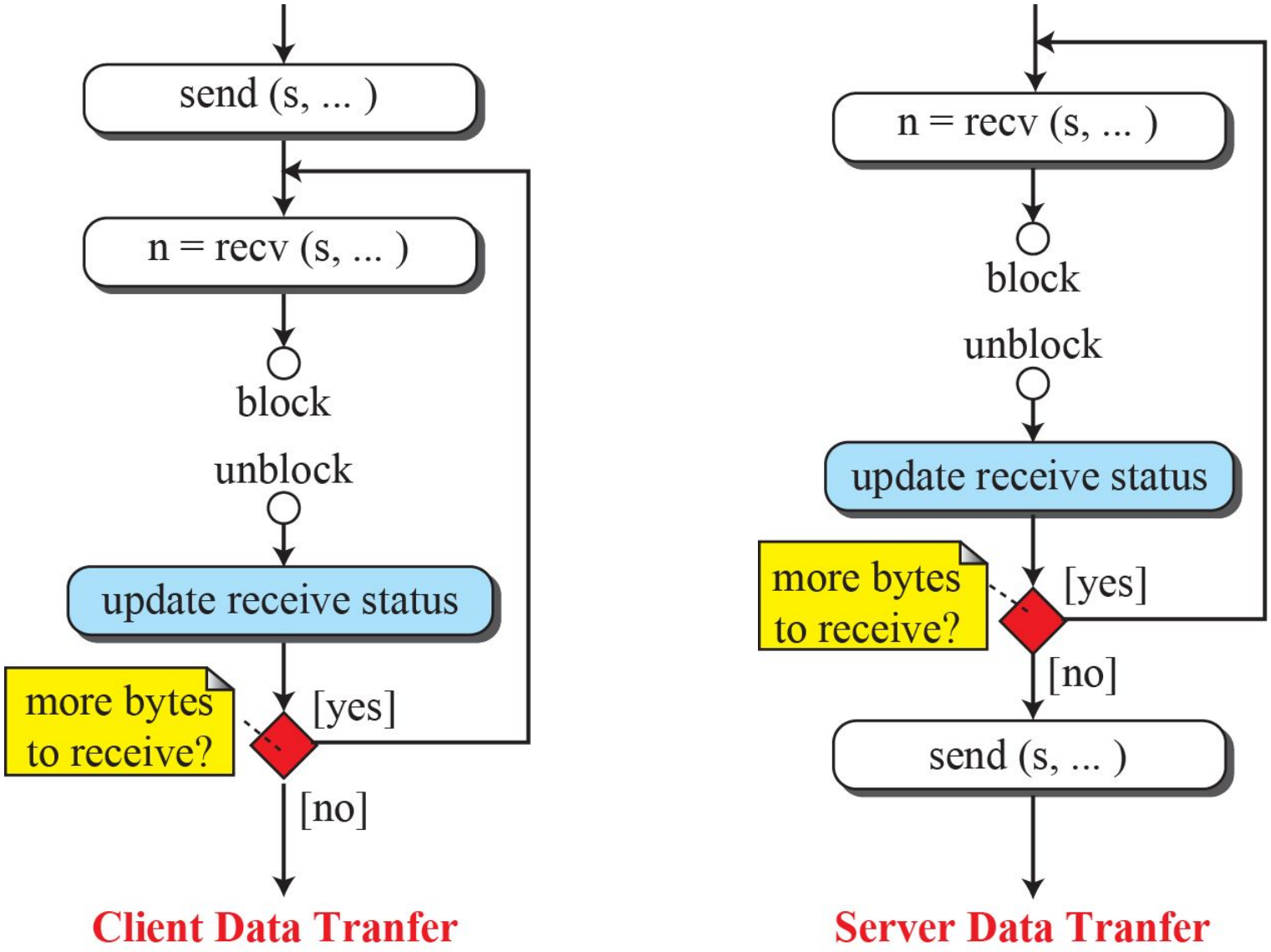


Figure 2.64: ***Buffer used for receiving***

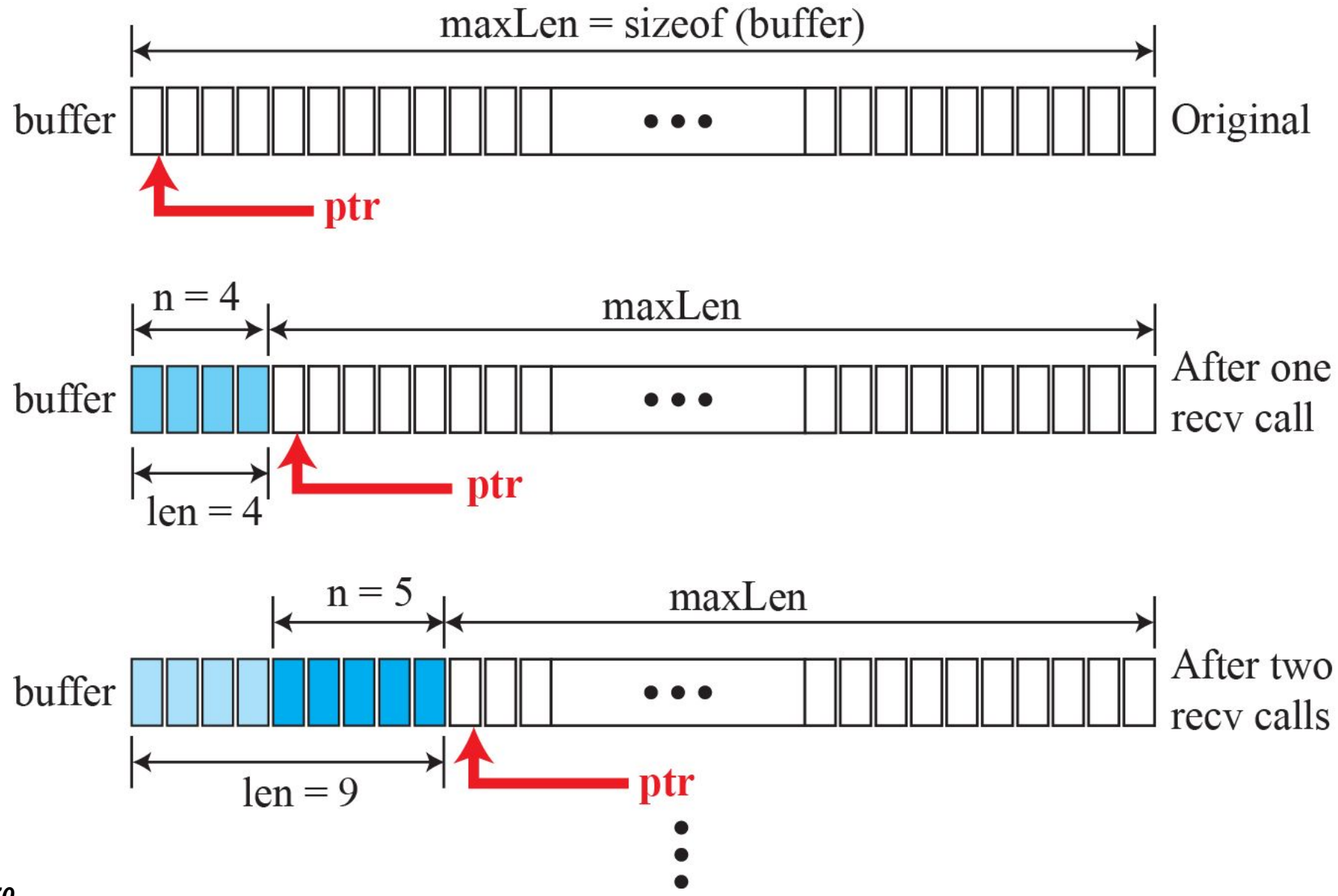


Table 2.24: Echo server program using the services of TCP

```
1   // Echo server program
2   #include "headerFiles.h"
3   int main (void)
4   {
5       // Declare and define
6       int ls;                          // Listen socket descriptor (reference)
7       int s;                           // socket descriptor (reference)
8       char buffer [256];               // Data buffer
9       char* ptr = buffer;              // Data buffer
10      int len = 0;                     // Number of bytes to send or receive
11      int maxLen = sizeof (buffer);    // Maximum number of bytes to receive
12      int n = 0;                       // Number of bytes for each recv call
13      int waitSize = 16;               // Size of waiting clients
14      struct sockaddr_in serverAddr;   // Server address
15      struct sockaddr_in clientAddr;   // Client address
16      int clntAddrLen;                 // Length of client address
17      // Create local (server) socket address
18      memset (&servAddr, 0, sizeof (servAddr));
19      servAddr.sin_family = AF_INET;
20      servAddr.sin_addr.s_addr = htonl (INADDR_ANY);     // Default IP address
```

Table 2.24: TCP Echo server program(continued)

```
21      servAddr.sin_port = htons (SERV_PORT);              // Default port
22      // Create listen socket
23      if (ls = socket (PF_INET, SOCK_STREAM, 0) < 0);
24      {
25          perror ("Error: Listen socket failed!");
26          exit (1);
27      }
28      // Bind listen socket to the local socket address
29      if (bind (ls, &servAddr, sizeof (servAddr)) < 0);
30      {
31          perror ("Error: binding failed!");
32          exit (1);
33      }
34      // Listen to connection requests
35      if (listen (ls, waitSize) < 0);
36      {
37          perror ("Error: listening failed!");
38          exit (1);
39      }
40      // Handle the connection
```

Table 2.24: TCP Echo server program (continued)

```
41      for ( ; ; )                                  // Run forever
42      {
43          // Accept connections from client
44          if (s = accept (ls, &clntAddr, &clntAddrLen) < 0);
45          {
46              perror ("Error: accepting failed!);
47              exit (1);
48          }
49          // Data transfer section
50          while ((n = recv (s, ptr, maxLen, 0)) > 0)
51          {
52              ptr + = n;                  // Move pointer along the buffer
53              maxLen - = n;               // Adjust maximum number of bytes to receive
54              len + = n;                  // Update number of bytes received
55          }
56          send (s, buffer, len, 0);       // Send back (echo) all bytes received
57          // Close the socket
58          close (s);
59      } // End of for loop
60  } // End of echo server program
```

Table 2.25: Echo client program using the services of TCP

```
1   // TCP echo client program
2   #include "headerFiles.h"
3   int main (int argc, char* argv[ ])          // Three arguments to be checked later
4   {
5       // Declare and define
6       int  s;                                 // Socket descriptor
7       int  n;                                 // Number of bytes in each recv call
8       char* servName;                         // Server name
9       int servPort;                           // Server port number
10      char* string;                           // String to be echoed
11      int  len;                               // Length of string to be echoed
12      char  buffer [256 + 1];                 // Buffer
13      char* ptr = buffer;                     // Pointer to move along the buffer
14      struct sockaddr_in serverAddr;          // Server socket address
15      // Check and set arguments
16      if (argc != 3)
17      {
18          printf ("Error: three arguments are needed!");
19          exit (1);
20      }
```

Table 2.25: TCP Echo client program (continued)

```
21      servName = arg [1];
22      servPort = atoi (arg [2]);
23      string = arg [3];
24      // Create remote (server) socket address
25      memset (&servAddr, 0, sizeof(servAddr);
26      serverAddr.sin_family = AF_INET;
27      inet_pton (AF_INET, servName, &serverAddr.sin_addr); // Server IP address
28      serverAddr.sin_port = htons (servPort);              // Server port number
29      // Create socket
30      if ((s = socket (PF_INET, SOCK_STREAM, 0) < 0);
31      {
32          perror ("Error: socket creation failed!");
33          exit (1);
34      }
35      // Connect  to the server
36      if (connect (sd, (struct sockaddr*)&servAddr, sizeof(servAddr)) < 0);
37      {
38          perror ("Error: connection failed!");
```

Table 2.24: TCP Echo client program(continued)

```
39              exit (1);
40          }
41          // Data transfer section
42          send (s, string, strlen(string), 0);
43          while ((n = recv (s, ptr, maxLen, 0)) > 0)
44          {
45              ptr + = n;                  // Move pointer along the buffer
46              maxLen - = n;               // Adjust the maximum number of bytes
47              len += n;                   // Update the length of string received
48          } // End of while loop
49          // Print and verify the echoed string
50          buffer [len] = '\0';
51          printf ("Echoed string received: ");
52          fputs (buffer, stdout);
53          // Close socket
54          close (s);
55          // Stop program
56          exit (0);
57      } // End of echo client program
```

Chapter 2: Summary

- *Applications in the Internet are designed using either a client-server paradigm or a peer-to-peer paradigm. In a client-server paradigm, an application program, called a server, provides services and another application program, called a client, receives services. A server program is an infinite program; a client program is finite. In a peer-to- peer paradigm, a peer can be both a client and a server.*

- *The World Wide Web (WWW) is a repository of information linked together from points all over the world. Hypertext and hypermedia documents are linked to one another through pointers. The HyperText Transfer Protocol (HTTP) is the main protocol used to access data on the World Wide Web (WWW).*

Chapter 2: Summary (continued)

- *Electronic mail is one of the most common applications on the Internet. The e-mail architecture consists of several components such as user agent (UA), main transfer agent (MTA), and main access agent (MAA). The protocol that implements MTA is called Simple Mail Transfer Protocol (SMTP). Two protocols are used to implement MAA: Post Office Protocol, version 3 (POP3) and Internet Mail Access Protocol, version 4 (IMAP4).*

Chapter 2: Summary (continued)

- *File Transfer Protocol (FTP) is a TCP/IP client-server application for copying files from one host to another. FTP requires two connections for data transfer: a control connection and a data connection. FTP employs NVT ASCII for communication between dissimilar systems.*

- *TELNET is a client-server application that allows a user to log into a remote machine, giving the user access to the remote system. When a user accesses a remote system via the TELNET process, this is comparable to a time-sharing environment.*

Chapter 2: Summary (continued)

- *The Domain Name System (DNS) is a client-server application that identifies each host on the Internet with a unique name. DNS organizes the name space in a hierarchical structure to decentralize the responsibilities involved in naming. TELNET is a client-server application that allows a user to log into a remote machine, giving the user access to the remote system.*

- *In a peer-to-peer network, Internet users that are ready to share their resources become peers and form a network. Peer-to-peer networks are divided into centralized and decentralized.*