PART IV

Internetworking Using TCP/IP

Internet architecture, addressing, binding, encapsulation, and protocols in the TCP/IP suite

Chapters

Chapter Contents

20

Internetworking: Concepts, Architecture, and Protocols

20.1 Introduction

Previous chapters describe basic networking, including the hardware components used in LAN and WAN networks as well as general concepts such as addressing and routing. This chapter begins an examination of another fundamental idea in computer communication — an internetworking technology that can be used to connect multiple physical networks into a large, uniform communication system. The chapter discusses the motivation for internetworking, introduces the hardware components used, describes the architecture in which the components are connected, and discusses the significance of the concept. The remaining chapters in this section expand the internetworking concept, and provide additional details about the technology. They examine individual protocols, and explain how each uses techniques from earlier chapters to achieve reliable, error-free communication.

20.2 The Motivation For Internetworking

Each network technology is designed to fit a specific set of constraints. For example, LAN technologies are designed to provide high-speed communication across short distances, while WAN technologies are designed to provide communication across large areas. Consequently, No single networking technology is best for all needs.

A large organization with diverse networking requirements needs multiple physical networks. More important, if the organization chooses the type of network that is best for each task, the organization will have several types of networks. For example, a LAN technology like Ethernet might be the best solution for connecting computers at a given site, but a leased data circuit might be used to interconnect a site in one city with a site in another.

20.3 The Concept Of Universal Service

The chief problem with multiple networks should be obvious: a computer attached to a given network can only communicate with other computers attached to the same network. The problem became evident in the 1970s as large organizations began to acquire multiple networks. Each network in the organization formed an island. In many early installations, each computer attached to a single network, and employees had to choose a computer appropriate for each task. That is, an employee was given access to multiple screens and keyboards, and the employee was forced to move from one computer to another to send a message across the appropriate network.

Users are neither satisfied nor productive when they must use a separate computer for each network. Consequently, most modern computer communication systems allow communication between any two computers analogous to the way a telephone system provides communication between any two telephones. Known as *universal service*, the concept is a fundamental part of networking. With universal service, a user on any computer in any organization can send messages or data to any other user. Furthermore, a user does not need to change computer systems when changing tasks — all information is available to all computers. As a result, users are more productive. To summarize:

A communication system that supplies universal service allows arbitrary pairs of computers to communicate.

20.4 Universal Service In A Heterogeneous World

Does universal service mean that everyone needs to adopt a single network technology, or is it possible to have universal service across multiple networks that use multiple technologies? Incompatibilities make it impossible to form a large network merely by interconnecting the wires among networks. Furthermore, extension techniques such as bridging cannot be used with heterogeneous network technologies because each technology uses its own packet format and addressing scheme. Thus, a frame created for one network technology cannot be transmitted on a network that uses a different technology. The point can be summarized:

Although universal service is highly desirable, incompatibilities among network hardware, frames, and addresses prevent a bridged network from including arbitrary technologies.

20.5 Internetworking

Despite the incompatibilities among network technologies, researchers have devised a scheme that provides universal service among heterogeneous networks. Called *internetworking*, the scheme uses both hardware and software. Additional hardware systems are used to interconnect a set of physical networks. Software on the attached computers then provides universal service. The resulting system of connected physical networks is known as an *internetwork* or *internet*.

Internetworking is quite general. In particular, an internet is not restricted in size — internets exist that contain a few networks and the global Internet contains tens of thousands of networks. Similarly, the number of computers attached to each network in an internet can vary — some networks have no computers attached, while others have hundreds.

20.6 Physical Network Connection With Routers

The basic hardware component used to connect heterogeneous networks is a *router*. Physically, a router is an independent hardware system dedicated to the task of interconnecting networks. Like a bridge, a router contains a processor and memory as well as a separate I/O interface for each network to which it connects. The network treats a connection to a router the same as a connection to any other computer. Figure 20.1 illustrates that the physical connection of networks with a router is straightforward.

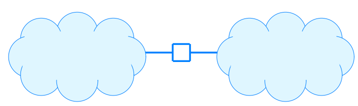

Figure 20.1 Two physical networks connected by a router, which has a separate interface for each network connection. Computers can attach to each network.

The figure uses a cloud to depict each network because router connections are not restricted to a particular network technology. A router can connect two LANs, a LAN and a WAN, or two WANs. Furthermore, when a router connects two networks in the same general category, the networks do not need to use the same technology. For example, a router can connect an Ethernet to a Wi-Fi network. Thus, each cloud represents an arbitrary network technology.

To summarize:

> *An Internet router is a special-purpose hardware system dedicated to the task of interconnecting networks. A router can interconnect networks that use different technologies, including different media, physical addressing schemes, or frame formats.*

20.7 Internet Architecture

Routers make it possible for organizations to choose network technologies appropriate for each need and to use routers to connect all networks into an internet. For example, Figure 20.2 illustrates how three routers can be used to connect four arbitrary physical networks into an internet.

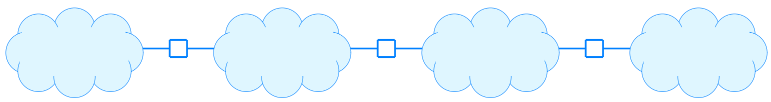

Figure 20.2 An internet formed by using three routers to interconnect four physical networks.

Although the figure shows each router with exactly two connections, commercial routers can connect more than two networks. Thus, a single router could connect all four networks in the example. Despite the feasibility, an organization seldom uses a single router to connect all of its networks. There are two reasons:

- Because the router must forward each packet, the processor in a given router is insufficient to handle the traffic passing among an arbitrary number of networks.
- Redundancy improves internet reliability. To avoid a single point of failure, protocol software continuously monitors internet connections and instructs routers to send traffic along alternative paths when a network or router fails.

Thus, when planning an internet, an organization must choose a design that meets the organization's need for reliability, capacity, and cost. In particular, the exact details of internet topology often depend on the bandwidth of the physical networks, the expected traffic, the organization's reliability requirements, and the cost and performance of available router hardware. To summarize:

> *An internet consists of a set of networks interconnected by routers. The internet scheme allows each organization to choose the number and type of networks, the number of routers to use to interconnect them, and the exact interconnection topology.*

20.8 Achieving Universal Service

The goal of internetworking is universal service across heterogeneous networks. To provide universal service among all computers on an internet, routers must agree to forward information from a source on one network to a specified destination on another. The task is complex because frame formats and addressing schemes used by the underlying networks can differ. As a result, protocol software is needed on computers and routers to make universal service possible.

Later chapters describe Internet† protocol software in detail. They show how Internet protocols overcome differences in frame formats and physical addresses to make communication possible among networks that use different technologies. Before considering how Internet protocols work, it is important to understand the effect that an internet system presents to attached computers.

20.9 A Virtual Network

In general, Internet software provides the appearance of a single, seamless communication system to which many computers attach. The system offers universal service: each computer is assigned an address, and any computer can send a packet to any other computer. Furthermore, Internet protocol software hides the details of physical network connections, physical addresses, and routing information — neither users nor application programs are aware of the underlying physical networks or the routers that connect them.

We say that an internet is a *virtual network* system because the communication system is an abstraction. That is, although a combination of hardware and software provides the illusion of a uniform network system, no such network exists. Figure 20.3 illustrates the virtual network concept as well as a corresponding physical structure.

†Recall that when written with an uppercase *I*, the term *Internet* refers to the global Internet and the associated protocols.

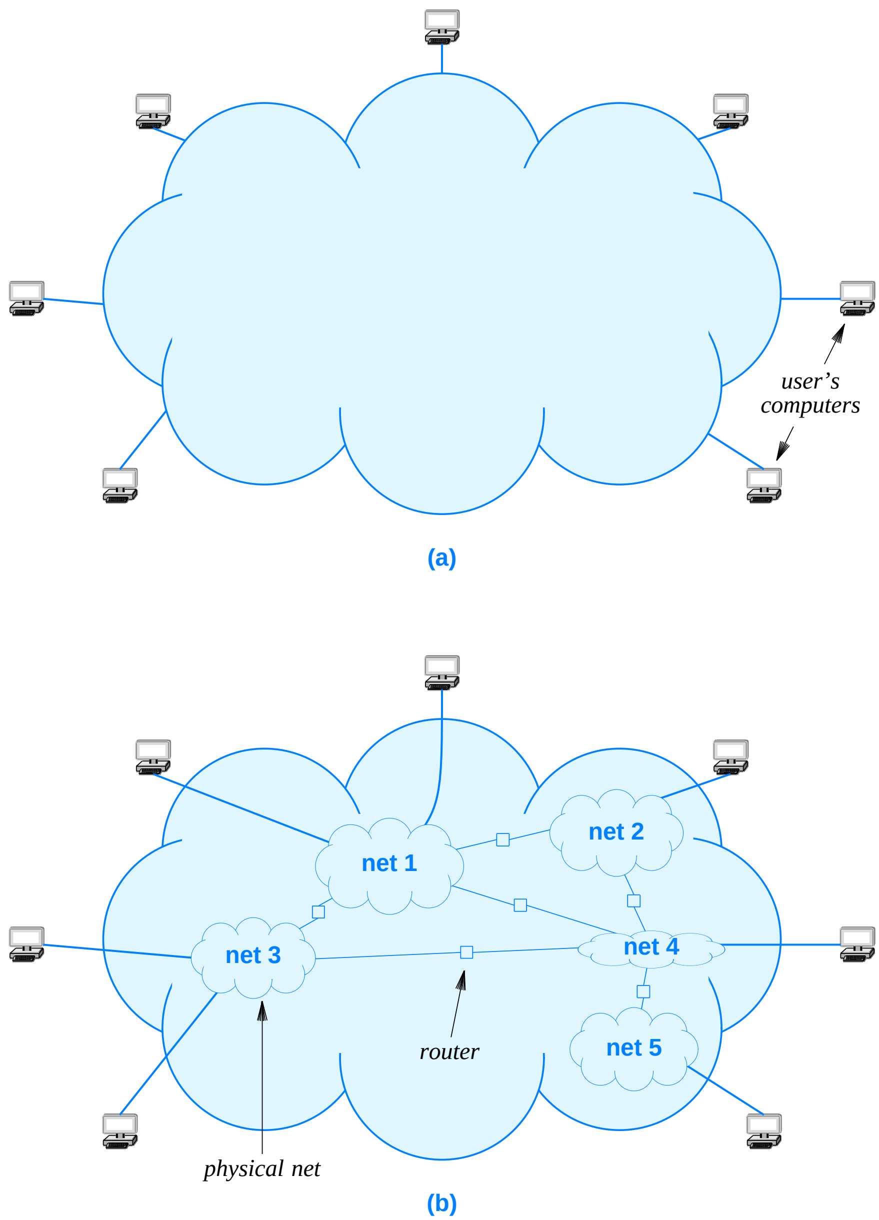

Figure 20.3 The Internet concept. (a) The illusion of a single network provided to users and applications, and (b) the underlying physical structure with routers interconnecting networks.

20.10 Protocols For Internetworking

Although several protocols have been proposed for use with internets, one suite stands out as the most widely used. The suite is formally known as the *TCP/IP Internet Protocols*; most networking professionals simply refer to the suite as *TCP/IP*†.

TCP/IP was developed at the same time as the global Internet. In fact, the same researchers who proposed TCP/IP also proposed the Internet architecture described above. Work on TCP/IP began in the 1970s, approximately the same time that Local Area Networks were being developed, and continued until the early 1990s when the Internet became commercial.

20.11 Review Of TCP/IP Layering

Recall from Chapter 1 that the Internet protocols use a five-layer reference model as Figure 20.4 illustrates.

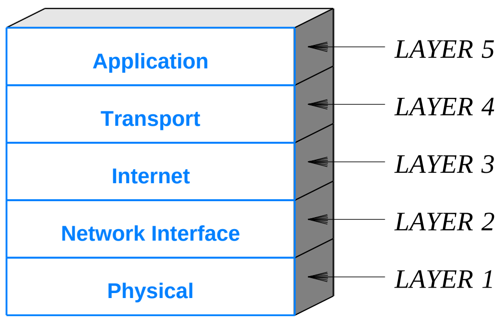

Figure 20.4 The five layers of the TCP/IP reference model.

We have already explored three of the layers. Chapters in part 1 of the text consider applications; chapters in parts 2 and 3 of the text discuss layer 1 and layer 2 protocols. Chapters in this part of the text consider the two remaining layers in detail:

Layer 3: Internet

Layer *3* (IP) specifies the format of packets sent across the Internet as well as the mechanisms used to forward packets from a computer through one or more routers to a final destination.

†TCP and IP are acronyms for two of the most important protocols in the suite; the name is pronounced by spelling out T-C-P-I-P.

Layer 4: Transport

Layer *4* (TCP) specifies the messages and procedures that are used to insure reliable transfer.

To summarize:

> *Internet protocols are organized into five conceptual layers, with IP at layer 3 and TCP at layer 4.*

20.12 Host Computers, Routers, And Protocol Layers

We use the term *host computer* to refer to a computer that connects to the Internet and runs applications. A host can be as small as a cell phone or as large as a mainframe. Furthermore, a host's CPU can be slow or fast, the memory can be large or small, and the network to which a host connects can operate at high or low speed. TCP/IP protocols make it possible for any pair of hosts to communicate, despite hardware differences.

Both hosts and routers need TCP/IP protocol software. However, routers do not use protocols from all layers. In particular, a router does not need layer *5* protocols for applications like file transfer because routers do not run conventional applications†. The next chapters discuss TCP/IP protocol software in more detail, and show how Internet layering works.

20.13 Summary

Logically, the Internet appears to be a single, seamless communication system. An arbitrary pair of computers connected to the Internet can communicate as if they were attached to a single network. That is, a computer can send a packet to any other computer that is attached to the Internet. Physically, the Internet is a collection of networks interconnected by devices called *routers*. Each router is a special-purpose device that connects to two or more networks and is dedicated to transferring Internet packets among the networks.

Computers that attach to the Internet are called *hosts*. A host may be a large computer (e.g., a supercomputer) or a small computer (e.g., a cell phone). Each host attaches to one of the physical networks in the Internet.

The illusion of a single communication system is provided by Internet protocol software. Each host or router in the Internet must run the software, which hides the details of the underlying physical connections and takes care of sending each packet to its destination.

†Some routers do run special applications that permit a manager to control the router remotely.

The most important protocols developed for internetworking are known as the *TCP/IP Internet Protocols*, usually abbreviated as *TCP/IP*. In addition to being used on private internets, TCP/IP has been used on the global Internet for many years.

EXERCISES

20.1 Will the Internet be replaced by a single networking technology? Why or why not?

20.2 What is the chief difficulty in providing universal service?

20.3 What are the two reasons an organization does not use a single router to connect all its networks?

20.4 If a given router can connect to at most K networks, how many routers, R, are required to connect N networks? Write an equation that gives R in terms of N and K.

20.5 Users view the Internet as a single network. What is the reality, and to what does a user's computer attach?

20.6 In the 5-layer reference model used with the TCP/IP Internet protocols, what is the purpose of each of the five layers?