

FOURTH EDITION

Computer Networks

ANDREW S. TANENBAUM



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Fourth Edition



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Although this book primarily focuses on networks, many of the topics are also important in distributed systems. For more information about distributed systems, see (Tanenbaum and Van Steen, 2002).

1.1 USES OF COMPUTER NETWORKS

Before we start to examine the technical issues in detail, it is worth devoting some time to pointing out why people are interested in computer networks and what they can be used for. After all, if nobody were interested in computer networks, few of them would be built. We will start with traditional uses at companies and for individuals and then move on to recent developments regarding mobile users and home networking.

1.1.1 Business Applications

Many companies have a substantial number of computers. For example, a company may have separate computers to monitor production, keep track of inventories, and do the payroll. Initially, each of these computers may have worked in isolation from the others, but at some point, management may have decided to connect them to be able to extract and correlate information about the entire company.

Put in slightly more general form, the issue here is **resource sharing**, and the goal is to make all programs, equipment, and especially data available to anyone on the network without regard to the physical location of the resource and the user. An obvious and widespread example is having a group of office workers share a common printer. None of the individuals really needs a private printer, and a high-volume networked printer is often cheaper, faster, and easier to maintain than a large collection of individual printers.

However, probably even more important than sharing physical resources such as printers, scanners, and CD burners, is sharing information. Every large and medium-sized company and many small companies are vitally dependent on computerized information. Most companies have customer records, inventories, accounts receivable, financial statements, tax information, and much more on-line. If all of its computers went down, a bank could not last more than five minutes. A modern manufacturing plant, with a computer-controlled assembly line, would not last even that long. Even a small travel agency or three-person law firm is now highly dependent on computer networks for allowing employees to access relevant information and documents instantly.

For smaller companies, all the computers are likely to be in a single office or perhaps a single building, but for larger ones, the computers and employees may be scattered over dozens of offices and plants in many countries. Nevertheless, a sales person in New York might sometimes need access to a product inventory

database in Singapore. In other words, the mere fact that a user happens to be 15,000 km away from his data should not prevent him from using the data as though they were local. This goal may be summarized by saying that it is an attempt to end the “tyranny of geography.”

In the simplest of terms, one can imagine a company’s information system as consisting of one or more databases and some number of employees who need to access them remotely. In this model, the data are stored on powerful computers called **servers**. Often these are centrally housed and maintained by a system administrator. In contrast, the employees have simpler machines, called **clients**, on their desks, with which they access remote data, for example, to include in spreadsheets they are constructing. (Sometimes we will refer to the human user of the client machine as the “client,” but it should be clear from the context whether we mean the computer or its user.) The client and server machines are connected by a network, as illustrated in Fig. 1-1. Note that we have shown the network as a simple oval, without any detail. We will use this form when we mean a network in the abstract sense. When more detail is required, it will be provided.

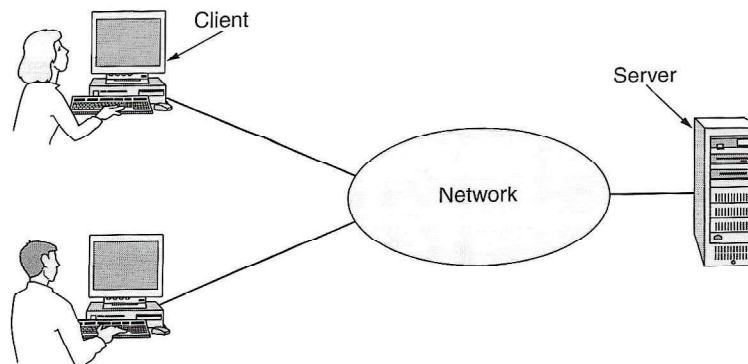


Figure 1-1. A network with two clients and one server.

This whole arrangement is called the **client-server model**. It is widely used and forms the basis of much network usage. It is applicable when the client and server are both in the same building (e.g., belong to the same company), but also when they are far apart. For example, when a person at home accesses a page on the World Wide Web, the same model is employed, with the remote Web server being the server and the user’s personal computer being the client. Under most conditions, one server can handle a large number of clients.

If we look at the client-server model in detail, we see that two processes are involved, one on the client machine and one on the server machine. Communication takes the form of the client process sending a message over the network to the server process. The client process then waits for a reply message. When the serv-

er process gets the request, it performs the requested work or looks up the requested data and sends back a reply. These messages are shown in Fig. 1-2.

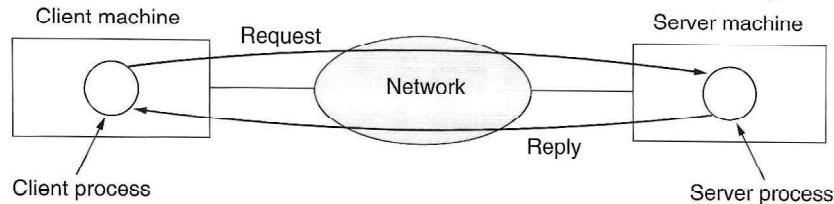


Figure 1-2. The client-server model involves requests and replies.

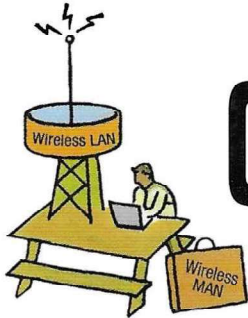
A second goal of setting up a computer network has to do with people rather than information or even computers. A computer network can provide a powerful **communication medium** among employees. Virtually every company that has two or more computers now has **e-mail (electronic mail)**, which employees generally use for a great deal of daily communication. In fact, a common gripe around the water cooler is how much e-mail everyone has to deal with, much of it meaningless because bosses have discovered that they can send the same (often content-free) message to all their subordinates at the push of a button.

But e-mail is not the only form of improved communication made possible by computer networks. With a network, it is easy for two or more people who work far apart to write a report together. When one worker makes a change to an on-line document, the others can see the change immediately, instead of waiting several days for a letter. Such a speedup makes cooperation among far-flung groups of people easy where it previously had been impossible.

Yet another form of computer-assisted communication is videoconferencing. Using this technology, employees at distant locations can hold a meeting, seeing and hearing each other and even writing on a shared virtual blackboard. Videoconferencing is a powerful tool for eliminating the cost and time previously devoted to travel. It is sometimes said that communication and transportation are having a race, and whichever wins will make the other obsolete.

A third goal for increasingly many companies is doing business electronically with other companies, especially suppliers and customers. For example, manufacturers of automobiles, aircraft, and computers, among others, buy subsystems from a variety of suppliers and then assemble the parts. Using computer networks, manufacturers can place orders electronically as needed. Being able to place orders in real time (i.e., as needed) reduces the need for large inventories and enhances efficiency.

A fourth goal that is starting to become more important is doing business with consumers over the Internet. Airlines, bookstores, and music vendors have discovered that many customers like the convenience of shopping from home. Consequently, many companies provide catalogs of their goods and services on-line and take orders on-line. This sector is expected to grow quickly in the future. It is called **e-commerce (electronic commerce)**.



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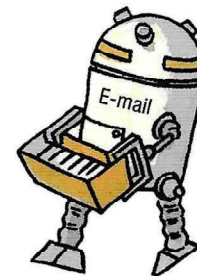
ANDREW S. TANENBAUM

The world's leading introduction to networking—fully updated for tomorrow's key technologies

Computer Networks, fourth edition, is the ideal introduction to today's networks—and *tomorrow's*. This classic bestseller has been thoroughly updated to reflect the newest and most important networking technologies with a special emphasis on wireless networking, including 802.11, Bluetooth™, broadband wireless, ad hoc networks, i-mode, and WAP. But fixed networks have not been ignored either, with coverage of ADSL, Internet over cable, gigabit Ethernet, peer-to-peer networks, NAT, and MPLS. And there is lots of new material on applications, including over 60 pages on the Web, plus Internet radio, Voice over IP, and video on demand. Finally, the coverage of network security has been revised and expanded to fill an entire chapter.

Author, educator, and researcher Andrew S. Tanenbaum, winner of the ACM Karl V. Karlstrom Outstanding Educator Award, carefully explains how networks work *on the inside*, from underlying hardware at the physical layer up through the top-level application layer. Tanenbaum covers all this and more:

- Physical layer (e.g., copper, fiber, wireless, satellites, and Internet over cable)
- Data link layer (e.g., protocol principles, protocol verification, HDLC, and PPP)
- MAC sublayer (e.g., gigabit Ethernet, 802.11, broadband wireless, and switching)
- Network layer (e.g., routing algorithms, congestion control, QoS, IPv4, and IPv6)
- Transport layer (e.g., socket programming, UDP, TCP, RTP, and network performance)
- Application layer (e.g., e-mail, the Web, PHP, wireless Web, MP3, and streaming audio)
- Network security (e.g., AES, RSA, quantum cryptography, IPsec, and Web security)



The book gives detailed descriptions of the principles associated with each layer and presents many examples drawn from the Internet and wireless networks.

About the Author

ANDREW S. TANENBAUM is Professor and Scientific Director of ASCI, a Netherlands. He is also a Fellow of the Royal Society. His previous books include *Structured Computer Systems*, co-authored with Albert R. Meyer; *Implementation*, second edition; *Principles and Paradigms* (Prentice Hall, 1996).

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