1 EVOLUTION OF COMPUTER NETWORKS

CHAPTER OUTLINE

1.1 INTRODUCTION

Studying the evolution of any area of science or technology will not only stimulate your natural curiosity, it will also give you a deeper understanding of the main achievements in this area, make you aware of the existing trends, and help you to evaluate the prospects of specific developments. Computer networks emerged relatively recently, in the late 1960s. They have inherited many useful properties from their predecessors, namely, older and more widely adopted telephone networks. This is not surprising, since both computers and telephones are universal instruments of communications.

However, computer networks have brought something new into the world of communications — namely, the practically inexhaustible store of information accumulated by human civilization during the several thousand years of its existence. This information store is continuing to grow at a steadily increasing rate. This became especially noticeable in the mid-1990s, when the rapid growth of the Internet clearly demonstrated that free and anonymous access to information and instant, written communications were highly valued by most individuals.

The influence of computer networks on other types of telecommunications networks resulted in network convergence, a process that started long before the Internet. Digital voice transmission in telephone networks was one of the first signs of that convergence. More recent indications of convergence are the active development of new services in computer networks that previously were the prerogatives of telephone, radio, and TV networks, such as Voice over IP (VoIP), radio broadcasts, and TV services. The process of convergence is continuing, though without offering clear signs of its future. However, knowing the evolution of computer networks, which is described in this chapter, makes it easier to understand the main problems that developers of computer networks must face.

1.2 ROOTS OF COMPUTER NETWORKS

KEY WORDS: mainframe, batch-processing systems, time-sharing systems, multi-terminal systems, computer network, datacom network or data-transmission network, Grosch's Law, Local Area Networks (LANs), standard LAN technologies: Ethernet, Arcnet, Token Ring, FDDI

1.2.1 Computer Networks as a Result of the Computing and Communications Technologies Evolution

The **computer networks** covered in this book are obviously not the only type of networks created throughout human civilization. Possibly the oldest example of a network covering large territories and serving multiple clients is the water-supply sys-

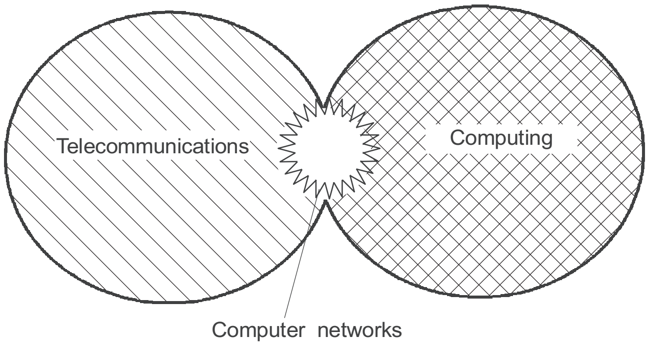

Figure 1.1 Evolution of computer networks at the interfaces of the computing and communications technologies

tem of ancient Rome. But no matter how remote and distinct by their nature different networks can seem, they all have something in common. For example, it is possible to draw a clear analogy between the components of electric networks and those of any large-scale computer network. That is, the information resources found in computer networks correspond to power stations; communications links of computer networks are analogous to high-voltage transmission lines, and access networks are similar to transforming stations. Finally, both in computer networks and in electric networks, one can find client terminals — end-user workstations in computer networks and household electric appliances in electric networks.

Computer networks, also known as **datacom** or **data-transmission networks**, represent a logical result of the evolution of two of the most important scientific and technical branches of modern civilization — computing and telecommunications technologies.

On one hand (Figure 1.1), computer networks represent a particular case of distributed computing systems in which a group of computers operate in a coordinated manner to perform a set of interrelated tasks by exchanging data in an automated mode. Computer networks can also be considered a means for transmitting information over long distances. To do so, computer networks implement various methods of data encoding and multiplexing that are widely adopted in telecommunications systems.

1.2.2 Batch-Processing Systems

First, consider the origins of computer networks. The computers of the 1950s — large, bulky, and expensive — were intended for a small number of privileged users. Quite often, these monstrous constructions occupied entire buildings. Such computers were not able to serve users interactively. Instead, they batched jobs and delivered results later.

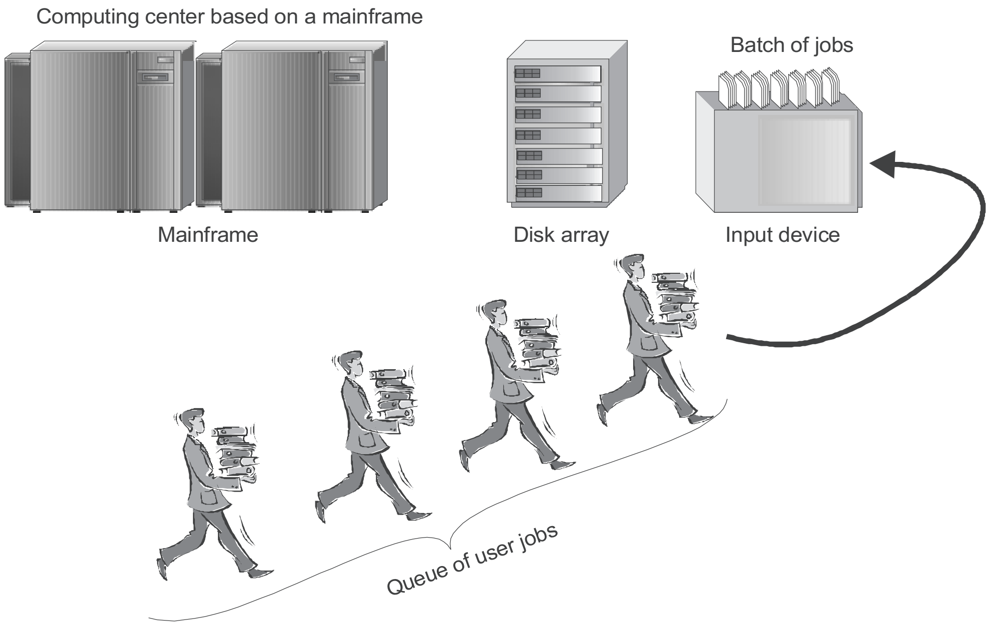

Figure 1.2 Centralized system based on a mainframe

Batch-processing systems were usually based on mainframes and were powerful and reliable universal computers. Users would prepare punched cards containing data and program code and then would transfer these cards to the computing center. Operators would enter these cards into the computer, and users would receive the results a day later in the form of a printout (Figure 1.2). Thus, a single punch card containing an error would mean a delay of at least 24 hours.

Obviously, from the end users' point of view, an interactive mode of operating that allows them to manage the processing of their data on the fly from the terminal is more convenient. The interests of end users were substantially neglected at the earliest stages of the evolution of computing systems. The efficiency of the operation of the most expensive component of a computer — the processor — was regarded as of paramount importance, even at the expense of the user productivity.

1.2.3 Multiterminal Systems: Prototype of the Computer Network

As processors became cheaper in the early 1960s, new methods of organizing computer processing appeared. These methods provided the possibility of taking end-user convenience into account. Thus, multiterminal systems evolved (Figure 1.3). In such time-sharing systems, the computer was at the disposal of several users. Users had their own terminals from which they could communicate with the computer. The response time of the computing system was short enough to mask that the computer served multiple users in parallel.

Terminals moved out of computing centers and onto desktops over entire organizations. Although processing power remained fully centralized, some functions, such as data input and output, became distributed. Such centralized, multiterminal systems looked similar to Local Area Networks (LANs). End users perceived working at the terminal practically the same way that most people now view working at a PC connected to a network. The user could access shared files and peripheral devices and maintain the illusion of using the computer in an exclusive mode, since the user could start any required program at any moment and receive the results almost immediately. (Some users were even convinced that all calculations were made somewhere inside the computer display.)

> Multiterminal systems, working in time-sharing mode, became the first step toward the development of LANs.

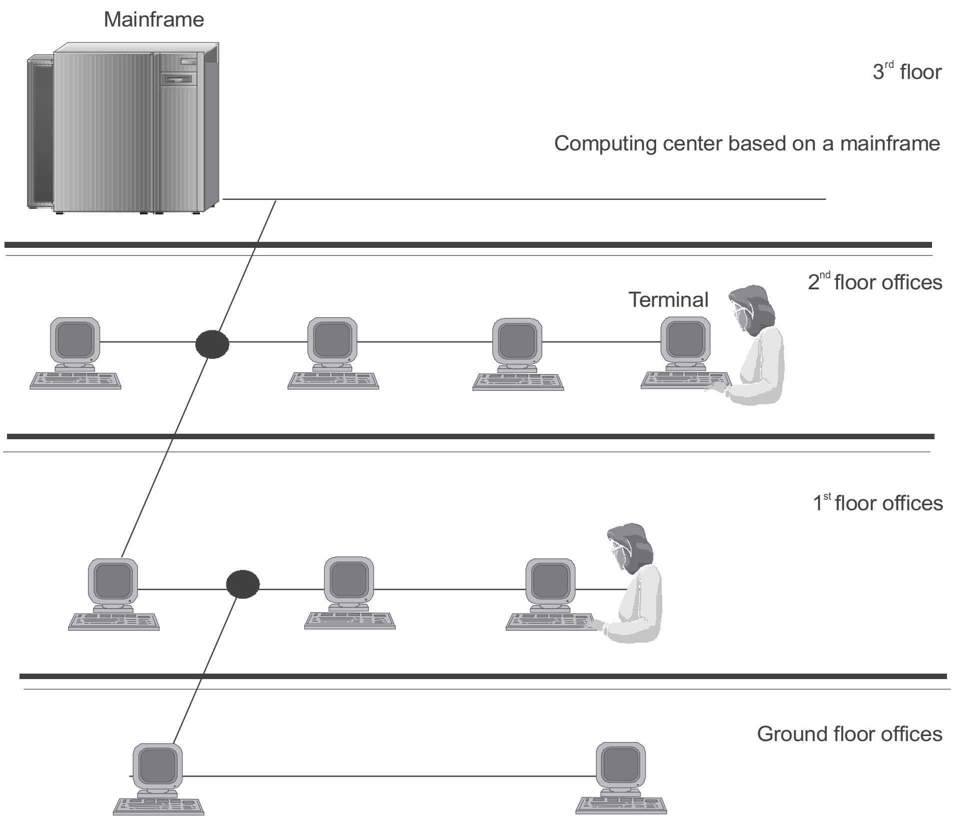

Figure 1.3 Multiterminal system as a prototype of a computer network

However, the evolution still had a long way to go before LANs appeared, because multi-terminal systems retained the essential features of centralized data processing despite superficial resemblance to distributed systems.

Organizations didn't feel a pressing need for LANs. Within a single building, there was nothing to connect to using a network. Most companies could not afford the luxury of purchasing more than one computer. During this period, the so-called *Grosch's Law* (named after Herbert Grosch) was universally true. It represented empirically the technological level of that time. According to this law, the cost of a computer system increases as a square root of the computational power of the system. Hence, it was more profitable to purchase one powerful machine rather than two less powerful ones because their total computational power proved to be significantly lower than that of the expensive machine.

1.3 FIRST COMPUTER NETWORKS

KEY WORDS: packet switching, bursty traffic, Wide Area Network (WAN), telephone network technology, backbone, transmission networks, packet, Internet, network operation system, standard LAN technologis: Ethernet, Arcnet, Token Ring, FDDI

1.3.1 First Wide Area Networks (WANs)

By contrast, the need for connecting computers located a long distance from one another was already imminent. It all started with the solution of a simpler task, i.e., providing access to a computer from remote terminals located hundreds and sometimes thousands of miles apart. Modems were used to connect terminals to computers through telephone lines. Such networks allowed multiple remote users to access the shared resources of several powerful supercomputers. By the time distributed systems appeared, not only were there connections between *terminals and computers*, connections between *computers* were also implemented.

Computers became able to exchange data in automatic mode, which, essentially, is the basic mechanism of any computer network. Developers of the first networks implemented services for file exchange, database synchronization, e-mail, and other network services that have become commonplace.

Chronologically, **Wide Area Networks** (**WANs**) were the first to appear. WANs joined geographically distributed computers, even those located in different cities or countries.

It was in the course of the development of WANs that many ideas fundamental to modern computer networks were introduced and developed, such as:

- Multilayer architecture of communications protocols
- Packet-switching technology
- Packet routing in heterogeneous networks

Although WANs inherited many features from older and more widespread long-haul networks, such as **telephone networks**, the most innovative feature was to depart from the circuit-switching principle, which had been successfully used in telephone networks for decades.

A circuit with a constant speed allocated for the entire session could not be used efficiently by the **bursty traffic**[1] of computer data (bursty means periods of intense data exchange need to alternate with long pauses). Experiments and mathematical modeling have shown that networks based on the packet-switching principle can more efficiently transmit bursty traffic.

According to principle of **packet switching** data are divided into small fragments, known as **packets**. The target host address is embedded into a packet header, allowing each packet to travel over the network on its own.

Since the construction of high-quality communications lines connecting distant locations is very expensive, the first WANs often used available communications links, initially intended for quite different purposes. For example, WANs for a long time were constructed on the basis of the telephone lines. Because the transmission rate of discrete computer data using such links was rather low, hundreds of Kilobits per second (Kbps), the set of services provided by such networks was limited to file transfer, mainly in background mode, and to e-mail. In addition to the low transmission rate, such channels had another drawback — they introduced significant distortions into the transmitted signals. Therefore, network protocols in WANs using low-quality communications lines were characterized by complicated procedures for data control and data restoration. A typical example of such a network is the X.25 network developed in the early 1970s, when low-rate, analog channels leased from telephone companies were prevalent for connecting the computers and switches of WANs.

In 1969, the U.S. Department of Defense initiated research into joining the computers of defense and research centers into a network. This network, which became known as **ARPANET**, served as a starting point for the construction of the first and most widely known WAN, nowadays known as the **Internet**.

ARPANET joined computers of different types, running various operating systems with different add-on modules by implementing communications protocols common for all computers participating in the network. Such operating systems can be considered the first true **network operating systems**.

True network operating systems, in contrast to multiterminal ones, allowed the system not only to distribute users but also to organize data storage. They also allowed for processing to be distributed among several computers connected by electric links. Any network operating system is capable of performing all functions of a local operating system

[1] *Burst* and *bursty traffic* are recognized and commonly adopted data communications terms. According to technical definitions provided by Cisco Systems, burst is a sequence of signals counted as one unit in accordance with some specific criterion or measure, and bursty traffic refers to an uneven pattern of data transmission.

and of providing additional functionality, allowing the system to communicate with other operating systems via the network. Software modules, implementing networking functions, were introduced into operating systems gradually, with advances in network technologies and computer hardware, as new tasks requiring network processing appeared.

The progress of WANs depended mainly on the progress of telephone networks.

From the late 1960s, voice transmission in a digital format became increasingly common in telephone networks.

This resulted in the arrival of high-speed digital channels that connected automatic telephone exchange stations and allowed simultaneous transmission of tens or even hundreds of conversations. Special technology was developed for the construction of **transmission networks**, or **backbones**. Such networks do not serve end users; rather, they represent the foundation upon which high-speed "point-to-point" digital channels are based. These channels connect the equipment of another network (the *overlay network*) that serves end users.

Initially, transmission networks represented exclusively internal technology used only by telephone companies. Gradually, however, these companies started to lease part of their digital channels, connected into transmission networks, to companies that used them for creating their own telephone networks and WANs. Nowadays, transmission networks have raised data transmission speeds to hundreds of Gigabits per second (Gbps) and, in some cases, to several Terabits per second; these networks cover the territories of all main industrial states.

Both variety and quality of services have helped WANs catch up with LANs, which had been the leaders despite their relatively late arrival.

1.3.2 First Local Area Networks (LANs)

In the early 1970s, an event took place that has had the greatest influence on the evolution of computer networks. As a result of technological advances in the field of computer-components manufacturing, large-scale integrated circuits (LSI devices) appeared. LSI devices were characterized by relatively low cost and advanced functional capabilities. This led to the development of minicomputers, which became the real competitors for mainframes. Grosch's Law ceased to represent reality, since a dozen minicomputers, having the same cost as one mainframe, were capable of accomplishing some tasks (especially ones that could be executed in parallel) much faster.

From that moment, even small companies could enjoy the possibility of having their own computers. Minicomputers could carry out tasks such as controlling technical equipment or managing stocks. This was the origin of the distributed computing concept, with computing resources becoming distributed over the entire enterprise. All computers within the same organization, however, continued to operate independently (Figure 1.4).

With time, the needs of computer users evolved. End users were no longer satisfied with isolated work on a standalone computer. For instance, they needed to exchange com-

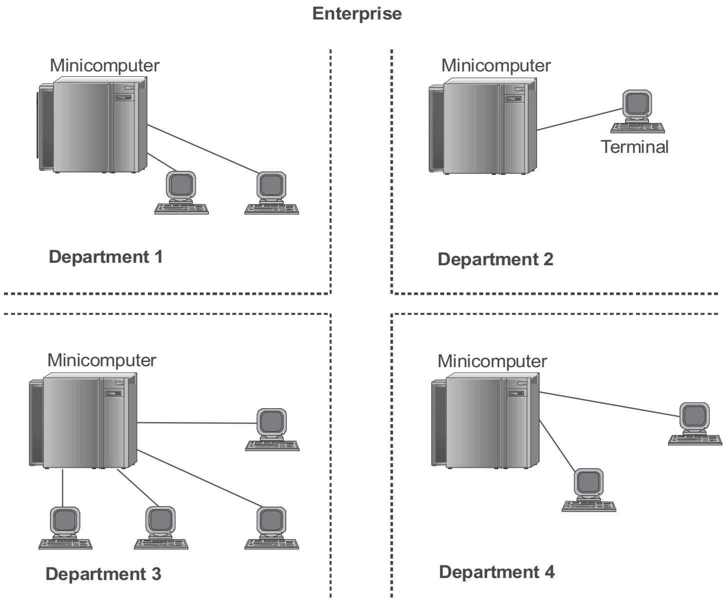

Figure 1.4 Independent operation of several minicomputers within the same enterprise

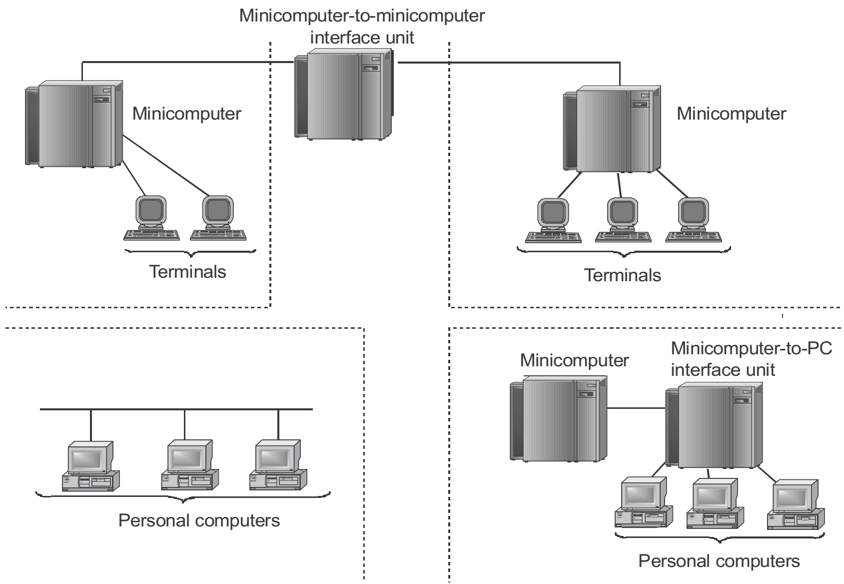

Figure 1.5 Types of links in the first LANs

puter data (often automatically) with users in other branches and offices. To satisfy these requirements, the first LANs appeared (Figure 1.5).

LANs represent groups of computers concentrated in a relatively small region — usually within a radius not exceeding 1.5 miles, although LANs can be extended to cover larger areas (dozens of miles). In general, LANs represent a communications system belonging to a single organization.

At first, *nonstandard networking technologies* were used to connect computers to the network.

Network technology is a coordinated set of software and hardware (for example, drivers, network adapters, cables and connectors) and mechanisms of data transmission across the communications links, sufficient for building a computer network.

Various proprietary interface units using proprietary methods for data representation on communications links, proprietary types of cables, etc., could connect only specific types and models of computers, namely, the ones for which they were designed. Some examples are the interfaces for connecting PDP-11 minicomputers to IBM 360 mainframes or Hewlett-Packard minicomputers to LSI-11 microcomputers.

From the mid-1980s, the situation began to change radically. **Standard technologies** for connecting computers to the network, such as Ethernet, Arcnet, Token Ring, and, somewhat later, FDDI, became firmly established.

The adoption of personal computers was a powerful incentive for the development of these technologies. PCs became ideal elements for building networks. On the one hand, they were powerful enough to support networking software; on the other hand, they obviously needed to connect their processing powers to solve complex tasks and share expensive peripheral devices and disk arrays. Because of this, PCs became prevalent in LANs, not only playing the roles of clients but also performing data storage and processing center functions (i.e., becoming network servers). As PCs became more popular, they forced minicomputers and mainframes out of these roles.

All standard LAN technologies were based on the same switching principle that turned out to be so successful when transmitting traffic in WANs, i.e., the packet-switching principle.

The process of building LANs then turned from handcrafting to a standard procedure using standard networking technologies. To build a network, it was enough to purchase a standard cable and network adapters according to the required specification (Ethernet, for example), connect adapters to the cable using standard connectors, and install on the computer one of the network operating systems popular at that time (Novell NetWare, for example).

LAN developers introduced many innovations affecting the organization of end-user work. Tasks such as accessing shared network resources became significantly simpler. In contrast to WAN users, people using LANs were released from the necessity of memorizing complicated identifiers of shared resources. For this purpose, the system would provide the list of available resources in a user-friendly format (for example, in a hierarchical, tree-like structure). Another advantage of working in LANs was that after establishing the connection to the remote resource, people could access the resource using the same commands that were used when working with local resources. The arrival of a large number of end users freed from studying specialized (and rather complicated) networking commands became the consequence, as well as the driving force, of such progress.

So the question arises: Why did all these conveniences become available to end users only with the arrival of LANs? Mainly, because LANs use high-quality cable lines. Even first-generation network adapters ensured a data transfer rate up to 10 Mbps. Since LANs are characterized by limited expansion, the cost of such lines was manageable. For this reason, economizing on the bandwidth, an important matter with the early WAN technologies, was not a primary concern in the development of LAN protocols. Under these conditions, periodic server broadcasts of resources and services became the main mechanism of organizing transparent access to LAN resources. Based on these broadcasts, client computers composed lists of available network resources and presented them to users.

In the late 1990s, the Ethernet family became the indisputable leader among LAN technologies. Besides classic Ethernet (10 Mbps) technology, this family included Fast Ethernet (100 Mbps) and Gigabit Ethernet (1,000 Mbps).

Simple algorithms ensured the low cost of Ethernet equipment. The range of the data transmission speeds enabled network architects to use a rational approach when building LANs, choosing specific Ethernet technology that best satisfied the requirements of the enterprise. All Ethernet technologies closely resembled one another by operating principles, simplifying maintenance and integration of such networks.

The chronological sequence of milestones in the history of computer network evolution is shown in Table 1.1.

Table 1.1 Chronology of the most significant events in the history of computer networks

First global connections between computers. First experiments with batch-processing networks.	Late 1960s
Start of digital voice transmission through telephone networks.	Late 1960s
Arrival of large-scale integrated circuits. First minicomputers. First proprietary LANs.	Early 1970s
Development of the IBM systems network architecture.	1974
Standardization of the X.25 technology.	1974
Arrival of the first personal computers.	Early 1980s
Creation of the Internet in its current form. Installation of the TCP/IP stack on all nodes.	Early 1980s
Arrival of the first standard LAN technologies.	Ethernet — 1980 Token Ring — 1985 FDDI — 1985
Start of commercial use of the Internet.	Late 1980s
Invention of the World Wide Web.	1991

1.4 CONVERGENCE OF NETWORKS

KEY WORDS: convergence, intranet; internet, Internet, Metropolitan Area Network (MAN), multiservice networks, Telecommunications networks, Data network, standard networking technologies, FDDI, Ethernet, Token Ring, ATM, Integrated Services Digital Network (ISDN); Internetwork, QoS

1.4.1 Convergence of LANs and WANs

By the late 1980s, the following differences between LANs and WANs were evident:

- *Length and quality of communications links.* LANs are distinguished from WANs by the small distances between network nodes. Principally, this factor enabled network developers to use communications lines of higher quality than those for WANs.
- *Complexity of data transmission methods.* Because of the low reliability of physical communications channels, WANs required more sophisticated methods of data transmission and more complex equipment than LANs.
- *Data exchange rate.* In LANs, the rates (10, 16, and 100 Mbps) were significantly higher than those in WANs (from 2.4 Kbps to 2 Mbps).
- *Variety of services.* High speeds of data exchange allowed network developers to implement a range of services in LANs. These services included broad capabilities of accessing and using files stored on the hard disks of other networked computers; sharing printing devices, modems, and faxes; accessing centralized databases; and e-mail. The range of services provided by WANs was mainly limited to mail and file services in their simplest forms (not the most convenient for end users).

Gradually, the differences between LANs and WANs began to diminish. Network developers started to join isolated LANs, using WANs as connecting media. Close integration between LANs and WANs resulted in significant interpenetration of appropriate technologies.

Convergence in data transmission methods is based on the platform of digital data transmission along fiber-optic communications lines. This transmission medium is used by practically all LAN technologies intended for high-speed data exchange at distances exceeding 110 yards. The same transmission medium is used as a basis for all contemporary backbones of transmission networks, providing digital channels for connecting WAN equipment.

The high quality of digital channels has changed the requirements of WAN protocols. Instead of procedures ensuring reliability, factors such as average speed of information delivery and priority processing of packets highly sensitive to traffic delays (such as voice traffic) were brought to the forefront. These changes were reflected in new WAN technologies such as Frame Relay and Asynchronous Transfer Mode (ATM). In such networks, it is assumed that bit corruption is such a rare event that it is much more profitable to simply discard erroneous packets. All problems related to packet loss are delegated to specific software modules of higher levels, which are not directly integrated into Frame Relay and ATM networks.

The dominance of the Internet protocol (IP) has contributed to the convergence of LANs and WANs. Nowadays, this protocol is used over any LAN or WAN technology, including Ethernet, Token Ring, ATM, and Frame Relay, to create a unified internetwork[2] on the basis of various subnets.

From the 1990s, WANs operating on the basis of fast digital channels have significantly widened the range of services, earlier developed in LANs. It became possible to create services whose operation is related to the delivery of large amounts of multimedia information in real time, including images, video, and voice. The World Wide Web (WWW), a hypertext information service that became the main information service on the Internet, is the most impressive example. Interactive capabilities of this service long ago exceeded the capabilities of similar services provided by LANs. Therefore, LAN architects have simply borrowed this service from WANs. The process of porting Internet technologies into LANs became so widespread that quite soon, the specialized term **intranet** appeared.

Nowadays, in LANs, users have to pay the same attention to the mechanisms of protecting information from unauthorized access that they do in WANs. This is because LANs are no longer isolated. Frequently, LANs have access to the "outside world" through WAN links.

Finally, it is necessary to mention that newer technologies continue to emerge. They were initially intended for both kinds of networks. The brightest specimen of the new-generation technologies is ATM,[3] which can serve as a basis for both LANs and WANs because it efficiently combines all kinds of traffic within a single transmission network. The Ethernet family of technologies, which originated from LANs, serves as another example. The new Ethernet 10G standard allows data transmission at 10 Gbps and is intended for the backbones of both WANs and large LANs.

Other evidence of the LAN–WAN convergence is the arrival of **Metropolitan Area Networks (MANs)**, which take an intermediate position between LANs and WANs. These networks are intended for serving large cities.

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[2] Internetwork is a common technical term referring to a collection of networks interconnected by routers and other devices. Generally, an internetwork functions as a single network. Sometimes it is called an internet. However, it is not to be confused with the Internet, the largest internetwork connecting tens of thousands of networks worldwide.

[3] Asynchronous Transfer Mode is a network technology that dynamically allocates bandwidth. ATM uses fixed-size data packets and a fixed channel between two points for data transfer. ATM was designed to support multiple services such as voice, graphics, data, and full-motion video. It allows telephone and cable TV companies to assign bandwidth to individual customers.

These MANs use digital communications channels, frequently fiber-optic, and are characterized by backbone speeds of 155 Mbps or higher. They provide an efficient way of interconnecting LANs as well as of connecting LANs to WANs. Initially, these networks were developed only for data transmission. Nowadays, the range of their services has been widened. For example, MANs support video conferences and integrated voice and text transmission. Contemporary MANs are distinguished by a variety of services, which enable their clients to connect communications equipment of various types, including Private Branch Exchange (PBX).

1.4.2 Convergence of Computer and Telecommunications Networks

The trend toward convergence of various computer and telecommunications networks of different types grows stronger every year. Attempts are made to create universal, so-called **multiservice networks,** capable of providing services for computer and communications networks.

Telecommunications networks include telephone, radio, and TV networks. The main feature that makes them similar to computer networks is that information is the main resource provided to clients. However, these networks, as a rule, provide information in a different form. For example, computer networks were initially intended for transmitting alphanumeric information, simply known as data. As a result, computer networks have another name — **data networks**. Telephone and radio networks were developed for transmitting voice information only; TV networks are capable of transmitting both voice and video.

Despite this, the convergence of computer and telecommunications networks is in progress.

First, *convergence of service types* provided to the clients is to be noticed. The first attempt to create a multiservice network capable of providing various services including telephony and data transmission, has resulted in the development of the Integrated Services Digital Network (ISDN) technology. In practice, however, ISDN now provides mainly telephone services.

For now, the Internet is the main candidate for the role of a global multiservice network of the new generation. Especially attractive are new types of integrated services combining several types of traditional services, such as Unified Messaging that combines e-mail, telephony, fax service, and paging. In practice, IP telephony, which is currently used, directly or indirectly, by millions of users all over the world, has proved to be the most successful. However, the Internet has a long evolutionary way to go before it becomes a true new-generation network.

Technological convergence of today's networks is based on the digital transmission of various kinds of information, packet switching, and service programming. Telephony long ago took several steps toward integration with computer networks. This is achieved because of voice presentation in digital format, allowing the possibility of transmitting telephone and computer traffic using the same digital channels. Currently, TV is also capable of transmitting information in digital format. Telephone networks routinely use a combination of circuit and packet switching. Thus, for transmitting service messages (known as signal messages) packet-switching methods are used that are similar to the protocols employed in computer networks; for voice transmission, traditional circuit switching is used.

Supplementary services provided by telephone networks, such as call transfer, conferencing, and telepolling, can be ensured by using the **Intelligent Network (IN)**, which represents a computer network with servers in which the service logic is programmed.

Today, packet-switching methods are gradually gaining on circuit-switching methods, traditionally used in telephone networks, even in the field of voice transmission. This trend has an obvious reason: packet switching allows more efficient bandwidth usage of both communications channels and switching equipment. For example, pauses in a telephone conversation can take up to 40% of the total connection time. However, only packet switching has the ability to "cut off" the pauses and use the released channel bandwidth for transmitting the traffic of other telephone subscribers. The popularity of the Internet, which is based on packet switching, is another argument in favor of migrating to packet switching.

The use of packet switching for the simultaneous transmission of heterogeneous traffic (including voice, video, and text) has increased the importance of developing new methods to ensure **Quality of Service (QoS)**. Methods to ensure QoS are intended to minimize the delay level for real-time traffic, such as voice traffic, and to ensure an average information rate and dynamic data traffic.

However, it should not be assumed that circuit-switching methods have become obsolete and, therefore, have no future. At this new stage of technological evolution, they also find their application, but in newer technologies.

Computer networks, in turn, have borrowed quite a lot from telephone and TV networks. In particular, although the Internet and corporate networks lack the high reliability typical for telephone networks, computer networks have started to add to their armory the reliability tools normally used in telephone networks.

It is becoming increasingly obvious that multiservice networks of the next generation cannot be created as a result of the victory of a single technology or approach. It can be created only as a result of a convergence process, which takes all the best features and characteristics from each technology and joins them into some new combination that provides the required quality for supporting the existing services and for creating new ones. To designate this approach, a new term was introduced — **infocommunications networks** — that explicitly specifies two components of contemporary networks. These are informational (computer-based) and telecommunications. Since this new term has not gained sufficient popularity yet, we will use the standard and generally accepted one — telecommunications network — in its extended meaning, i.e., including computer networks.

SUMMARY

- Computer networks are the logical result of the evolution of computer and communications technologies. They represent a particular case of distributed computer systems and can be considered a medium for transmitting information over long distances. For the latter purpose, they implement data encoding and multiplexing methods developed and adopted in various communications systems.
- All networks can be classified, based on geographical location, in the following categories: wide area networks (WANs), local area networks (LANs) and metropolitan area networks (MANs).
- Chronologically, WANs were the first networks to appear. They connect computers distributed over hundreds of miles. They are often based upon existing, low-quality communications links, resulting in low data-transmission speeds. Compared to LANs, WANs provide a limited set of services, mainly file transfer and e-mail, in background rather than in real time.
- LANs usually cover regions within a radius of no more than 1.5 miles. They are based on expensive, high-quality connection links that allow simple methods of data transmission at higher speeds of data exchange (about 100 Mbps) than allowed by WANs. Usually, LANs provide a range of services implemented online.
- MANs are intended for serving large cities. Being characterized by rather long distances between network nodes (sometimes tens of miles) they also provide high-quality communications links and support high speeds of data exchange. MANs ensure economic and efficient connection of LANs, providing them access to WANs.
- The most important stage in the evolution of computer networks was the arrival of standard networking technologies. These include Ethernet, FDDI, and Token Ring. These technologies allow different types computers to connect quickly and efficiently.
- During the late 1980s, LANs and WANs were characterized by significant differences between the length and the quality of communications links, the complexity of the data transmission methods, data exchange rates, the range of provided services, and scalability. Later, as a result of the close integration of LAN, WAN, and MAN, the convergence of these technologies took place.
- The trend of convergence of the different types of networks is characteristic not only for LANs and WANs but also for other types of telecommunications networks, including telephone, radio, and TV networks. For now, research is aimed at creating universal multiservice networks, capable of efficiently transmitting information of any kind, including data, voice, and video.

REVIEW QUESTIONS

1. Which characteristics of a multiterminal system make it different from a computer network?
2. When were the first important results achieved in the field of joining computers using long-haul links?
3. What is ARPANET?
   A. A network of supercomputers belonging to military organizations and research institutes in the United States
   B. An international scientific research network
   C. The technology of creating WANs
4. When did the first network operating systems appear?
5. In what order did the events listed here take place?
   A. The invention of the Web
   B. The development of standard LAN technologies
   C. The start of voice transmission in digital form through telephone networks
6. Which of the events stimulated LAN development?
7. Specify when the following technologies were standardized: Ethernet, Token Ring, and FDDI.
8. List the main directions in which the convergence of computer and telecommunications networks proceeds.
9. Explain the meaning of the following terms: multiservice network, infocommunications network, and Intelligent Network.

PROBLEMS

1. Explain why WANs appeared earlier than LANs.
2. Using various sources on the Internet, find historical relationships between the X.25 technology and the ARPANET network.
3. Do you think that the history of computer networks can be interpreted as the history of the Internet evolution? Substantiate your opinion.