PART I

INTRODUCTION AND PERIOD BEFORE 1800

1

INTRODUCTION

1.1 DEFINITION OF TELECOMMUNICATIONS

Telecommunication is a technology that eliminates distance between continents, between countries, between persons. To contact another person by telephone, only the distance between one's actual location and the next telephone needs to be covered. This distance can be mere centimeters in the industrialized world and kilometers in the developing world. For centuries, messages were transported by messengers, or couriers, who either walked or were transported by horse, coach, or boat, and when fire, smoke, or sound signals were sent they simply confirmed prearranged messages. With telecommunications a message does not need a messenger. Telecommunications eliminated a master-to-servant relationship: replacing the service of a messenger by mechanical telegraph in 1794, by copper wires in 1837, by electromagnetic waves in 1896, and by optical fiber in 1973. Telecommunications enormously reduces the time required to transport messages, accelerates business transactions, and improves human relationships.

The word *communications*, derived from the Latin word *communicatio*, the social process of information exchange, covers the human need for direct contact and mutual understanding. The word *telecommunication*, adding *tele* (= distance), was created by Edouard Estaunié (1862–1942)[1] in 1904 in his book *Traité pratique de télécommunication electrique (télégraphie–téléphonie)* (Figure 1.1), in which he defined telecommunication as "information exchange by means of electrical signals." Estaunié thus limited telecommunications explicitly to "electrical signals." In the

[1] Director of the Ecôle Supérieure des Postes et Télégraphes de France, author of various books in which he criticized the prevailing social conditions, and member of the Académie Française.

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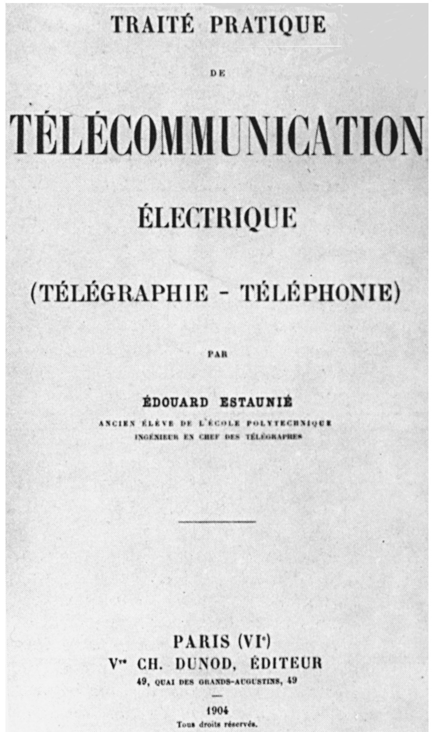

TRAITÉ PRATIQUE

DE

TÉLÉCOMMUNICATION

ÉLECTRIQUE

(TÉLÉGRAPHIE - TÉLÉPHONIE)

PAR

ÉDOUARD ESTAUNIÉ

ANCIEN ÉLÈVE DE L'ÉCOLE POLYTECHNIQUE
INGÉNIEUR EN CHEF DES TÉLÉGRAPHES

PARIS (VI^e)
V^{ve} CH. DUNOD, ÉDITEUR
49, QUAI DES GRANDS-AUGUSTINS, 49

1904
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Figure 1.1 Facsimile of the title page of the book in which the word *telecommunication* was created. (Scanned from Catherine Bertho, *Histoire des télécommunications en France*, 1984, p. 13.)

preface to his book, he modestly apologized for the invention of the new word, stating: "I have been forced to add a new word to a glossary that is already too long in the opinion of many electricians. I hope they will forgive me. Words are born in new sciences like plants in spring. We must resign ourselves to this, and the harm is not so great after all, because the summer that follows will take care of killing off the poor shoots." Fortunately, the word *telecommunication* did not belong to the "poor shoots" and has already survived a hundred summers. Telecommunications became more complex, and new definitions were created, as summarized in Technology Box 1.1.

In order to telecommunicate, local, regional, national, and international telecommunication networks are required. Figure 1.2 shows the basic configuration of the classical telecommunication networks. In local telecommunication networks, also called *access networks*, individual telecommunication users (the telecommunication originators as well as the telecommunication recipients) are all connected with one or more *local switches* (also called *local exchanges* or *central offices*). Telecommunication users such as the subscribers of public networks are connected by their local exchange—primarily by means of a single cable pair but previously also by open wire, at distant or isolated locations by radio, and currently, increasingly, by broadband optical fiber or wireless systems. In regional and national telecommunication

TECHNOLOGY BOX 1.1

Definitions of Telecommunications

The *International Telecommunication Union* (ITU) officially recognized the term *telecommunications* in 1932 and defined it as: "any telegraph or telephone communication of signs, signals, writings, images and sound of any nature, by wire, radio, or other system or processes of electric or visual (semaphore) signaling." Currently, the ITU defines telecommunications as "any transmission, emission, or reception of signs, signals, writings, images, and sounds; or intelligence of any nature by wire, radio, visual, or other electromagnetic systems."

In this definition the ITU postulates transmission as a basic function of telecommunications. The word *transmission*, from the Latin *trans mettere* for transfer or transport in the figurative sense, however, quite confusingly, is used for many purposes. It was used in the industrial revolution to represent a *transmission system* for the transmission by mechanical means of power from a central steam engine to the various production machines in a factory. In electrical power technology, *high-tension transmission line and ht-transmission grid* are well-known names for high-voltage overhead electricity distribution lines.

In the book *Transmission Systems for Communications* published by members of the technical staff of Bell Labs in 1954, which used to be *the bible of transmission*, the primary function of a transmission system is described as being "to provide circuits having the capability of accepting information-bearing electrical signals at a point and delivering related signals bearing the same information to a distant point."

In my book *Guide to Telecommunications Transmission Systems*, published in 1997, transmission within the context of telecommunications is defined concisely as the "technology of information transport."

In the context of telecommunications, a transmission system transports information between the source of a signal and a recipient. Transmission thus stands for the *tele* part of the word telecommunications and as such is the basis of all telecommunication systems. Transmission equipment serves to combine, send, amplify, receive, and separate electrical signals in such a way that long-distance communication is made possible.

In terms of technology, telecommunications transmission systems are divided into *line transmission* and *radio transmission* systems:

- *Line transmission* is the technology of sending and receiving electrical signals by means of copper wire, and nowadays, increasingly by means of optical fiber, on overhead lines, by underground cable, and by submarine cables.
- *Radio transmission* in the context of telecommunications stands for the technology of information transmission on electromagnetic waves by means of high-frequency radio and mobile radio, including cellular radio systems, radio relay, and satellites.

Source: Adapted from A. A. Huurdeman, *Guide to Telecommunications Transmission Systems*, Artech House, Norwood, MA, 1997; with permission of Artech House Books.

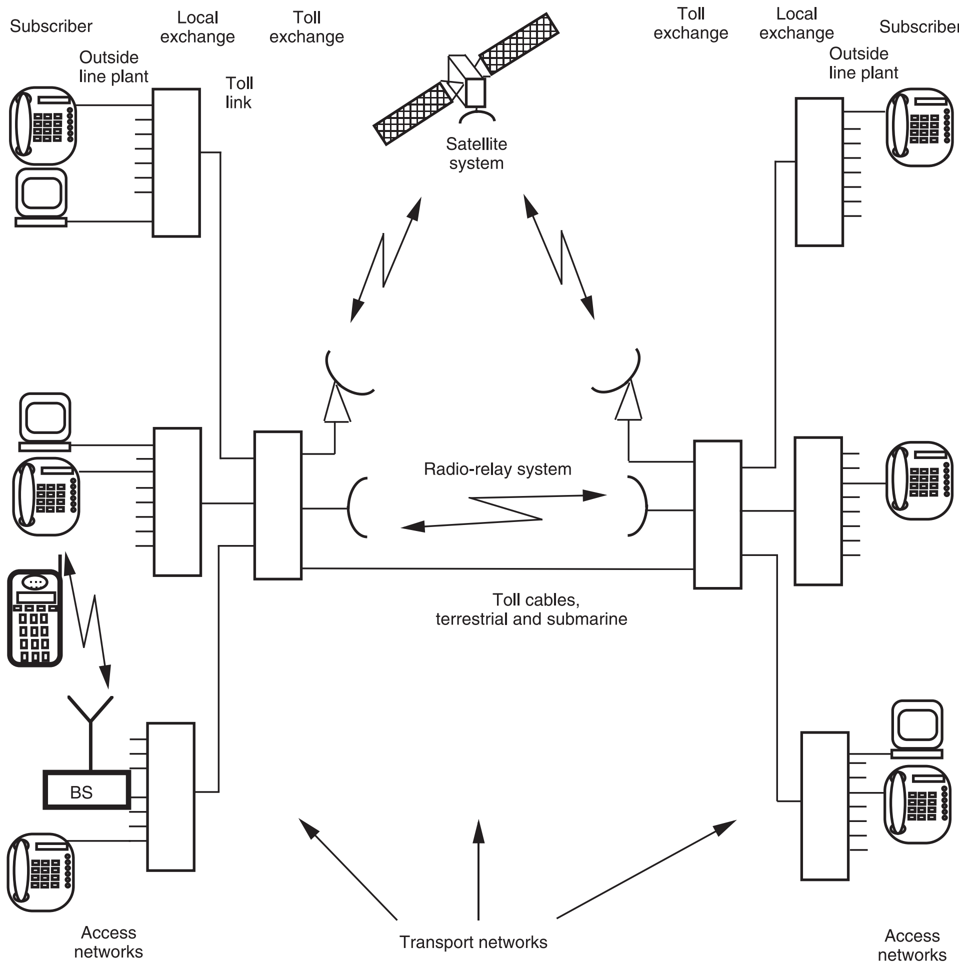

Figure 1.2 Classical telecommunication networks.

networks, a number of local exchanges are connected via transmission links in *transport networks* with a *tandem exchange* (also called a *toll* or *trunk exchange*); all the tandem exchanges of a region or a nation are also interconnected by transmission links. A transmission link can consist of copper wire or optical fiber cable, radio relay, or satellite.

In international telecommunication networks, telecommunication users are connected via their local exchange and one or more tandem exchanges with international exchanges in their country. International exchanges worldwide are interconnected by transmission links either directly or by means of one or more other international exchanges. Currently, this vast network of hierarchically arranged circuit-switching exchanges is being complemented by a new network based on packet switching, using the Internet Protocol.

1.2 TELECOMMUNICATIONS TREE

The evolution of telecommunications from optical telegraphy (also called semaphore communication) to multimedia in its various stages can be visualized in a telecommunications tree (Figure 1.3). Indeed, a tree appears to be very appropriate to illustrate this evolution. On the one hand, it enables us to show the formation of a new technology as soon as the necessary prerequisites are given, and on the other, it demonstrates the complementary function of the various domains that together make telecommunications happen. The trunk of the tree represents the technological prerequisites for successive unfolding of the various telecommunication domains into the branches of the tree. The leaves of the branches represent evolution within the separate telecommunication domains. In the following summary of the evolution, the evolution stages that appear in the tree are italicized.

The bases of telecommunications, and thus the roots of the tree, are *science* and *industrialization*. They made telecommunications possible, and on the other hand, cannot now exist without telecommunications.

Optical telegraphy became possible, and thus telecommunications could germinate, once the *telescope* was available and basic mechanical constructions could be made with sufficient accuracy. *Optical telegraph lines* were constructed within a number of countries for exclusive communications within those countries. Optical telegraphy is the only telecommunications domain so far that disappeared completely and was replaced by a better technology (electrical telegraphy); thus this branch is only a historical relic and therefore has been sawn off.

The theory of *electromagnetism* and the development of *precision mechanics* nourished the growth of an electrical telegraphy branch. *Electrical telegraphy* started with code-writing telegraphs and needle telegraphs, which were replaced by direct text-writing *teleprinters*, which are still used in the international *telex* network but are giving way increasingly to *telefax*, which developed over a 100-year period from *image telegraphy* and *photo telegraphy*. Telegraphy, especially radio-telegraphy, could easily be intercepted, so that *cryptography* became widely used to increase the privacy of telegraphic messages.

Understanding the basic *laws of electricity* and the discovery of *gutta-percha* began the evolution of *copper-line transmission* systems on open wire, copper cable, and coaxial cable. *Carrier-frequency systems* were used to increase the number of channels per physical circuit. *Digitalization* substantially improved the quality and reduced the cost of transmission and switching.

The basic *theory of sound* developed by Helmholtz supported the evolution from telegraphy to *telephony*. *National telephone networks* were built in most countries. Direct dialing in *international telephone networks* became possible worldwide when submarine telephone cables and satellite systems were installed.

The early *automation* of industrial processes enabled the replacement of manual switchboards by automatic *switching* devices. In switching, quite unnoticed by the general public, a tremendous evolution happened in a 100-year period, from *electromechanical switching* by means of *crossbar* and *electronic switching* to *digital switching* with integrated services digital network (*ISDN*) functions.

The discovery of *electromagnetic radiation* and the subsequent development of devices for generating and detecting such waves led to the development of *radio-*

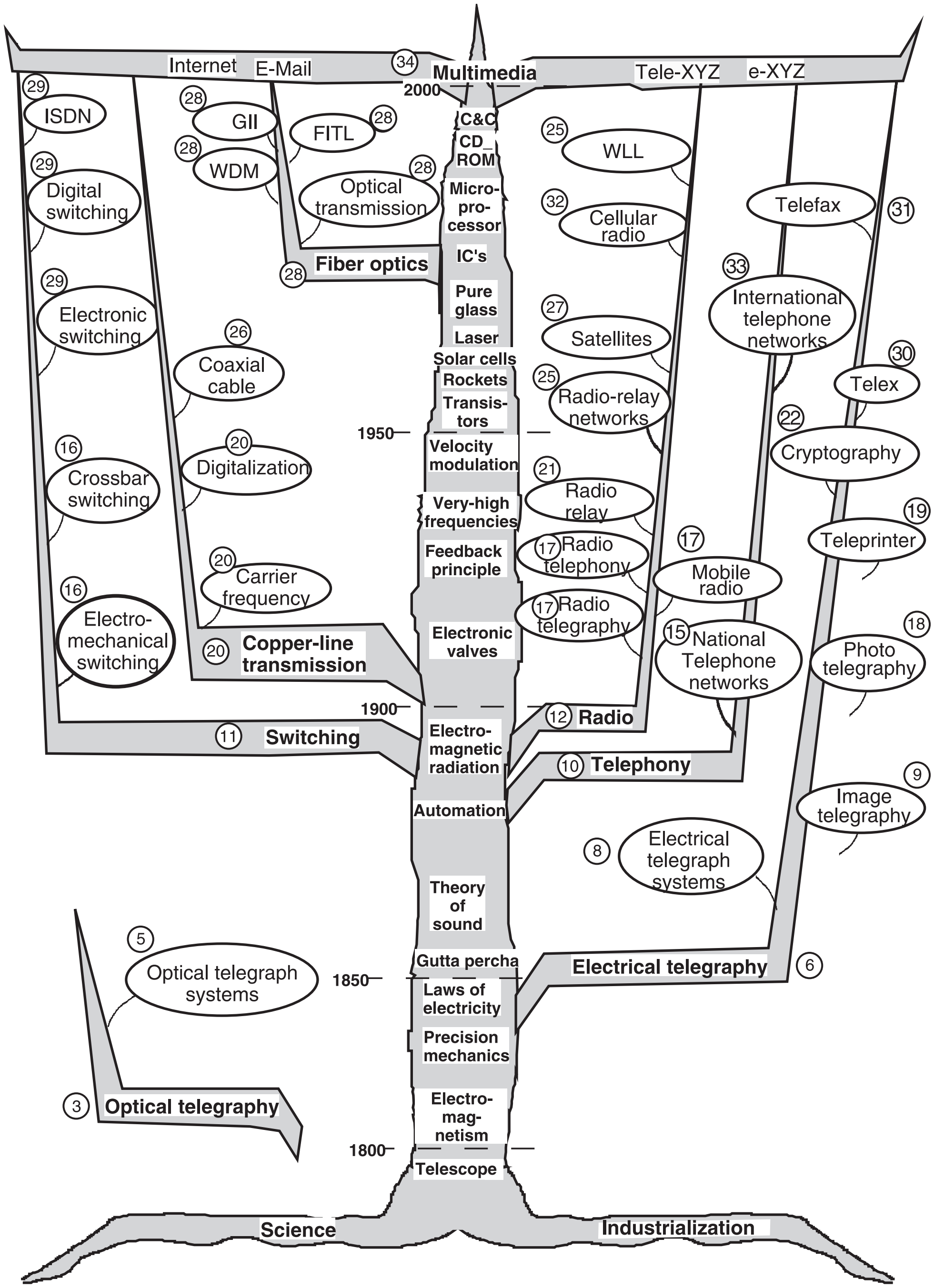

Figure 1.3 Telecommunications tree.

telegraphy. The creation of *electronic tubes* (diodes and triodes) started the electronic era, which enabled the evolution from radio-telegraphy to *radio-telephony* and *mobile radio*. Marine radio was the first mobile radio application, followed by vehicle-mounted private mobile radio and since the 1970s, by infrastructure-sharing trunk systems.

The *feedback* principle applied in electronic circuitry facilitated the generation of high frequencies and thus the development of medium- and shortwave radio transmission and a new technology of circuit combination: carrier frequency, or multiplexing. *Carrier frequency* equipment enabled transmission on a single medium (copper-wire pair, coaxial cable pair, radio-relay, satellite, or optical fiber pair) of thousands of telephone channels. With analog and later also with digital multiplex equipment, installation of national and international *coaxial cable networks* all over the world began in the 1960s.

The development of *very high frequency generators* in 1920 and *velocity-modulated electronic tubes* in the early 1930s made *radio-relay* transmission possible, whereby relay stations, suitably located within lines of sight, receive, amplify, and retransmit radio signals over hundreds and even thousands of kilometers. *Radio-relay networks* were installed beginning in the 1950s, mainly for the distribution of television channels but also as a standby or instead of coaxial cable systems, especially in difficult regions where laying cable would be more expensive. Currently, radio-relay systems are used increasingly for direct access of single subscribers to the public telephone network with wireless-local-loop (*WLL*) systems. This replaces the expensive "last-mile" cable connection between a telephone subscriber and the nearest telephone exchange.

Rockets, transistors, and *solar cells* were the ingredients for the *satellite* branch. Here an evolution is going on of the complementary operation of fixed global and international regional satellite networks, national domestic networks, and global mobile personal communication by satellite networks for person-to-person communication.

The *laser* and extremely *pure glass* enabled the *fiber optics* branch to grow. Long-distance systems with digital signal regenerating repeaters with optoelectronic components are evolving by means of optical amplifiers to regeneration-free soliton transmission systems. For new subscriber access networks, optical fiber cable with fiber-in-the-loop (*FITL*) systems is used increasingly instead of copper cable. Currently, with wavelength-division multiplexing (*WDM*), a number of composite data streams, each with a capacity of 2.5 to 40 Gbps, are transmitted on a single optical fiber pair. Optical fiber cables using WDM are currently being installed between the continents as a major contribution to a global information infrastructure (GII).

ICs (integrated circuits) and *microprocessors* were the nourishment for the cellular radio branch. *Cellular radio* is currently the quickest-growing domain of telecommunications. Here a rapid evolution took place from vehicle-bound analog cellular radio, via vehicle-bound and handheld digital cellular radio, handheld cordless systems, and currently to personal communications networks with person-to-person communication under a single worldwide personal telephone number independent of home, office, or leisure-time location. By year-end 2000, in addition to 987 million fixed telephone lines, some 740 million mobile phones were in use worldwide, and in 36 countries there are more mobile than fixed telephones.

The convergence of communications and computers (*C&C*) and the application of *CD-ROMs* for high-volume data storage is currently leading to *multimedia* services, such as the *Internet* for worldwide interactive information exchange, *tele* working/medicine/banking/learning/shopping/booking/travel scheduling/entertaining services, and the almost costless *e-mail*.

A global information infrastructure with satellites and optical fiber cable spans the globe. As soon as this infrastructure has been completed, with sufficient connections to communities still unserved, the objective postulated by the International Telecommunication Union (ITU) can be met: "that everybody on this planet can obtain the right answer to her/his questions in a matter of seconds, at affordable cost."

Within two centuries, telecommunications experienced tremendous progress. Especially in the last 100 years, with the application of electronics, transistors, microprocessors, satellites, and optoelectronics, telecommunications became the decisive technology for global human development. This development is best demonstrated by the example of transatlantic submarine cable transmission:

- *1866*. The first transatlantic telegraph cable installed and operated by private enterprise transmitted one Morse-coded telegraph channel with a speed of about 5 words per minute.
- *1956*. The first transatlantic telephone cable, TAT-1, co-owned by the U.S. AT&T, the Deutsche Bundespost, the French France Telecom, the U.K. General Post Office, and other administrations, operated 36 telephone channels on two separate cables.
- *2000*. The state-of-the art transatlantic fiber optic cable, Flag Atlantic-1, owned by the private company Flag Telecom, has 12 fibers each with a capacity of 40 WDM 10-Gbps channels, thus a total of 4.8 Tbps, which is equivalent to 58,060,800 telephone channels.

In another recent comparison it was stated that if automobile technology had progressed at the same pace as telecommunications, a Rolls-Royce would cost less than $2 and get 40,000 miles to the gallon (equal to 17,000 km/L).

Despite its age, the telecommunications tree will continue to grow during a still unpredictable future. Some leaves will drop, as already indicated for the leaves that represent image telegraph, photo telegraphy, and teleprinter, which are no longer used. In the near future other leaves will disappear, such as those representing electromechanical switching, crossbar switching, and telex. Complete branches will probably disappear in the first quarter of the twenty-first century, such as electrical telegraphy and copper-line transmission. New leaves will grow. The first new leaf will probably represent an entirely new range of combined optical transmission-switching systems. Another leaf might represent wireless broadband links in metropolitan areas provided by "subspace" flying base stations located in unmanned balloons and airplanes circling in the stratosphere.

The chronological development of telecommunications for the period 1790–2000 is shown in Figure 1.4. A more detailed chronological summary of the major telecommunications events for this period is given in Appendix A.

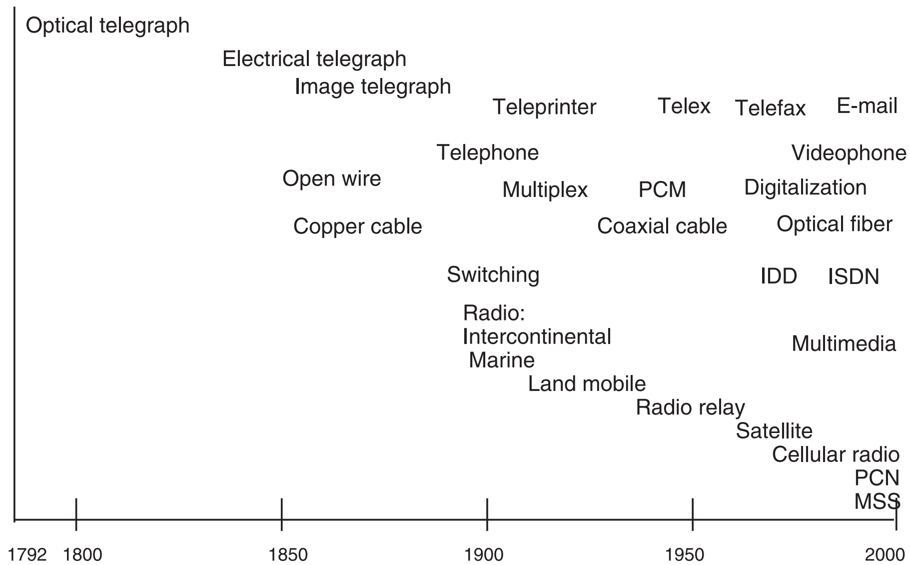

Figure 1.4 Chronology of telecommunications.

1.3 MAJOR CREATORS OF TELECOMMUNICATIONS

Telecommunications development has been the result of timely use of newly discovered technical features by ingenious pioneers who had the vision to create new applications. Those persons, in their time, however, usually faced strong opposition and needed to put forth substantial effort to obtain recognition and acceptance of their invention. Most of them experienced the fate of any discoverer, described very appropriately by the French physicist Dominique François Jean Arago (1786–1853): "Those who discover a new fact in the sciences of observation must expect, first, to have its correctness denied,—next its importance and utility contested,—and afterwards will come the chapter of priority,—then, passages, obscure, insignificant, and previously unnoticed, will be brought forward in crowds as affording evident proofs of the discovery not being new." In this introduction, a brief homage is given to the major pioneers who created telecommunications.

Claude Chappe (1763–1805) Claude Chappe began the era of telecommunications with the successful operation of his optical telegraph between Paris and Lille on August 15, 1794. People accused him, however, of having copied what they claimed to be their idea. Chappe took these attacks so seriously that he became depressed, and he committed suicide at the age of 42.

Samuel Finley Breese Morse (1791–1872) The electrical telegraph had many "fathers" and they all developed unique solutions, so that a dozen different electrical telegraph systems operated simultaneously in various countries. In the worldwide competition for the best technology, the writing telegraph of Morse proved its superiority and found worldwide use. Morse became an internationally respected telecommunications expert. To celebrate his eightieth birthday in 1871, a bronze statue of Morse with his 1844 telegraph instrument was placed in Central Park in New York. He died one year later.

Alexander Graham Bell (1847–1922) The telephone era begun in 1876 in the United States with the operation of a telephone line across a 2-mile stretch between Boston and Cambridge, Massachusetts, with telephone apparatus produced by Bell. For Bell a 10-year patent battle started that in the end, legally gave him the honor and satisfaction of being the inventor of the telephone. Bell then became the most successful of all telecommunications pioneers and gained international prestige. With his wife, Mabel Bell, he lived a prosperous life—the last years in Nova Scotia, where he died at the age of 74.

Heinrich Rudolf Hertz (1857–1894) Heinrich Hertz laid the basis for radio transmission with successful experiments in 1887–1889 that proved the existence of electromagnetic radiation and its similarity to the behavior of light. Hertz very soon gained substantial international appreciation. Unfortunately, he became ill and died at the age of 37.

Guglielmo Marconi (1874–1937) It was Marconi who two years after Hertz died began the radio era. Marconi succeeded in transmitting a radio signal over a few kilometers at Bologna in 1896. He successfully combined technical ingenuity with commercial aptitude. Famous and wealthy, at the age of 53 Marconi turned to private life and Italian politics. A heart attack stopped his life at the age of 63. All radio transmitters worldwide observed 2 minutes of silence.

Almon Brown Strowger (1839–1902) A funeral director in Kansas City, Missouri, Almon B. Strowger, with his "girl-less, cuss-less, out-of-order-less, and wait-less telephone exchange" started a development that has resulted in today's gigantic worldwide telephone network, which is interconnected through thousands of automatic telephone exchanges. For health reasons, Strowger retired at the age of 57 to Florida, where he died in Greenwood at the age of 62.

Michael Idvorsky Pupin (1858–1935) Michael Idvorsky Pupin was born the son of a "free and independent farmer" in Idvor, Serbia–Croatia. He emigrated to the United States, where he developed the Pupin coil, which made him a millionaire. In 1923 he published his autobiography, *From Immigrant to Inventor*, for which he obtained a Pulitzer Prize. Pupin died in New York at the age of 76.

Alec H. Reeves (1902–1971) Alec H. Reeves conceived the idea of digitizing speech and patented his pulse-code-modulation (PCM) procedure, but at a time when the prevailing technology prevented its economical realization. Thirty years later, when his ideas could be realized, the importance of his fundamental invention was recognized by the award to Reeves in 1965 of the Ballantine Medal of the Franklin Institute, by the City of Columbus Gold Medal in 1966 and in 1969 by the inclusion of PCM on the 1-shilling postage stamp in the United Kingdom.

Remarkably, eight of the nine creators above are honored for achievements in the eighteenth and nineteenth centuries. They conceived devices that could be realized with the help of only a few persons. To move the arms of his optical telegraph, Chappe needed a mechanical motion device, which he obtained from the experienced clockmaker Abraham-Louis Breguet. To construct an electromagnetic writing device on his easel, Morse availed himself of the technical skill of his student, Alfred Lewis Vail. Bell had his electrician, Watson, and Almon B. Strowger, fortunately, had a technically talented nephew, Walter S. Strowger. Marconi experimented with his radio with the assistance of his brother. Production of the first Pupin coil needed the idea rather than much technical skill. However, to realize in the twentieth century Reeves's idea of PCM, even once the transistor was available, some 10 to 20 engineers at Bell Telephone Laboratories had to undertake years of research work.

In contrast to these essentially one-person inventions of the eighteenth and nineteenth centuries, teamwork was required for the big telecommunications achievements of the twentieth century, and even then, success was not always guaranteed. Development of the first electronic telephone exchange in the 1950s, the No. 1 ESS of AT&T, took seven years and absorbed $100 million. Before the world's first commercial cellular radio system, conceived by the engineers of Bell Labs in 1946, could be put into operation in Japan in 1979, 100 Japanese engineers and technicians required a 12-year period of development. ITT spent a record $1 billion in the 1980s for the development of their digital switching system (System 12), and then abandoned telecommunications. Iridium, the first global mobile personal communication satellite system, was conceived in 1987. Over 1000 engineers, technicians, and mathematicians, mainly in the United States but also in Europe and Asia, with great skill and energy, worked out elaborate designs for components and systems for software, management plans, and logistics at a cost of $3.4 billion before the system could be put into operation on November 1, 1998. By then, unfortunately, they were too late. The unexpectedly rapid worldwide penetration of cellular radio made the Iridium system superfluous.