Creating the First Web: The 19th-Century Expansion of Telegraphy

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The Internet is the result of scientific and technological developments that have occurred in the field of information and communication technology (ICT) in the last 50 years. It has greatly changed not only our way of accessing and exchanging information but also, more generally, our way of life in various aspects and at many different levels. This change has occurred to such an extent that several authors regard it as the fourth big leap in humankind's communication, after complex language (about 70,000 years ago), writing (approximately 5,000 years ago), and printing (more than 1,000 years ago in China and more than 550 years ago in Europe) [1], [2].

Nevertheless, the Internet is not the first global network for fast communications among remote users, having been preceded by telegraphy by more than a century [3]. The birth of the telegraph, in the 1830s, gave rise to a period of frenetic construction in the following decades, and 19,000 km of lines were laid in the United States alone by 1850 [4].

The Siemens and Halske company was founded by Werner Siemens (1816–1892) and Johann Halske (1814–1890) in Germany in 1847 to produce advanced telegraphic needle receivers and cables insulated with gutta-percha, a natural material similar to rubber that had recently gone into industrial production and allowed laying underground cables. The 500-km Berlin–Frankfurt line was the first long-distance line exploiting this technology, in 1848 [5]. Siemens and Halske kept the lead in the expansion of the telegraph in Europe in the following years. In 1853, the company provided the Russian lines, stretching over 10,000 km from Finland to the Crimea.

The expansion in America culminated with the first transcontinental line, which connected New York to San Francisco, a distance of over 2,900 km, and was completed by the Western Union Telegraph Company in 1861. It allowed for the transmission of coast-to-coast messages in a few minutes, versus the 10 days needed by the Pony Express service. By 1862, the extent of the lines in America had more than tripled, totaling 77,000 km, whereas the British lines had reached 24,000 km, and those of continental Europe had reached 128,000 km.

In 1870, Siemens and Halske completed the Indo–European telegraph line, after two years of construction, actually building the 4,700-km portion from the Prussia–Russia border to Teheran, Persia (Figure 1). The line connected London to Calcutta, with a total length of 11,000 km [6]. It was provided with advanced forwarding devices with punched tapes that passed the message automatically from one segment of the line to the next, quickly and exempt from human errors, a technique dubbed "independent translation." The first message sent traveled from London to Teheran in 1 min and then was forwarded to Calcutta in a total time of 28 min. For the sake of comparison, traditional delivery methods required weeks.

Underwater lines started operating in the 1850s, exploiting the insulating capabilities of gutta-percha. The first was the 40-km Dover–Calais cable laid by the Submarine Telegraph Company at a depth of 55 m in 1852, which was followed by several other cables laid at increasing depths and over longer distances. The first reliable transatlantic cable was laid by the Anglo-American Telegraph Company, led by Cyrus Field (1819–1892), in 1866, after unsuccessful attempts in 1858 and after the dust of the American Civil War had settled [7]. It stretched for 3,700 km between Valentia Bay in Ireland and Heart's Content in Newfoundland, at depths up to 4,400 m. It required a huge investment and raised colossal technological challenges, regarding both cable construction and paying out: William Thomson (1824–1907; Lord Kelvin of Largs from 1892) developed the ultrasensitive mirror-galvanometer in 1858 to detect the extremely attenuated signals at the receiving station. Thomson also first explored the submarine cable equation in 1854, formalized by Gustav Kirchhoff (1824–1887) into the telegrapher's equation three years later.

When the transatlantic cable went into service, the Western Union Telegraph Company was laying a competing transcontinental line to connect America and Europe through Alaska and Siberia, but it was abandoned in 1867, in spite of the huge amount of money spent on the work already done, to avoid an even larger financial disaster. The first transatlantic cable was soon followed by several other long-distance submarine cables.

Those telegraph lines, both land and submarine, were sensational technological achievements that had a great impact on economics, politics, information, culture, and everyday life. Several technical developments supported the expansion of the telegraph. Practicable power supplies for early telegraphs consisted of the porous-pot copper-zinc 1.1-V cell conceived by Englishman John Daniel (1790–1845) in 1836 and improved by J.C. Fuller in 1853. It was followed by the porous-pot zinc-platinum 1.8-V cell developed by Welshman William Grove (1811–1896) in 1839 and by the much-cheaper zinc-carbon 1.9-V cell proposed by German Robert Bunsen (1811–1899) in 1841. However, all those batteries were primary cells, which needed to be replaced once exhausted, at a significant cost.

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A major advance came from Werner Siemens, who first developed a dynamo with a double-T armature solid-iron rotor in 1856, allowing for a much-cheaper powering of the telegraph [8]. He improved the device by adding self-excitation in 1867. Although this feature was conceived independently by other inventors at the same time, it was first industrialized by Siemens and Halske.

Numerous devices were developed to improve the efficiency of the telegraph. The success of the Morse system sprang from its advantages over competing systems—mainly, the simplicity of the one-conductor lines with ground return and the efficiency of the coding system. Nevertheless, it presented a number of issues, and much development was done to overcome them. A major problem was the huge cost of laying long lines that could transmit only one message at a time in either direction, what now is called *half-duplex*.

In 1853, the Austrian inventor Julius Gintl (1804–1883) conceived the first two-way telegraphic transmission system, namely, the first full-duplex telegraph, capable of transmitting two simultaneous telegraphic signals in opposite directions on the same line. Gintl's system was perfected and presented at the 1855 Paris Universal Exhibition, earning him a gold medal. An improved and more practical duplex system was patented by Joseph Stearns in America in 1872; this system resorted to one signal using on/off states and the other one using +/– states. Stearns sold his patent rights to Western Union, which could thus consolidate its dominant position in the American market. He also licensed the system in several European countries, both for land and submarine lines, including the transatlantic cables.

In 1874, Thomas Edison (1847–1931) invented the quadruplex system, capable of four simultaneous messages on the same line, two in each direction

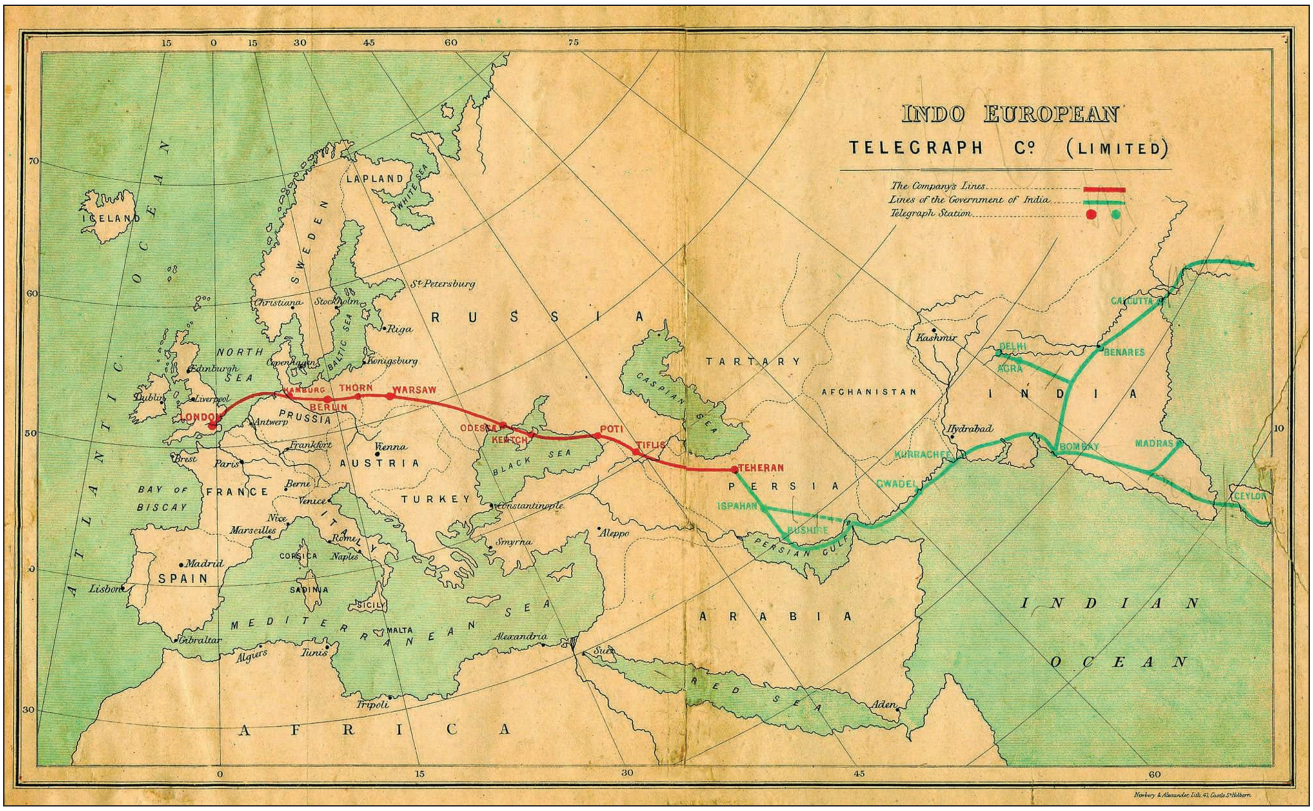

FIGURE 1 – The path of the Indo-European telegraph, connecting London to Calcutta, completed by Siemens and Halske in 1870. (Source: Courtesy of Siemens Historical Institute; used with permission.)

(Figure 2). He sold the patent rights to the Western Union Telegraph Company for US$10,000, at least double his initial expectation; that amount constituted the funding for starting his famous Menlo Park Laboratory, the first industrial research company, where many of Edison's major inventions were developed. The sale provided a huge profit to Western Union as well, allowing it to quadruple the traffic on a single line.

Another issue with telegraphy derived from the need to have human operators convert an alphabetic message into a sequence of dots and dashes in Morse code, transmit them, and convert them back to alphabetic characters, which required two trained operators and involved a processing time (even in the case of experienced operators), risk of error, and threats to confidentiality. The solution was found in the teletype–teleprinter, which automatically converted the received dots and dashes into letters of the alphabet, requiring only one operator trained in using a typewriter keyboard. An early device performing synchronous data transmission and capable of about 40 words/min was patented by the American inventor Royal Earl House (1814–1895) in 1846. A more efficient model was introduced by the English-born American David Edward Hughes (1831–1900) in 1855, and it spread in the American and European telegraph systems in the following years (Figure 3).

A major figure in the maturity of the telegraph and a pioneer of digital communication was the French engineer Jean-Maurice-Émile Baudot (1845–1903). Around 1870, he conceived a telegraph five-bit code with equal on/off intervals that could transmit the Roman alphabet and control symbols. Soon after, he developed the hardware for using this code. His inventions were based on the five-unit code of Gauss and Weber as well as on Hughes's technology. In 1872, he invented time multiplexing, which allowed transmitting five messages simultaneously using Hughes's machines. In 1874, he was able to patent the Rapid Telegraph System, based on his previous inventions, which was capable of 30 words/min [9]. It was adopted by the French Telegraph Administration in 1875, and the Paris–Rome line, stretching over 1,700 km, started operating in 1877. After receiving the gold medal at the 1878 Paris Universal Exhibition, the Baudot system spread to other countries.

Signal transmission benefited from other developments. In 1882, the Belgian inventor François van Rysselberghe (1846–1893) built the first electric filters, made of a capacitor and an inductor, to separate a telegraphic signal from a telephonic signal transmitted on the same line [10]. Following an idea proposed by Englishman Oliver Heaviside (1850–1925) while studying the telegrapher's equation in 1887, the Serbian-born American physicist Michael Pupin (1858–1935) introduced and patented the Pupin coil in 1899. Placed at regular intervals along the telegraph (or telephone) lines, these coils balanced the transversal capacitance, thus

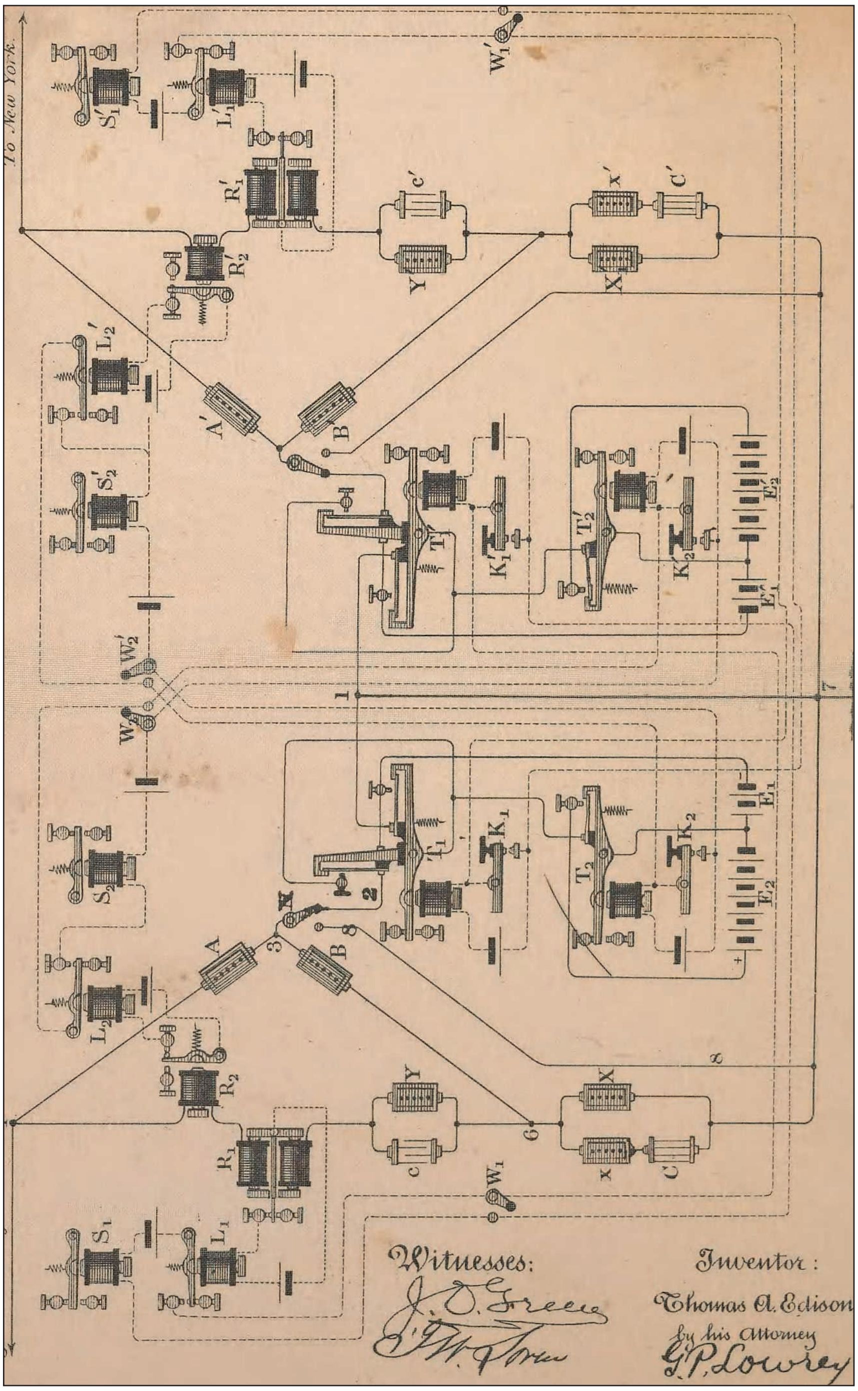

FIGURE 2 – The quadruplex system scheme patented by Thomas Edison in 1874. (Source: Wikimedia Commons.)

FIGURE 3 – The letter-printing telegraph set built by Siemens and Halske in Saint Petersburg, Russia, ca. 1900, based on the 1855 patent of David Hughes. (Source: Wikimedia Commons.)

eliminating distortion and reducing attenuation. The coil was soon licensed to the Western Electric Manufacturing Company in America and to Siemens and Halske in Europe.

Similar results were obtained by the American engineer George Campbell (1870–1954) of AT&T. This latter company was incorporated in 1885 by the Bell System Company, which gained control of the Western Electric Manufacturing Company in 1881. Subsequently, AT&T acquired the Bell Company in 1899 and was headed to become the largest telegraph and telephone company in the world. After sending his first wireless signals in 1895, the young Anglo-Italian Guglielmo Marconi (1874–1937) founded his Wireless Telegraph Trading Signal Co. in 1897 (its name became Marconi's Wireless Telegraph Company after 1900), paving the way for major progress in telegraphy.

Aside from all these technological achievements, the sensational success of the telegraph in the 19th century relied also on the efficient addressing of regulatory needs. As telegraph lines owned by different companies were expanding, the problem of interconnecting them inside each country and between different countries emerged, which raised issues of standardization.

To address these problems, the International Telegraph Convention was signed on 17 May 1865, and the International Telecommunication Union (ITU) was established [11]. It was the first international organization. Early implementations included the use of Morse code as the international telegraphic alphabet, the protection of the secrecy of correspondence, and the right of everyone to use the international telegraphy. The ITU allowed the telegraphic networks of different nations to be interconnected, creating a large international communication network, a real communication web that we can now consider as a predecessor of the Internet. It preceded the national and international integration of the power grids by several decades [12], [13].

The ITU evolved into a specialized agency of the United Nations for ICTs in 1947, and, since 1969, it has celebrated World Telecommunication and Information Society Day every 17 May. Developing its mission over the decades, the ITU made possible the building of the worldwide telephone network, then the largest existing technical system, and, recently, the Internet [14].

The wide diffusion of telegraphs and their political, economic, and social importance promoted cooperation and the exchange of scientific and technological knowledge. It was with this aim that the Society of Telegraph Engineers was founded in Great Britain in 1871; it evolved into the Society of Telegraph Engineers and Electricians in 1880 and then the Institution of Electrical Engineers (IEE) in 1888. It was incorporated into the Institution of Engineering and Technology (IET) in 2006. The IEE was the model upon which other professional associations were founded in other nations, notably the American Institute of Electrical Engineers (AIEE; founded in 1884) and the Institute of Radio Engineers (IRE; founded in 1912), which merged into the Institute of Electrical and Electronics Engineers (IEEE) in 1963.

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