José Luiz Frauendorf
Érika Almeida de Souza

The Architectural and Technological Revolution of 5G

Springer

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José Luiz Frauendorf
Ouro Fino, MG, Brazil

Érika Almeida de Souza
São Paulo, SP, Brazil

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I dedicate this book to a little-known Brazilian hero. He was born in Piracicaba, in the interior of the State of São Paulo, Brazil, in the middle of the nineteenth century, more precisely on October 26, 1853. His name: ***Evaristo Conrado Engelberg****, son of Swiss immigrants. A mechanical engineer by profession, he developed something important, the coffee and rice hulling and separation machine, at a time when Brazil and the State of São Paulo depended economically and fundamentally on coffee culture, considered the green gold. At that time, coffee represented 56% of all Brazilian exports. Engelberg became so famous that Brazilian Emperor Dom Pedro II went personally to Piracicaba to meet him. He became a member of the Paris Academy of Inventors and was awarded with the gold medal. He set up factories in Brazil and in the USA to produce his invention. He didn't become rich, probably because he didn't have enough capital to participate in the investments of the companies that he helped to create and that carried his name. He had to leave the companies, but not before having the satisfaction of seeing his invention patented in the USA on August 4, 1914. He died in 1932, and today he is only remembered in a few books that tell the history of industrialization in Brazil. I am very proud to be his great-grandson. José Luiz Frauendorf*

Foreword

I met Frauendorf when I took over the direction of DirecTV Brazil in 1997. At that time, he was the general director of operations of TVA, a Pay-TV company. Soon after, he became an independent consultant, but continued to work for Editora Abril. Later, as general director of TVA, I had the pleasure of interacting with him for many years and always learned a lot in our conversations and debates. In fact, Frauendorf and Virgílio Amaral, TVA's Technology Director, were very patient, teaching me everything I could learn about wireless technology.

Frauendorf then became general director of Neotec, the Brazilian association of MMDS (Multichannel Multipoint Distribution Service) operators. This association was formed by initiative of the brothers Lins de Albuquerque, Hermano, and Carlos André, from TV Filme Brasília. Neotec was created with the objective of searching in the international market new digital technologies that would allow the expansion of services provided by operators that held the MMDS spectrum concession. The operators, around 2001, were limited, providing pay TV service over the air using the 2.5 GHz band and had great difficulty competing with operators that were providing service using coax cable. At that time everything was analog, but digitalization was very close.

In addition to TVA, TV Filme, Acom, Teleserv, and MMDSC made up a very united team willing to fight for the right to use the spectrum for any other possible service. Carlos André Lins de Albuquerque, representing TV Filme, João Reino and Mário de Paula for Acom, Gisele Gomes for Teleserv, and Odilon Silva for MMDSC completed the team that worked together to optimize the use of the 2.5 GHz spectrum. In leading the association, Frauendorf was tireless in searching new technologies and regulatory alternatives.

Acom had already launched its digital service in Natal and served as a "guinea pig" for the digitization of video services, but this was not enough. MMDS had to provide access to the Internet. TV Filme had launched the provision of access using an MMDS channel for the downstream, and the return, upstream, was done by telephone line. Soon, the services evolved to DOCSIS modems, the same used by cable TV operators. But the team wanted something innovative.

TV Filme, located in the USA some companies that developed specific technologies for wireless. Two of them, Navine and NextNet, were interested in the Neotec project and were willing to perform field tests in Brazil. The Brazilian city of Belo Horizonte, where TV Filme had a concession, was chosen as the ideal stage for the tests. Effectively, after overcoming all the importation and licensing bureaucratic procedures, the equipment arrived in Brazil and the tests could begin in early 2003.

Navine used TD-SCDMA modulation, which had been employed initially in China, like W-CDMA modulation used in 3G. NextNet came with a technological innovation, OFDM modulation, the same used in digital television. OFDM's superiority was verified right at the beginning of the tests that lasted many months. A van was traveling the central streets of BH receiving and transmitting video signals and allowing Internet access, while the connection was always maintained, provided by handover between the three cells installed, covering each an area of 2 to 5 km radius. The success was impressive. The speeds achieved for that time were quite satisfactory: 2 Mbps downstream and 0.8 Mbps upstream.

All operators were invited to witness the success of the tests, as well as, of course, the staff of Anatel, the Brazilian Telecommunications Agency. The then board member of Anatel, Antônio Carlos Valente, soon warned: *Hire a good lawyer to defend your rights*. This was how Dr. Elinor Cotait came to represent Neotec in all the battles for the rights of operators to use the spectrum.

We are very proud of all the work developed by the MMDS operators' association, which was, at that time, recognized internationally.

The results of the BH tests were presented by Frauendorf at a WCA (Wireless Communications Alliance) conference in Palo Alto, California, in January 2004. Among the influential and recognized people in the market who attended the congress were Sean Maloney, VP of Intel, and Barry J. West, CTO of Nextel Communications (Sprint). The invitation for Neotec to be part of the WiMAX Forum, where the proposed technologies solutions were in discussions, was immediate. Intel and Samsung had an agreement to create WiMAX, which would be a system similar to Wi-Fi for outdoor use and intended to be the fourth generation of cellular systems. Shortly after, the WiMAX/4G—Global Development Committee (GDC) was created within the WCA and Neotec was indicated to the co-chair position alongside a representative from Sprint.

All this development motivated Samsung and Motorola to promote WiMAX tests in Brazil, which took place in São Paulo in 2005, and I had the pleasure to follow. Interesting to note that, in the case of Samsung, São Paulo was the second city where field tests were conducted, right after the tests in Seoul, Korea, and before the tests performed by Sprint in the USA, demonstrating that Brazil was really committed to the development of the new technology.

WiMAX didn't take off, but it was the embryo of what we now know as LTE/4G, which in turn was the embryo of 5G, which will enable the transformation of various industries and services.

I was very happy when Frauendorf called me saying that he was launching a book 20 years after Neotec was founded, writing about the technology whose birth and development worldwide he had the opportunity to follow. I was very proud to have participated in an organization that was developing pioneering and innovative work in a country that does not always value initiatives like this.

It is a privilege for me to be able to tell a little of this story and, at the same time, to register how important was the participation of Virgílio, Carlos André, Odilon, João Reino, Mário de Paula, and Gisele in Neotec. The partnership with the operators allowed Frauendorf, as general director of the Association, to have the opportunity to follow the evolution of cellular technology in Brazil and in the world.

To Frauendorf, my special thanks for his dedication and competence in conducting this important project, which, with the arrival of 5G, will bring so many benefits to society.

Chairman of the Board of Directors IBGC (Brazilian Institute of Corporate Governance)

Leila Abraham Loria,
São Paulo, Brazil

Preface

I stayed almost 10 years away from my professional origin, taking care of other interests not related to telecommunications.

I had the privilege of working with WiMAX technology, an innovative technology, evolution of Wi-Fi for outdoor networks and precursor of LTE/4G. It was an incredible learning experience. Unfortunately, the technology didn't take off and I got frustrated.

With the pandemic, I had to retire from the day-to-day work I've done for over 50 years. I became interested in 5G just because I soon realized there was something disruptive on the horizon. The beginning was difficult. The number of acronyms confused me. I felt like I didn't understand anything. In part, this was due to my total lack of knowledge about the architecture of the LTE system, used in both 4G and 4.5G. In fact, I knew very little about the previous systems, as I had not participated in any project that required me to deepen my knowledge in this segment. I was heavily involved in video digitization for a long time, an activity that required me to be very focused.

Gradually, I understood the logic that guided the development of 5G and realized the greatness of this revolutionary technology that will certainly radically change the telecommunications scenario in a very short time. As I understood it, I realized how innovative it is.

As I had done since I was in college, I made summaries of everything I learned. I acted more like a journalist studying a new subject. I hope this book can be of value and inspire those who wish to understand a little about cellular systems and anticipate everything that 5G will mean for users, network operators, and, above all, equipment suppliers, service providers, and application developers.

Basically, the great objective of this book is to divulge new opportunities that will be available to those who are alert.

Three technological quantum leaps are occurring almost simultaneously. The most advanced is photovoltaics, which will greatly change the way electricity is generated and consumed.

The second is exactly 5G, the subject of this book.

The third is electric and hydrogen-powered vehicles, which are already beginning to unbalance a long-standing hegemony. A single indicator is enough to demonstrate their transformative character. While a conventional car is composed of 30,000 parts, electric cars require only 6,000 to be assembled. It is just a matter of time and production scale. Countless opportunities will come around.

But, as more heads think much better than just one, I went searching help from incredible people who shared my professional history, to help me in the task I had set myself. Érika Almeida de Souza collaborated a lot with the preliminary texts, inserting points that required further clarification. She ended up becoming my co-author for her valuable contributions. Erich Baumeier, with an excellent professional background in IT, information technology, also collaborated a lot with comments and suggestions, mainly in the segment he dominates. Working with more people makes the task even more interesting and much more enjoyable.

Our intention is to write something that will help all readers interested in 5G to be more knowledgeable and aware of the new opportunities. I hope we can achieve our goals. Happy reading!

Important note: for those less familiar with some basic concepts used in telecommunications and computer networks, we advise reading three additional chapters: "Digital Modulation," "Computer Networks," and "AI—Artificial Intelligence/ML—Machine Learning."

Ouro Fino, MG, Brazil José Luiz Frauendorf
April 2022

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About the Authors

José Luiz Frauendorf was born in São Paulo, Brazil. He got his degree in electronic engineer from the Institute Mauá of Technology. He started his professional career at AEG Telefunken, in Backnang, Germany, where he worked on the development of telecommunication systems, including coaxial cable systems and microwaves. Later, he was transferred to Brazil with the responsibility of implementing at the local subsidiary the manufacturing of public telephony systems which included voice channels multiplexing systems, microwave systems, and monitoring and supervision systems for telecommunications stations. With the acquisition by Grupo Docas de Santos of ELEBRA Eletrônica Brasileira, he was invited to take over the product development area of ELEBRA Informática. Subsequently, he held the position of industrial and technical director of ELEBRA Computers until its acquisition by Digital Equipment Corporation, when he became the plant manager of the Brazilian subsidiary. He participated in TVA—Grupo ABRIL Television System, having been its general director of operations. After that, he became general director of NEOTEC, an association created to develop technologies to provide multimedia services using the 2.5GHz spectrum. Frauendorf coordinated tests of systems providing broadband services using WCDMA and OFDM modulation systems, and later WiMAX technology, in several Brazilian cities. In 2010, he participated in the turnaround of a family company, from which he withdrew when it was sold in 2014. After his experience in the polymer segment, he developed a new technology for electrically insulating gloves using synthetic materials. His invention was patented in several countries. Since 2020, he has been dedicating himself in writing books and disseminating news in the areas of new technologies.

Érica Almeida de Souza got her degree in telecommunications engineering and postgraduate from INATEL (National Institute of Telecommunications). She participated in several training courses in telephony and data transmission at Huawei, both in China and in Brazil. She started her professional career at the former CFLCL, now Energisa. She also worked at Panasonic do Brasil and later at Huawei, where she had the opportunity to promote training courses in Brazil and Latin America. She is currently caring out advance training courses at IWF Training and Consulting.

Abbreviations

3GPP	Third Generation Partnership Project
AAA	Authentication, Authorization and Accounting
ACIR	Adjacent Channel Interference Ratio
ACK	Acknowledgement
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ADC	Analog-to Digital Conversion
ADSL	Asymmetric Digital Subscriber Line
AKA	Authentication and Key Agreement
AM	Acknowledged Mode
AMBR	Aggregate Maximum Bit Rate
AMD	Acknowledged Mode Data
AMR	Adaptive Multi-Rate
AMR-NB	Adaptive Multi-Rate Narrowband
AMR-WB	Adaptive Multi-Rate Wideband
ARP	Allocation Retention Priority
ASN	Abstract Syntax Notation
ATB	Adaptive Transmission Bandwidth
AWGN	Additive White Gaussian Noise
BB	Baseband
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BE	Best Effort
BEM	Block Edge Mask
BICC	Bearer Independent Call Control Protocol
BLER	Block Error Rate
BO	Backoffice
BOM	Bill of Material
BPF	Band Pass Filter
BPSK	Binary Phase Shift Keying
BS	Base Station

BSC	Base Station Controller
BSR	Buffer Status Report
BT	Bluetooth
BTS	Base Transceiver Station
BW	Bandwidth
CBR	Constant Bit Rate
CCCH	Common Control Channel
CCE	Control Channel Element
CDD	Cyclic Delay Diversity
CDF	Cumulative Density Function
CDM	Code Division Multiplexing
CDMA	Code Division Multiple Access
CIR	Carrier to Interference Ratio
CLM	Closed Loop Mode/Close Loop Methodology
CM	Cubic Metric
CMOS	Complementary Metal Oxide Semiconductor
CoMP	Coordinated Multiple Point
CP	Cyclic Prefix
CPE	Common Phase Error
CPICH	Common Pilot Channel
CQI	Channel Quality Information
CRC	Cyclic Redundancy Check
C-RNTI	Cell Radio Network Temporary Identifier
CS	Circuit Switched
CSCF	Call Session Control Function
CSFB	Circuit Switched Fallback
CSI	Channel State Information
CT	Core and Terminals
CTL	Control
CW	Continuous Wave
DAC	Digital to Analog Conversion
DARP	Downlink Advanced Receiver Performance
D-BCH	Dynamic Broadcast Channel
DC	Direct Current
DCCH	Dedicated Control Channel
DCH	Dedicated Channel
DC-HSDPA	Dual Cell (Dual Carrier) HSDPA
DCI	Downlink Control Information
DCR	Direct Conversion Receiver
DCXO	Digitally Compensated Crystal Oscillator
DD	Duplex Distance
DFCA	Dynamic Frequency and Channel Allocation
DFT	Discrete Fourier Transform
DG	Duplex Gap
DL	Downlink

DL-SCH	Downlink Shared Channel
DPCCH	Dedicated Physical Control Channel
DR	Dynamic Range
DRX	Discontinuous Reception
DSP	Digital Signal Processing
DTCH	Dedicated Traffic Channel
DTM	Dual Transfer Mode
DTX	Discontinuous Transmission
DVB-H	Digital Video Broadcast–Handheld
DwPTS	Downlink Pilot Time Slot
E-DCH	Enhanced DCH
EDGE	Enhanced Data Rates for GSM Evolution
EFL	Effective Frequency Load
EFR	Enhanced Full Rate
EGPRS	Enhanced GPRS
E-HRDP	Evolved HRPD (High-Rate Packet Data) network
EIRP	Equivalent Isotropic Radiated Power
EMI	Electromagnetic Interference
EPC	Evolved Packet Core
EPDG	Evolved Packet Data Gateway
ETU	Extended Typical Urban
E-UTRA	Evolved Universal Terrestrial Radio Access
EVA	Extended Vehicular A
EVDO	Evolution Data Only
EVM	Error Vector Magnitude
EVS	Error Vector Spectrum
FACH	Forward Access Channel
FCC	Federal Communications Commission
FD	Frequency Domain
FDD	Frequency Division Duplex
FDE	Frequency Domain Equalizer
FDM	Frequency Division Multiplexing
FDPS	Frequency Domain Packet Scheduling
FE	Front End
FFT	Fast Fourier Transform
FM	Frequency Modulated
FNS	Frequency Non-Selective
FR	Full Rate
FRC	Fixed Reference Channel
FS	Frequency Selective
GB	Gigabyte
GBR	Guaranteed Bit Rate
GDD	Group Delay Dispersion
GERAN	GSM/EDGE Radio Access Network
GGSN	Gateway GPRS Support Node

GMSK	Gaussian Minimum Shift Keying
GP	Guard Period
GPON	Gigabit Passive Optical Network
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRE	Generic Routing Encapsulation
GSM	Global System for Mobile Communications
GTP	GPRS Tunneling Protocol
GTP-C	GPRS Tunneling Protocol, Control Plane
GUTI	Globally Unique Temporary Identity
GW	Gateway
HARQ	Hybrid Automatic Repeat and Request
HB	High Band
HD-FDD	Half Duplex Frequency Division Duplex
HFN	Hyper Frame Number
HII	High Interference Indicator
HO	Handover
HPBW	Half Power Beam Width
HPF	High Pass Filter
HPSK	Hybrid Phase Shift Keying
HRPD	High-Rate Packet Data
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HSGW	HRPD Serving Gateway
HSPA	High Speed Packet Access
HS-PDSCH	High Speed Physical Downlink Shared Channel
HSS	Home Subscriber Server
HS-SCCH	High Speed Shared Control Channel
HSUPA	High Speed Uplink Packet Access
IC	Interference Cancellation
ICI	Inter-carrier Interference
ICIC	Inter-Cell Interference Coordination
ICS	IMS Centralized Service
ID	Identity
IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
IL	Insertion Loss
IMD	Intermodulation Distortion
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IoT	Internet of Things
IOT	Inter-Operability Testing
IP	Internet Protocol
IR	Image Rejection
IRC	Interference Rejection Combining

ISD	Inter-site Distance
ISDN	Integrated Services Digital Network
ISI	Inter-Symbol Interference
IWF	Interworking Function
LAI	Location Area Identity
LB	Low Band
LCID	Logical Channel Identification
LCS	Location Services
LMA	Local Mobility Anchor
LMMSE	Linear Minimum Mean Square Error
LNA	Low Noise Amplifier
LO	Local Oscillator
LOS	Line of Sight
LTE	Long-Term Evolution
MAC	Medium Access Control
MAP	Mobile Application Part
MBMS	Multimedia Broadcast Multicast System
MBR	Maximum Bit Rate
MCH	Multicast Channel
MCL	Minimum Coupling Loss
MCS	Modulation and Coding Scheme
MGW	Media Gateway
MIB	Master Information Block
MIMO	Multiple Input Multiple Output
MIP	Mobile IP
MIPI	Mobile Industry Processor Interface
MIPS	Million Instructions Per Second
MM	Mobility Management
MME	Mobility Management Entity
MMSE	Minimum Mean Square Error
MPR	Maximum Power Reduction
MRC	Maximal Ratio Combining
MSC	Mobile Switching Center
MSC-S	Mobile Switching Center Server
MSD	Maximum Sensitivity Degradation
MU	Multiuser
NACC	Network Assisted Cell Change
NACK	Negative Acknowledgement
NAS	Non-access Stratum
NAT	Network Address Translation
NB	Narrowband
NF	Noise Figure
NMO	Network Mode of Operation
NRT	Non-real Time
OFDM	Orthogonal Frequency Division Multiplexing

OFDMA	Orthogonal Frequency Division Multiple Access
OI	Overload Indicator
OLLA	Outer Loop Link Adaptation
OOB	Out of Band
OOBN	Out-of-Band Noise
O&M	Operation and Maintenance
PA	Power Amplifier
PAPR	Peak to Average Power Ratio
PAR	Peak-to-Average Ratio
PBR	Prioritized Bit Rate
PC	Personal Computer
PC	Power Control
PCC	Policy and Charging Control
PCCC	Parallel Concatenated Convolutional Coding
PCCPCH	Primary Common Control Physical Channel
PCFICH	Physical Control Format Indicator Channel
PCH	Paging Channel
PCI	Physical Cell Identity
PCM	Pulse Code Modulation
PCRF	Policy and Charging Rules Function
PCS	Personal Communication Services
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDF	Probability Density Function
PDI	Precoding Matrix Indicator
PDN	Packet Data Network
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
P-GW	Packet Data Network Gateway
PHICH	Physical HARQ Indicator Channel
PHY	Physical Layer
PLL	Phase Locked Loop
PLMN	Public Land Mobile Network
PMI	Precoding Matrix Index
PMIP	Proxy Mobile IP
PN	Phase Noise
PRACH	Physical Random-Access Channel
PRB	Physical Resource Block
PS	Packet Switched
PSD	Power Spectral Density
PSS	Primary Synchronization Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier

QN	Quantization Noise
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Random Access Channel
RAD	Required Activity Detection
RAN	Radio Access Network
RAR	Random Access Response
RAT	Radio Access Technology
RB	Resource Block
RBG	Resource Block Group
RF	Radio Frequency
RI	Rank Indicator
RLC	Radio Link Control
RNC	Radio Network Controller
RNTP	Relative Narrowband Transmit Power
ROHC	Robust Header Compression
RRC	Radio Resource Control
RRM	Radio Resource Management
RS	Reference Signal
RSCP	Received Symbol Code Power
RSRP	Reference Symbol Received Power
RSRQ	Reference Symbol Received Quality
RSSI	Received Signal Strength Indicator
RT	Real Time
RTT	Round Trip Time
RV	Redundancy Version
SA	Stand Alone
SAE	System Architecture Evolution
SAIC	Single Antenna Interference Cancellation
S-CCPCH	Secondary Common Control Physical Channel
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCH	Synchronization Channel
SCM	Spatial Channel Model
SCTP	Stream Control Transmission Protocol
SDU	Service Data Unit
SE	Spectral Efficiency
SEM	Spectrum Emission Mask
SF	Spreading Factor
SFBC	Space Frequency Block Coding
SFN	System Frame Number
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SIB	System Information Block
SID	Silence Indicator Description
SIM	Subscriber Identity Module

SIMO	Single Input Multiple Output
SINR	Signal to Interference and Noise Ratio
SMS	Short Message Service
SNDR	Signal to Noise and Distortion Ratio
SNR	Signal-to-Noise Ratio
SON	Self-Optimized Networks
SON	Self-Organizing Networks
SR	Scheduling Request
S-RACH	Short Random-Access Channel
SRB	Signaling Radio Bearer
S-RNC	Serving RNC
SRS	Sounding Reference Signals
SR-VCC	Single Radio Voice Call Continuity
SSS	Secondary Synchronization Signal
S-TMSI	S-Temporary Mobile Subscriber Identity
SU-MIMO	Single User Multiple Input Multiple Output
S1AP	S1 Application Protocol
TA	Tracking Area
TBS	Transport Block Size
TD	Time Domain
TDD	Time Division Duplex
TD-LTE	Time Division Long-Term Evolution
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TM	Transparent Mode
TPC	Transmit Power Control
TRX	Transceiver
TSG	Technical Specification Group
TTI	Transmission Time Interval
TU	Typical Urban
UDP	User Datagram Protocol
UE	User Equipment
UHF	Ultra-High Frequency
UICC	Universal Integrated Circuit Card
UL	Uplink
UL-SCH	Uplink Shared Channel
UM	Unacknowledged Mode
UMD	Unacknowledged Mode Data
UMTS	Universal Mobile Telecommunications System
UpPTS	Uplink Pilot Time Slot
USB	Universal Serial Bus
USIM	Universal Subscriber Identity Module
USSD	Unstructured Supplementary Service Data
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
VCC	Voice Call Continuity

VCO	Voltage Controlled Oscillator
VDSL	Very High-Bit Rate Digital Subscriber Line
VLR	Visitor Location Register
V-MIMO	Virtual MIMO
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WG	Working Group
WLAN	Wireless Local Area Network
WRC	World Radiocommunication Conference
X1AP	X1 Application Protocol

Chapter 1
Remembering the Technological Revolutions

Humankind takes cultural and technological leaps from time to time. The first one was during the Renaissance, more specifically between the fifteenth and sixteenth centuries. But it was only with the invention of the steam engine, already in the eighteenth century, that animal traction, the power of windmills and water wheels, and even with the progressive abolition of slavery, that humanity had a new option of driving force, met the *First Industrial Revolution*, and entered the Age of Steam and machinery. It was then that the first railroads were born. This revolution brought some important consequences, such as the coming of the people from the countryside to the cities, and the replacement of craft work by industrial work, especially in the textile industry. Unfortunately, the emergence of capitalism, creating the bourgeois and proletarian classes, would generate social conflicts in a very short time. The main source of energy was coal, which caused the increase of atmospheric pollution.

The *Second Industrial Revolution* did not take long to emerge, already at the beginning of the twentieth century. It was characterized by the introduction of electricity, telegraph, and telephone, allowing greater communication between peoples. It was indeed a revolution, especially with the possibility of displacement of people and the intensification of the use of railroads. It became a landmark of the internalization of the American territory, beginning a new era of development for its population. The steel industry allowed the construction of ships and the consequent impulse to maritime navigation. The radio, the cinema, the airplane, the combustion engine, and the plastic were also born, and the concept of mass production with Ford was established. The process was totally verticalized and standardized, there was no room for customization. The oligopolies and transnational companies emerged, with a strong concentration of economic power. The chemical and mechanical industries gained prominence. The airplane began to emerge as a means of transportation, competing with railroad and naval transportation. Oil and electricity replaced partially coal as sources of energy generation.

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