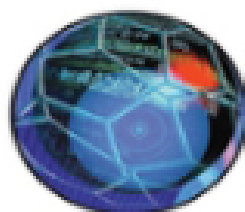




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# TELECOMMUNICATIONS AND DATA COMMUNICATIONS HANDBOOK



RAY HORAK

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# **TELECOMMUNICATIONS AND DATA COMMUNICATIONS HANDBOOK**



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# TELECOMMUNICATIONS AND DATA COMMUNICATIONS HANDBOOK

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**WILEY-INTERSCIENCE**

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To Margaret,  
For whom my love and devotion are infinite and everlasting.

# PREFACE

*I was a civil engineering student in Berlin. Berlin is a nice town and there were many opportunities for a student to spend his time in an agreeable manner, for instance with the nice girls. But instead of that we had to perform big and awful calculations.*

Konrad Zuse, 1910

Those of us who have been involved in communications technology for any number of years have witnessed a transformation that truly is revolutionary. The *big and awful* calculations got even bigger and more awful as the technologies became more complex. Yet, the old voice network remained much the same from the late 1800s through the 1960s—Alexander Graham Bell would have recognized it clearly and understood it completely. Around the time of World War II, however, dramatically new technologies started to make their presence felt. Microwave radio systems began to appear and the foundation for electronic computer systems was laid. Soon thereafter, serious computer systems began to emerge and the need to network them soon became obvious. Over time, the networks themselves gradually became computerized. During the 1940s, the groundwork also was laid for the development of fiber optic transmission systems, which have the ability to transport incredible volumes of information over very long distances and with crystal clarity. Videoconferencing systems began to emerge in the 1960s, although they became practical only in the last few years and have yet to gain widespread acceptance. Local Area Networks (LANs) appeared in the early 1980s with the development and standardization of Ethernet.

The rate of development of the underlying system and network technologies gathered speed in the last 20 years to the point that it has become difficult for even the most technically astute to keep pace with the rate of change, much less the depth and breadth of its impact. Copper wires have yielded to glass fibers. Rather than flowing through networks in continuous streams over connections, information often moves in packets, frames, and cells—sometimes on a connectionless basis. Worldwide, the volume of data traffic now exceeds voice traffic. Increasingly, however, the definition of *data* is no longer confined to computer data. Rather, data now include voice data, video data, image data, and even multimedia data. The networks not only connect telephones and computers but also have become networks of computers themselves. Wired networks no longer are just supplemented by wireless network technologies but in many applications are now being challenged by them, especially where portability and mobility are advantageous. In fact, there now are more cellular phones in the world than there are wireline phones, and a great many people now use cellular phones as their primary and even sole telephone.

Government regulation of monopolies has yielded to free market competition, a trend that began in 1984 with the Modified Final Judgment (MEJ) in the United States. Monopolistic companies have been torn apart in the interests of increased competition only to be reconstituted in altered states when the regulators became convinced that the market, indeed, is the best regulator. Competition has become rife in virtually every sector of the communications world, bringing with it the inherent advantages of alternative choice, improved performance, greater creativity, enhanced technology, lower cost, and a bewildering range of options. Community Antenna Television (CATV) providers have entered the fray, offering voice

services and Internet access over cable systems originally put in place for entertainment TV, and telephone companies are now beginning to offer cable TV service. The Internet has been commercialized and now is available in every corner of the world, supplanting more traditional means of communication and even threatening more traditional voice and data networks. Underlying Internet technologies and protocols have become the foundation for next-generation networks that are virtually certain to replace the circuit-switched network that served us so well for over 100 years. Audio, images, animated images, and even video clips are attached to electronic mail. Once available only to the technically elite digerati working in privileged circumstances with dumb terminals connected to mainframe computers, e-mail now is available to all of us, just about anywhere, and through devices as simple and mobile as cell phones.

This book delivers a comprehensive overview of a wide range of communications systems and networks, including voice, data, video, and multimedia. It is written in plain English and provides a commonsense basis for understanding system and network technologies, their origins and evolutions, and the applications they serve. Further, it discusses the origin, evolution, and nature of many relevant standards and explores remaining standards issues. It also provides a view of the evolution and status of regulation and examines a number of key regulatory issues awaiting resolution. From fundamental concepts through the convergence of voice and data networks, this book offers a single source of information for those who need to understand communications networking.

Reserving most discussion of volts, amps, ohms, algorithms, and the like for a later date and another book by another author, this one weaves a fabric of understanding through a complex set of technologies that underlie

meaningful contemporary and future applications. Further, this book serves as a language primer, providing a short course in the vocabulary and syntax of the language of telecommunications—having read this book, you will be conversant in telecommunications techno-speak. Finally, you will understand how networks work and why.

## **HOW THIS BOOK IS ORGANIZED**

This book is organized into 15 chapters, each of which addresses closely related areas of telecommunications technology and applications, with an eye toward the development of meaningful and cost-effective solutions to legitimate communications requirements. Taken as a whole, this document is a discourse on the origins, current status, and foreseeable future of the networked world. As this book weaves a bit of a story throughout, it is best read from cover to cover. Yet, those who are either impatient or highly focused will find that each chapter is fully capable of standing on its own.

The first several chapters set the stage for understanding the fundamental nature of systems and networks. Chapter 1 offers a set of basic concepts and provides a set of definitions that apply fairly universally across all communications and networks. Chapter 2 offers a detailed explanation of the essentials of transmission systems, both wired and wireless, including twisted pair, coaxial cable, microwave radio, satellite radio, Free Space Optics (FSO), fiber optics, and Power Line Carrier (PLC). Each transmission system is explained in detail and is compared and contrasted with others along a number of critical dimensions.

Chapter 3 is devoted to discussion of premises-based communications systems that primarily support voice applications, although they increasingly support data and even video communications as well. It begins with an



examination of Key Telephone Systems (KTSs) and goes on to examine the several generations of Private Branch exchanges (PBXs) and their capabilities and applications as well as emerging trends. This chapter then examines Centrex and Automatic Call Distributors (ACDs) and concludes with an examination of Computer Telephony (CT) and Internet Protocol (IP)-based voice systems, recent developments that provide tremendous value and efficiency in the processing and management of voice calls.

Chapter 4 is dedicated to electronic messaging technologies and systems, including facsimile, voice processing, electronic mail, Instant Messaging (IM), Short Message Service (SMS), and Multimedia Message Service (MMS). Increasingly, these technologies are viewed as converging into a unified suite of messaging systems, if not a unified information stream, and ultimately into a suite of unified communications systems. Indeed, we see the beginnings of such unification in the Internet, the World Wide Web (WWW), and next-generation IP-based networks.

Chapter 5 concentrates on the conventional Public Switched Telephone Network (PSTN), addressing the origin, evolution, and contemporary nature of the traditional voice network. The underlying technologies, regulatory and standards domains, carrier/service provider domains, and functional domains all are discussed. This chapter also defines the nature and specifics of the signaling and control systems that manage and control the operation of the various network elements in order to ensure that the network functions as a whole. A wide variety of voice network services are defined and illustrated. The chapter concludes with a discussion of a number of critical PSTN issues, including numbering plan administration, number portability, equal access, and the impact of developing IP-based voice networks.

Chapter 6 begins the discussion of data communications, addressing a number of basic concepts. Data terminal equipment, data communications equipment, communications software, and the network are explained as the various functional domains in a data communications network. Protocols are explained, both as a concept and in terms of certain specific, baseline examples. Additionally, a number of key elements of a data communications protocol are discussed, with specific examples provided. Network architectures are examined, with concentration on layered operations models such as that of the Open Systems Interconnection (OSI) Reference Model, which sets the framework for interconnectivity and interoperability. Discussion follows of the various influential standards organizations, with security issues and techniques serving as the conclusion.

Chapter 7 centers on conventional digital and data networks, which are based on the voice network model. Dedicated and circuit-switched networks are discussed in the context of both private and public data networks. Specific data network options, presented in rough order of deployment, include Dataphone Digital Service (DDS), Switched 56 and classic Virtual Private Networks (VPNs), T-Carrier and E-Carrier, X.25 and packet switching, and ISDN.

Chapter 8 steps back from the traditional Wide Area Network (WAN) to explore the world of the LAN, the concept of which was first formally expressed in 1973. Since the first LAN Standard was published in 1982, LANs have grown to the point that they are virtually ubiquitous. This chapter defines LANs in terms of fundamental dimensions such as acceptable transmission media, physical and logical topologies, baseband versus broadband, and media access control. LAN and internetworking devices are discussed, including hubs, bridges, switches, routers, and gateways. Network Operating Systems (NOSs) are presented in the

context of the client/server model, and the fundamentals of LAN internetworking are discussed, with emphasis on the Transmission Control Protocol (TCP)/IP suite. The chapter finishes with a discussion of relatively recent developments including Virtual LANs (VLANs), remote LAN access, high-speed LAN technologies and standards such as 100BaseT and Gigabit Ethernet (GbE), Wireless LANs (WLANs), and Storage Area Networks (SANs).

The next two chapters deal with broadband networking, the high-speed future of communications. Chapter 9 is dedicated to discussion of the physical infrastructure, with the initial focus on recently developed local loop technologies, both wired and wireless. Considerable discussion is devoted to Digital Subscriber Line (DSL), CATV networks, Passive Optical Network (PON), Wireless Local Loop (WLL), and Broadband over Power Line (BPL). Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) and Wavelength Division Multiplexing (WDM) fiber optics, the ultimate in broadband wireline networking, are presented in detail. Chapter 10 focuses on broadband fast packet networks in the forms of Frame Relay (FR) and Asynchronous Transfer Mode (ATM). Discussion of Broadband Integrated Services Digital Network (B-ISDN) and Advanced Intelligent Networks (AINs) conclude the chapter.

Chapter 11 explores the world of wireless communications—not traditional wireless transmission systems such as microwave and satellite, but rather special network alternatives. Popular options examined include Specialized Mobile Radio (SMR), paging, and 2G, 2.5G, and 3G cellular networks. Discussion of Low-Earth Orbiting (LEO) satellites networking rounds out the discussion of wireless communications.

Chapter 12 is devoted to video and multimedia systems and networks. The addition of a visual dimension enhances communications to a very significant extent, although it

places great demands on the supporting networks. As video and multimedia networking is highly capacity intensive and as broadband networks are by no means fully deployed, cost-effective applications remain few. But the future beckons—and the future certainly includes video and multimedia.

Chapter 13 profiles the Internet, including its origins, nature, and structure. The TCP/IP protocol suite is discussed in detail, and QoS (Quality of Service) protocols and mechanisms are explained. Internet access options, equipment, and costs are explored, and issues of regulation and security are discussed. A sample of the more interesting and legitimate applications are visited, most especially that of the World Wide Web (WWW). Voice over IP (VoIP) and Multiprotocol Label Switching (MPLS) are examined in detail.

Chapter 14 addresses network convergence, the coming together of voice, data, video, and entertainment networks. As the networked world becomes increasingly deregulated and as users develop an ever more insatiable appetite for ever more exotic and capacity-intensive applications, a host of companies are vying to satisfy that hunger. CATV providers in the United States now deliver not only entertainment TV service but also voice and high-speed Internet access. Telcos now not only offer voice and high-speed Internet access but also are beginning to offer entertainment TV service. The stakes are enormous in magnitude, as the outcome will shape the future of the networked world. The status, the issues, and the likely outcomes are explored in this chapter.

Chapter 15 rounds out the tour of the networked world with a profile of regulation, both domestic United States and international. The origins, evolution, and current status of regulation are tracked through key legislative, judicial, and agency events. Current regulatory issues are discussed with

emphasis on deregulation, most especially in the context of the Internet and convergence.

Finally, there are two appendixes. The first is a complete listing of every germane abbreviation, acronym, contraction, initialism, and symbol mentioned in this book, and there are hundreds of them. Consider this appendix to be your secret decoder ring. It also provides you with a tool for finding your way through the highly detailed Index, for I do not list subject matter by acronym or abbreviation there. Rather, I list things in the Index in order of the terms, themselves, spelled out fully. The second appendix is a listing of all the standards bodies and special interest groups that I consider to be of relevance. Included in each listing is full contact information, current as of the time of this writing (June 2007).

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# ACKNOWLEDGMENTS

*I am a hoarder of two things: documents and trusted friends.*

Muriel Spark, "Introduction," Curriculum Vitae, 1992

I owe a great deal to many who gave freely of their time, effort, knowledge, experience, expertise, and technical resources to make this book a reality. This book builds on my best-selling *Communications Systems and Networks*, the first edition of which I wrote for John Wiley & Sons in 1997. Through three editions, that first book sold well over 50,000 copies, which makes it a best seller by any measure.

*Communications Systems and Networks* began, and continued to evolve, as a course manual for my public seminars which were sponsored by *Network World* as the cornerstone of its Technical Seminar series. Bill Reinstein of *Network World*, with the encouragement of Mark Miller of DigiNet Corporation, had the courage to depart from his highly successful model and to sponsor a series of seminars on network essentials. The result was a seminar designed to introduce datacommunications and its underlying technologies to a new generation of communications professionals. We also updated more than a few old-timers in the process. Bill Reinstein, Deb Mahler, and Bill Bernardi made it all happen for me at *Network World*. They are great, and I'll always be indebted to them.

Mark Miller, further, saw a book in that first seminar manual. As a first-time author, the first edition of *Communications Systems and Networks* nearly killed me, or so it seemed at the time. I thought that the second edition and third editions would be much easier, but that wasn't the case at all. In the intervening years, the basics never changed, of course—a Hertz is still a Hz, a binary digit is still

a bit, and a wavelength is still a  $\lambda$ —and the basics remain extremely important. Many of the technologies, applications, service providers, and regulations, however, have changed so much as to be almost unrecognizable.

So it is with this book, which builds on the original work but goes into much more technical detail and reflects 10 years of change in the business, including a host of new technologies. This book is a condensation of more than 30 years of my knowledge and experience, hundreds of years of the knowledge and experience of my professional associates (who, thankfully, also are my friends), and hundreds of books and thousands of articles written by others over the last 130 years. I am a hoarder of paper, and I forever will owe those authors a debt of gratitude for putting their thoughts and observations on paper and now on the Web.

Mark Miller, president of the Diginet Corporation, was invaluable in the development of this work, and the predecessor works. As consulting editor, he applied his considerable technical expertise to ensure their absolute integrity. Mark Miller put his name on this book, which gives me great pride. His 20 published books are well respected in the industry, and he kindly allowed me to draw from them extensively during the course of this work. Thank you, Mark, for your friendship and guidance over the last dozen years or so.

Bill Flanagan, president of Flanagan Consulting, served as technical editor, providing a great deal of guidance across a wide range of technologies and applications. Bill is perhaps as knowledgeable as anyone across the full range of subject matter covered in this book and has written 11 excellent books, from which I drew extensively. Technically, Bill is absolutely brilliant and totally unyielding. He went through every word of every draft as if his life depended on making me correct every single Hz, bit, and byte. Bill particularly

likes to quote George Bernard Shaw: "Beware of false knowledge; it is more dangerous than ignorance." Bill is right, as usual. He also happens to be a patient and skilled collaborator with a great sense of balance and a wonderful sense of humor. I also have worked with him on several consulting projects and know him to be incredibly honest, ethical, fair, and just an all around good guy. I have learned over the years to trust very few people very far, but I trust Bill Flanagan a very long way, indeed.

T.S. Eliot is quoted as having said that "Most editors are failed writers, but so are most writers." He certainly didn't have Mark or Bill in mind, for their success as writers clearly has made them better editors and they, in turn, have made me a better writer.

I also am indebted to the tens of thousands of people who have attended my public and private seminars around the world over the past 20 years. I never taught a seminar that I didn't learn something about a technology, or an application, or a way to phrase a concept to make it more understandable. It is such a pleasure to do something that you love, to work with people who are enthusiastic and giving, to learn at the same time that you teach and write, and to get paid for all of it. Thank you all so very much.

Most of all, I am forever indebted to Margaret Horak, my gorgeous and giving wife. We first met over 25 years ago, but circumstances caused us to lose each other for too many years. Quite by accident, we found each other again through an article I wrote in 1990 for my friend Rick Luhmann, who then was editor-in-chief of *Teleconnect Magazine*. That article, quite clearly, was my greatest literary achievement. Margaret's love and devotion have translated into long hours of graphics development in the late hours of the night and on the weekends. Her graphic interpretations of my words have added immeasurably to my works over the last dozen years or so. Also, her common



sense, level-headedness, good nature, and wonderful sense of humor kept me focused and helped me put this all in perspective. Her unyielding love for me has made me work ever harder, every minute of every day, to make her proud. I can only hope that I succeeded, for Margaret truly is my great treasure. Margaret, you are my heart and my soul.

*It is not enough to wire the world if you short-circuit the soul. Technology without heart is not enough.*

Tom Brokaw in a speech at commencement exercises at the  
College of Santa Fe (New Mexico), May 15, 1999

## ABOUT THE AUTHOR

Ray Horak is an internationally recognized author, columnist, lecturer, and consultant. *Communications Systems and Networks*, his previous book for Wiley, was a best seller by any measure, with over 50,000 copies sold through the third edition. He has written well over 100 articles for major publications, a number of white papers and case studies, and several regular columns. Ray serves on the editorial advisory boards of several leading technology periodicals and is on the advisory boards of several colleges and universities. Ray lectures before thousands of communications professionals annually around the world. As an author and a lecturer, he is well known for his ability to explain the most complex technologies in a plain-English, commonsense style—and with more than just a dash of humor, just to keep things in perspective.

Ray's 30 plus years' experience in the networked world began with Southwestern Bell Telephone Company (now AT&T), which was part of the AT&T Bell System (which no longer exists) at the time. Toward the end of his nine-year Bell System career, Southwestern Bell loaned him to AT&T (which bears no resemblance to the *new* AT&T) and Bell Telephone Laboratories (now just Bell Labs, which is a part of Lucent, which was just acquired by Alcatel, a French company, if you can believe that) in a failed-attempt to make him fit the Bell-shaped mold (which has since been broken, for better or worse). Ray then spent nine years with CONTEL (subsequently acquired by GTE, which subsequently was merged into Bell Atlantic along with NYNEX, and the whole mess has been renamed Verizon), where he founded several successful companies, which were later either sold to or merged with other companies (which no longer exist).