

计 算 机 科 学 丛 书

Second Edition

High-Performance Communication Networks

高性能 通信网络

(英文版·第2版)

(美) Jean Walrand, Pravin Varaiya 著
加州大学伯克利分校



机械工业出版社
China Machine Press



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Preface

Much has changed in the networking world since 1995 when we wrote the first edition. "Online" and "Web" joined "Internet" in the popular vocabulary. Cellular phones became as common as the telephone. The "fast" 56 Kbps modem introduced with much publicity in 1998 was quickly surpassed by the megabit-per-second access delivered at home by cable TV and ADSL. And at work, 100 Mbps Ethernet came to the desktop.

The ongoing process of network convergence today is seen in the multi-billion-dollar acquisitions of cable TV operators and data networks by telephone companies. Service providers and equipment manufacturers are beginning to compete in the delivery of quality of service or QoS. That competition will shape the future of ATM and IP.

Advances in wireless communication promise soon to bring "anytime, anywhere" connectivity. Within a decade optical networking will provide orders of magnitude increases in bandwidth. These advances will sustain the networking boom of the 1990s. The social consequences of these developments are difficult to predict, but the technological trends are in place. We wrote the second edition to explain these and related technological advances, some unexpected, others already evident in 1995.

Audience

This book is a uniquely comprehensive study of the major communication networks: data, telephone, cable TV, and wireless. We describe the technologies that help create these networks, explain the protocols and control mechanisms that operate them, and analyze the economic principles that regulate their use

and evolution. We wrote the book for the professionals and students who want such a comprehensive view of networking.

The professionals are those in industry who must evaluate their decisions in the context of the wide role that networking plays in their organizations. They may be networking engineers and computer scientists and their managers, corporate network managers and administrators, operations research and system engineers engaged in network design and operations or in upgrading networking infrastructure. Their decisions often will require an understanding of alternative technologies and performance evaluation and a sense of the pace and direction of innovation. We believe this book will help gain such an understanding.

College seniors and graduate students come to networking with training in electric engineering, computer science, or operations research. They are attracted to the field because of its career opportunities or because a familiarity with networking is now necessary for their own specialization in communications or software engineering or control. They may have taken at most one or, more likely, no undergraduate course in networking. This book will meet the diverse needs of these students and give them a wider, more sophisticated appreciation of this exciting field than other books with a narrow view of networking.

The distinction between these two intended audiences is only nominal. Today's professional was yesterday's student, and the astonishing pace of technical change will tomorrow make him or her a student again. To cope well with that pace requires a comprehensive view, and that is what we believe this book offers.

Approach

We have conducted research in networking for twenty years. For the past fifteen years we have taught an introductory graduate course in networking to students from electrical engineering, computer science, and operations research. For more than ten years we have offered short courses to professionals from the telecommunications industry and to managers in charge of networking in their companies. For the past five years we have had intense interactions with industry, as consultant and technical adviser (PV, JW) and as entrepreneur (JW). This experience in research, teaching, and industry has shaped our book. In all three contexts we find the need for comprehensiveness of coverage and multiple perspectives.

Most books take a narrow view of the subject and approach networking from a single perspective. Typically, it is identified with the Internet or ATM

networks and described through the associated protocols. Or networks are modeled as networks of queues, whose operation is explained through routing algorithms and queuing analyses. Or networks are described through their enabling technology: wireless communication, optics, or switching.

We present a comprehensive study, discussing networks as the need arises from the basis of first principles from communications engineering, computer science, operations research, and economics. We have minimized the use of advanced concepts from these disciplines. It is our hope that the reader can thus gain a greater appreciation of these multiple views and a deeper understanding of how networks are built, how they are used, and who will pay for them. We discuss questions of network performance and control in an intuitive manner and, in a separate chapter, we present the rigorous mathematical argument.

Highlights of the Second Edition

In addition to changes and updates we have made throughout the manuscript, we would like to highlight four major enhancements in the new edition. First, in the previous edition the Internet was treated simply as an example of packet-switched networks. There is now a complete study of the Internet, including the TCP/IP protocol suite and the advances proposed to improve its performance or provide quality of service.

Second, wireless communication, absent from the previous edition, now receives an extended discussion. The growing importance of wireless telephone access and its potential for use in data transfer mandated its inclusion.

Third, rapid advances in the last five years in wave-division multiplexing and wave-selective switching have brought forward the era of optical networking. These advances will eventually change the fundamentals of network design, operations, and economics, and so they are described here.

Lastly, quality of service (QoS) is likely to become an important dimension of competition among providers. The ability to operate networks that can give QoS guarantees is also key to service integration. The economics of QoS and the mechanisms needed to guarantee QoS receive much attention in the new edition.

Contents

We give a chapter by chapter outline, pointing out the changes in the new edition. Chapter 1 contains a brief historical account and explains the principles

of networking. Added are recent estimates of the size, growth, and trends in the telecommunications industry. Chapter 2 explains how network services are produced by layered architectures. A new section summarizes applications that are driving networking demand.

Chapter 3 discusses packet-switched networks using the OSI model, and the important LAN implementations. The 100-Mbps Ethernet, and the replacement of Ethernet hubs by intelligent Ethernet switches that can create virtual local area networks or VLANs, have reorganized enterprise networking. Descriptions of these innovations and gigabit Ethernets are added.

A unified treatment of the Internet and TCP/IP networks occupies Chapter 4. Advances in Internet technology in addressing, faster switching, improvements in the TCP/IP protocol suite, and protocol proposals that seek better control are discussed.

Circuit-switched networks is the subject of Chapter 5. SONET continues to receive emphasis. The most significant addition is the discussion of broadband access networks: cable TV and ADSL, and European proposals advancing passive optical networks. Widespread deployment of these technologies will spur commercial development of broadband services.

Chapter 6 updates the explanation of ATM with important recent work, including internetworking protocols MPOA, and more detailed specifications of PNNI routing and UNI signaling. Much of this work is focused on more efficient ATM support of IP. How ATM and IP will compete and cooperate to provide QoS remains unresolved.

Wireless access has exploded worldwide over the last five years. Primarily used for voice and short message transfers, wireless communication is beginning to be used for data. Chapter 7 explains the characteristics of wireless links and the challenges these characteristics pose for networking. The discussion explains why, unlike the convergence experienced in wireline networks, wireless networking is fragmented and widespread adoption of wireless technology for data remains uncertain.

Chapter 8 provides an accessible discussion, and Chapter 9 explains the mathematical derivations, of network performance and control. The treatment covers circuit-switched, packet-switched, and ATM networks. Resource allocation (bandwidth and priority assignment) to achieve QoS guarantees using window and rate control algorithms are discussed there. The treatment of congestion control is novel.

Chapter 9, devoted to economics, now has a focus based on a formulation of demand for network services. Implementation of QoS guarantees will require pricing of QoS-differentiated services—a major departure from the current practice of flat-rate tariffs for network access. There are analyses of data about

how users value service quality in terms of their willingness to pay. The data are obtained from a market trial at Berkeley that began in April 1998.

Five years ago, wave-division multiplexing (WDM) was limited to laboratory demonstrations. Today, backbone optical links are being upgraded by installing WDM equipment. WDM links with 1 terabit per second speed (equal to the traffic carried by the entire Internet today) will be sold next year. Advances in optical routing and switching in less than ten years will culminate in all-optical networks, offering orders of magnitude higher speeds with a small increase in cost. This could inaugurate another revolution in communications. WDM and optical switching are discussed in Chapter 10. The treatment of optical links in the first edition has been abridged.

Chapter 11 updates the discussion on fast packet switching to incorporate multicasting and some recent work on fast table search. Chapter 12 gives a revised version of the future of networking.

How To Use This Book

This book can be used by industry professionals, or as a text for undergraduate or graduate students. Professionals may study a topic as they need it to facilitate understanding of a particular development. An interesting undergraduate course can be taught around Chapters 1 through 3 and either Chapters 4 and 6, if the audience is primarily from computer science, or Chapters 5 and 7, if the students are primarily from electrical engineering.

We ourselves have used this material in two ways. At Berkeley, we have taught a one-semester, 45-hour introductory graduate course to students from electrical engineering, computer science, and operations research. (The course always attracts some seniors.) Students need no prior exposure to communication networks—the emphasis is on descriptive breadth that conveys the excitement of the technological advances and the challenges posed by speed, distance, and demanding applications. Three or four times each year we have taught a short course to practitioners, between 8 and 20 hours long. The aim there is to provide an overview of recent developments, to decipher trends, and to speculate about opportunities.

Support Materials

Our own lectures make heavy use of the figures in the book. Postscript files of the figures are available from the Web page for our book at <http://www.mkp.com>.

Each chapter of the book ends in problems that test understanding of the material and challenge the reader to use that understanding in situations that may arise in practice. We will keep adding to these problems and post them at the Web site. A solutions manual is also available from the publisher.

Acknowledgments

This book synthesizes the different viewpoints of networking specialists who know more about each view than we do. Inevitably, errors of fact and judgment and balance of treatment have crept into the book. We would be very grateful to our readers for bringing those errors to our attention and for providing us with feedback about their experiences in learning or teaching from this book. We can be reached via e-mail at `{wlr, varaiya}@eecs.berkeley.edu`. We will post corrections and comments at the Web site <http://www.mkp.com>. In this second edition we have incorporated comments from instructors who have used the first edition.

Andrea Goldsmith's chapter on wireless communications discusses a very important technology that was entirely missing in the first edition. We are greatly indebted to her for the excellent discussion of a rapidly evolving field. She can be reached at andrea@ee.stanford.edu.

A draft of the entire manuscript for the second edition was reviewed by Vijay Bhagavath, AT&T Labs; Scott Jordan, Northwestern University; Ivy Hsu, Nortel Networks; and Ramesh Rao, UC, San Diego. Anthony Ephremides, University of Maryland, reviewed Chapter 7; Kevin Fall, UC, Berkeley, reviewed Chapter 4; Riad Hartani, Nortel Networks, reviewed Chapter 6; and Eytan Mediano, MIT Lincoln Laboratory, reviewed Chapter 10.

We are immensely grateful to them for their criticisms as well as their suggestions for improving the book. Most of those suggestions have been incorporated.

Our editor, Jennifer Mann, provided the encouragement and friendly coaxing that we needed to start work on the second edition and to bring it to completion. Her assistant, Karyn Johnson, helped with logistics and with her enthusiasm. Finally, our thanks to our production editor, Heather Collins, who somehow managed a very tight schedule.

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