计 算 机 科 学 丛 书

Second Edition

Communication Networks

A First Course

通信网络基础

（英文版·第2版）

(美) Jean Walrand 著
伯克利加州大学

机械工业出版社
China Machine Press
WCB
McGraw-Hill

计算机科学丛书

通信网络基础

（英文版·第2版）

Communication Networks
A First Course

(Second Edition)

（美） Jean Walrand 著

（伯克利加州大学）

机械工业出版社
China Machine Press

WCB
McGraw-Hill

RISBN 007-1168567

本书版权登记号：图字：01-99-0111

图书在版编目(CIP)数据

通信网络基础(第2版)：英文/(美)沃尔兰德(Walrand, J.)著，－影印版.－北京：机械工业出版社，1999.3

(计算机科学丛书)

书名原文：Communication Networks, A First Course. Second Edition.

ISBN 7-111-07018-6

Ⅰ.通… Ⅱ.沃… Ⅲ.通信网－基本知识－英文 Ⅳ.TN913.2

中国版本图书馆CIP数据核字(1999)第02372号

机械工业出版社（北京市西城区百万庄大街22号 邮政编码 100037）

责任编辑：华 章

北京牛山世兴印刷厂印刷·新华书店北京发行所发行

2005年1月第1版第4次印刷

787mm × 1092mm 1/16 · 22印张

印数：8 001- 9 000册

定价：32.00元

凡购本书，如有倒页、脱页、缺页，由本社发行部调换

本社购书热线：（010）68326294

Preface

A universal revolution is underway in telecommunications. The changes taking place are having a dramatic impact on how individuals and institutions communicate and do business with one another. Government at all levels, retailing and finance, health care, education, and entertainment are among the areas of human activity profoundly affected by the technological advances now underway.

In order to adapt and contribute effectively to these changes engineers and computer scientists need to acquire a solid foundation and understanding of communication networks. The purpose of this text is to help both students and practicing professionals master the background knowledge necessary to participate in and influence ongoing developments in telecommunications.

This book has been written and designed to be accessible to junior-level engineering and computer science students as well as to advanced undergraduate and graduate students with no prior knowledge of communication theory or computer networks. Several of the chapters make use of elementary probability concepts and calculations, which are explained in an appendix. The last chapter of the book uses results from queueing theory, derivations of which are included in another appendix.

Throughout the text, to the extent possible, descriptions of communication networks have been separated from their mathematical analysis to accommodate differing levels of reader comprehension and preparedness.

Many of the implementation details of current networks are transitory; only a few basic principles are likely to survive the current changes in telecommunication technology. This text has been organized and written with a focus on principles—such as the management of complexity, standardized connectivity, and resource sharing—which will continue to guide the development of networks. These principles motivate the layering of software, standardization, hierarchical addressing and routing, and the multiplexing and switching methods implemented in networks. Although many specific networks are discussed in

the book, a continuous effort has been made along the way to emphasize the underlying structure of the field.

Since the first edition was published in 1991, networks have experienced an explosive growth fueled largely by the World Wide Web. Although the mechanisms of networks and their design principles have not substantially changed, the level of interest in the Internet and networking possibilities has increased substantially.

Yet another significant development is the progress made in the deployment of Asynchronous Transfer Mode (ATM) networks. ATM is used for local area network (LAN) backbones, inside LAN switches and Internet protocol (IP) routers, and as an Internet technology.

Other networking technologies are also being pushed forward: fast access links on cable television networks and on telephone lines, wireless access with cellular data networks, better compression for multimedia, and improved security.

This second edition has been rewritten to integrate these developments. The book is now organized by network technology: Internet, LANs, and ATM are the main themes. After explaining how these networks work, we explore more specialized topics. Thus, the book is organized "big picture first" then more specific details.

Organization of the Book

In a nutshell, the book explains the Internet, Ethernet, and a few other local area networks, Asynchronous Transfer Mode, some concepts of digital communication links, and elements of security and compression. You learn how networks work and also how well they work and why.

After 30 years of trials and errors by many clever researchers, it is tempting to enunciate deep design principles that have guided the progress of networks until today. What is closer to the truth is that, as the needs and technology evolve, different solutions emerge as preferable at various times.

A simple story could be told about why networks should be dumb and all the complex tasks should be left to the terminals. This story would make short shrift of the fabulous success of the telephone network and ignore emerging requirements for sophisticated services that a dumb network may not be able to offer. Instead of limiting itself to this simple story, this text discusses the pros and cons of different designs.

The plan of the book is as follows: Chapter 1, "Introduction to Communication Networks," introduces communication networks and reviews their history. The chapter explains circuit switching and packet switching, as well as the store-and-forward and channel-sharing methods used by networks to transport information. Packet switching, the decomposition of information into packets of bits that are then transported along links of the network before being reassembled at the destination, is the procedure that makes efficient and reliable networks possible. The historical overview is designed to provide a sense of the rapid pace of evolution of network technology.

Chapter 2, "The Way Networks Work," examines the most popular networks and explains their main operating principles. The chapter starts with Ethernet then discusses Internet and ATM networks. We then explore general architecture models of networks to situate the specific examples in a general framework. The chapter concludes with some

complementary material that describes some conceptual breakthroughs that have made the information revolution possible.

Chapter 3, "Internet," examines the main protocols and design principles of Internet. The chapter starts with a brief history of this 30-year old network of networks then explains the delivery of packets and the end-to-end operations that supervise these deliveries.

Chapter 4, "Local Area Networks," describes the most widely used local area networks and explains their operating principles and performance characteristics. The chapter focuses on how the networks work and on their main characteristics. The performance of these networks is discussed in complementary sections that can be skipped if desired.

Chapter 5, "Asynchronous Transfer Mode," explains the main features of this transport technology. ATM is a good switching and link technology that is used for backbones of local area networks and for Internet links. This technology may play a role between end terminals that require high-quality connections.

Chapter 6, "Data Link Layer and Retransmission Protocols," explains how reliable transmissions are implemented. This chapter discusses error control mechanisms and congestion control.

Chapter 7, "Physical Layer," explores the digital communication links: optical links, copper lines, and radio waves. The focus is on the characteristics of these links as network components and on the phenomena that limit the bit rate and distance of these links.

Chapter 8, "Security and Compression," explains the main ideas behind these two essential fields. We discuss the major security threats that networked computers face and the protections against those threats. The chapter examines principles behind audio, video, and data compression.

Chapter 9, "Performance Evaluation and Monitoring," discusses the monitoring of networks. The chapter also presents a few simple results on delays in networks and illustrates these results. We conclude with an explanation of the methodology of simulations.

Appendix A, "Probability," is a self-contained introduction to the concepts and methods of probability theory applicable to our topic. For instance, the calculation of average delays of packets subject to retransmission after a timeout is explained. Appendix B, "Queues and Networks of Queues," is an elementary introduction to queueing theory. This appendix explains the analysis of simple queues and networks of queues illustrated in Chapter 9. Appendix C, "Communication Principles," provides some elements of communication theory for readers with little background in that subject.

Each chapter concludes with problems selected to help readers test their understanding of the material in the book. Each problem section includes some more challenging problems, which are marked with an asterisk (*). Selected references are listed at the end of each chapter and a compilation of all references previously cited appears in Appendix D.

Acknowledgments from the first edition

I am grateful to many students and colleagues for their suggestions and their help with this textbook. In particular, N. Bambos (University of California, Los Angeles), D. Browning (Georgia Institute of Technology), A. Fawaz (Teknekron Communication Systems, Berkeley), B. Hajek (University of Illinois, Urbana), T. Hsiao (Purdue University), P. Lapsley (University of California, Berkeley), N. McKeown (University of California, Berkeley),

B. Mukherjee (University of California, Davis), K. J. Pires (University of California, Berkeley), P. Varaiya (University of California, Berkeley), S. Verdu (Princeton University), all have provided valuable comments on the text. P. Konstantopoulos (University of California, Berkeley) formulated the problems in the last four chapters. Part of the text was written when I was enjoying the warm hospitality of F. Baccelli at INRIA in Sophia-Antipolis, France. Marjorie Singer Anderson was an invaluable developmental editor responsible for the final style of the text.

Finally, this book would not have been written without the encouragement and the help of Howard S. Aksen, who is the most graceful, competent, and supportive publisher and editor a technical author can hope for.

Acknowledgments for the second edition

This second edition has benefited from the comments of many kind users of the first edition. I am grateful to all of them and specially to Professor McKeown and his classes at Stanford for trying the manuscript and suggesting improvements. The editing team was most helpful. Without the support of Pat Frederickson, Betsy Jones, and Kelley Butcher, this book would not have been possible.

In addition, special thanks are due to reviewers who provided detailed recommendations, including

Shih-Chun Chang, George Mason University
Costas Courcoubetis, University of Crete
Dr. Richard Edell, University of California at Berkeley
Gale T. Finley, University of District of Columbia
Victor Frost, University of Kansas
Michael Greenwald, Stanford University
Phil Ho, University of California at Berkeley
Herman Hughes, Michigan State University
Doug Jacobson, Iowa State University
Alan G. Konheim, University of California, Santa Barbara
Richard La, University of California at Berkeley
Stephane Lafortune, University of Michigan
Jean-Yves Le Boudec EPFL, Lausanne, Switzerland
Willis Marti, Texas A&M University
Jeonghoon Mo, University of California at Berkeley
W. Melody Moh, San Jose State University
Lawrence J. Osborne, Lamar University
Bart Preneel, University of Leuven, Belgium
Gene Hill Price, Old Dominion University
Matt Siler, University of California at Berkeley

Mark Soper, University of California at Berkeley
Robert L. Stafford, Temple University
William Teter, SUNY, Plattsburgh
K. Wendy Tang, The State University of New York at Stony Brook
Pramod Visnanath, University of California at Berkeley
Laurence Yogman, Stanford University
James M. Westall, Clemson University

Contents

CHAPTER 1

Introduction to Communication Networks

1.1 What Are Communication Networks?

Communication networks are arrangements of hardware and software that allow users to exchange information. This very broad definition will help you begin learning about one of the fastest-growing areas in electrical engineering and computer science. Once we examine some common communication networks, we will develop a more precise definition. In this chapter we will elaborate on the importance of this field and review its evolution.

The telephone network is the most familiar and ubiquitous communication network. It is designed for voice transmission. An office computer network is a communication network used by organizations to connect personal computers and workstations so they may share programs and data and to link those computers to printers and, possibly, to some other peripherals (e.g., file servers that provide mass storage or plotters). Computer networks also are used in manufacturing plants to connect machine tools, robots, and sensors. The Internet is a network of computer networks that covers most of the world and allows millions of users to exchange messages and computer files and some limited video and audio signals.

Although all these systems are communication networks, they are quite different in the information that they transmit and in the way they are used. Nevertheless, they operate on similar principles. The unifying characteristics of all networks help us develop a definition of communication networks that describes the arrangements of hardware and software that we study in this text. Each system described is designed to exchange *information*, which may be voice, sounds, graphics, pictures, video, text, or data, among *users*. Most often the users are humans, but they also can be computer programs or devices. Before the information is transmitted, it is converted into bits (zeros or ones). Then the bits are sent to a receiver as electrical or optical signals (electromagnetic waves, to be more precise). Finally, the information is reconstructed from the received bits. This transmission method, called *digital transmission*, reduces the transmission errors.