大学计算机教育丛书（影印版）

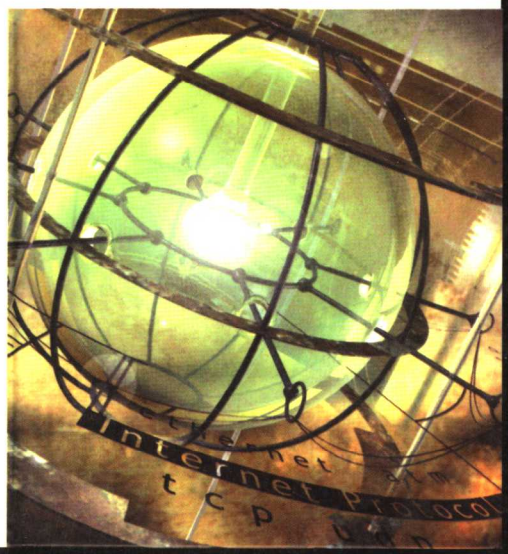
Communication Networks

Fundamental Concepts and key Architectures

Alberto Leon-Garcia,Indra widjaja.

通信网

基本概念
与
主体结构



清华大学出版社
http://www.tup.tsinghua.edu.cn
WCB
McGraw-Hill
http://www.mhhe.com

Communication Networks

通信网

基本概念与主体结构

Communication Networks

Fundamental Concepts and key Architectures

通 信 网

基本概念与主体结构

Alberto Leon-Garcia

Indra Widjaja

清华大学出版社
WCB
McGraw-Hill

(京)新登字 158 号

北京市版权局著作权合同登记号: 01-2000-2900

图书在版编目(CIP)数据

通信网: 基本概念与主体结构: 英文/利昂-加西亚(Leon-Garcia, A.),维德加加(Widjaja, I.)编著. -影印版. -北京: 清华大学出版社, 2000.11
(大学计算机教育丛书)
ISBN 7-302-04123-7

Ⅰ.通… Ⅱ.①利…②维… Ⅲ.通信网-基本知识-英文 Ⅳ.TN915

中国版本图书馆 CIP 数据核字(2000)第 78323 号

出版者: 清华大学出版社(北京清华大学学研大厦,邮编 100084)
http://www.tup.tsinghua.edu.cn
印刷者: 清华大学印刷厂
发行者: 新华书店总店北京发行所
开 本: 787×960 1/16 印张: 56
版 次: 2000 年 12 月第 1 版 2000 年 12 月第 1 次印刷
书 号: ISBN 7-302-04123-7/TP·2434
印 数: 0001~6000
定 价: 72.00 元

出版者的话

今天，我们的大学生、研究生和教学、科研工作者，面临的是一个国际化的信息时代。他们将需要随时查阅大量的外文资料；会有更多的机会参加国际性学术交流活动；接待外国学者；走上国际会议的讲坛。作为科技工作者，他们不仅应有与国外同行进行口头和书面交流的能力，更为重要的是，他们必须具备极强的查阅外文资料获取信息的能力。有鉴于此，在原国家教委所颁布的“大学英语教学大纲”中有一条规定：专业阅读应作为必修课程开设。同时，在大纲中还规定了这门课程的学时和教学要求。有些高校除开设“专业阅读”课之外，还在某些专业课拟进行英语授课。但教、学双方都苦于没有一定数量的合适的英文原版教材作为教学参考书。为满足这方面的需要，我们陆续精选了一批国外计算机科学方面最新版本的著名教材，进行影印出版。我社获得国外著名出版公司和原著作者的授权将国际先进水平的教材引入我国高等学校，为师生们提供了教学用书，相信会对高校教材改革产生积极的影响。

我们欢迎高校师生将使用影印版教材的效果、意见反馈给我们，更欢迎国内专家、教授积极向我社推荐国外优秀计算机教育教材，以利我们将《大学计算机教育丛书（影印版）》做得更好，更适合高校师生的需要。

清华大学出版社

《大学计算机教育丛书（影印版）》项目组

1999.6

PREFACE

OBJECTIVE

Communication networks have entered an era of fundamental change where market and regulatory forces have finally caught up with the relentless advance of technology, as evidenced by the following:

- The explosive growth of multimedia personal computing and the World Wide Web, demonstrating the value of network-based services.
- The deregulation of the telecommunications industry opening the door to new access network technologies (digital cellular systems, cable modems, high-speed DSL modems, direct broadcast satellite systems, satellite constellation networks, broadband wireless cable) that will cause telecommunications infrastructure to migrate towards a flexible packet-based backbone network technology.
- The explosion in available bandwidth due to optical transmission technology and the entry of new national and global backbone service providers.
- The emergence of the Internet suite of protocols as the primary means for providing ubiquitous connectivity across the emerging network of networks.
- The predominance of data traffic over voice traffic dictating that future networks will be designed for data, and that telephone voice service must eventually operate—possibly solely—over the Internet.

Thus, the main architectural elements of the network of networks that will emerge in the next ten years are becoming more evident. The purpose of this book is to introduce electrical engineering, computer engineering, and computer science students to fundamental network architecture concepts and to their application in these emerging networks.

TARGET COURSES

The book is designed for introductory one-semester or one-year courses in communication networks in the upper-level undergraduate and first-year graduate programs. The second half of the book can be used in more advanced courses that deal with the details of current network architectures. The book can also be used by engineering and computer professionals seeking an introduction to networking.

As prerequisites the book assumes a general knowledge of computer systems and programming, and elementary calculus. In certain parts of the text, knowledge of elementary probability is useful but not essential.

APPROACH AND CONTENT

Networks are extremely complex systems consisting of many components whose operation depends on many processes. To understand networks it is essential that students be exposed to *the big picture of networks* that allows them to see how the various parts of the network fit into one whole. We have designed the book so that students are presented with this big picture at the beginning of the book. The students then have a context in which to place the various topics as they progress through the book.

The book attempts to provide a *balanced view of all important elements of networking*. This is a very big challenge in the typical one-semester introductory course which has very limited time available. We have organized the book so that all the relevant topics can be covered at some minimum essential level of detail. Additional material is provided that allows the instructor to cover certain topics in greater depth.

The book is organized into four sections: the first section provides the big picture; the second section develops fundamental concepts; the third section deals with advanced topics and detailed network architectures; and in the fourth section two appendices provide important supporting material.

Big Picture First: Networks, Services, and Layered Architectures

This section begins in Chapter 1 with a discussion of network-based applications that the student is familiar with (World Wide Web, e-mail, telephone call, and home video entertainment). These examples are used to emphasize that modern networks must be designed to support a wide range of applications. We then discuss the evolution of telegraph, telephone, and computer networks, up to the present Internet. This historical discussion is used to identify the essential functions that are common to all networks. We show how there is usually more than one way to carry out a function, for example, connectionless versus circuit-switched transfer of information, and that the specific structure of a network is determined by a combination of technological, market, and regulatory factors at a given point in time.

The view of the network as a provider of services to applications is developed in Chapter 2. We consider the e-mail and Web browsing applications, and we explain the application layer protocols that support these, namely HTTP, SMTP, and DNS. We also explain how these protocols in turn make use of the communication services provided by TCP and UDP. Together these examples motivate the notion of layering, leading naturally to a discussion of the OSI reference model. A detailed example is used to show how Ethernet, PPP, IP, TCP, and UDP work together to support the application layer protocols. The key notions of addressing and encapsulation are developed in this example. Chapter 2 concludes with two optional sections: an introduction to sockets and an introduction to additional application layer protocols and to several TCP/IP utilities. We believe that the student will be familiar with some of the application layer topics,

and so Chapter 2 can serve as a bridge to the less visible topics relating to the internal operation of a network. Sockets and TCP/IP utilities provide the basis for very useful and practical exercises and experiments that provide students with some "hands on" networking experience.

Fundamental Network Architecture Concepts

The second section develops the fundamental concepts of network architecture, proceeding from the physical layer to the network layer. We complement the discussion of fundamental concepts with sections that explore trends in network architecture.

Chapter 3 deals with digital transmission including error detetection. We identify the bit rate requirements that applications impose on the network, and then we examine the transmission capabilities of existing and emerging networks. We introduce the relationship between bandwidth, bit rate, and signal-to-noise ratio, and then develop the basic digital transmission techniques, using modem standards as examples. The properties of various media (copper wires, coaxial cable, radio, optical fiber) and their possible role in emerging access networks are then discussed. This chapter contains more material than can be covered in the introductory course, so it is written to allow the instructor to pick and choose what sections to cover.

Chapter 4 discusses digital transmission systems and the telephone network. The first few sections deal with properties of current and emerging optical networks. The digital multiplexing hierarchy and the SONET standard are introduced. We develop the fault recovery features of SONET rings and we emphasize the capability of SONET optical networks to create arbitrary logical topologies under software control. We then introduce wavelength division multiplexing and explain how WDM optical networks share the flexible network configuration features of SONET. The design of circuit switches for traditional telephone networks and for future optical networks is discussed next. The latter sections deal with telephone networks, with a focus on the signaling system that enables telephone service and associated enhanced services, e.g., caller ID, 800-call. We consider the telephone network and the layered architecture of its signaling system. We discuss the frequency reuse concept and its application in telephone and satellite cellular networks.

Chapter 5 is the usual place to discuss data link controls. Instead of dealing immediately with this topic, we first introduce the notions of peer-to-peer protocols and service models. ARQ protocols that provide reliable transfer service are developed in detail as specific examples of peer-to-peer protocols. The detailed discussion gives the student an appreciation of what is involved in implementing a protocol. The end-to-end and hop-by-hop approaches to deploying peer-to-peer protocols are compared, and additional examples of peer-to-peer protocols are introduced for flow control and for timing recovery. We also preview the reliable stream service provided by TCP. The details of HDLC and

PPP data link standards are then presented. Finally we discuss the sharing of a data link by multiple packet flows and introduce the notion of multiplexing gain.

Chapter 6 deals with the transfer information across shared media, using LANs and wireless networks as specific examples. We begin with an introduction to broadcast networks and to approaches to sharing a medium. We explain the function of LANs and their placement in the OSI reference model. We consider random access as well as scheduling approaches to transferring packets across a shared medium. We examine the impact of delay-bandwidth product on performance, and we show why this dictates the evolution of Ethernet from a shared medium access technique to a switched technique. In addition to token ring and FDDI LANs, we also present a full discussion of the IEEE 802.11 wireless LAN standard. We also discuss FDMA, TDMA, and CDMA channelization approaches to sharing media and we show their application in various existing cellular radio networks. We have taken great care to make the difficult topic of CDMA accessible to the student.

Chapter 7 deals with packet switching networks. To provide a context for the chapter we begin by presenting an end-to-end view of packet transfer across the Internet. We then develop the notions of datagram and virtual-circuit packet switching, using IP and ATM as examples. We introduce basic design approaches to packet switches and routers. Shortest-path algorithms and the link state and distance vector approaches to selecting routes in a network are presented next. ATM and the concept of label switching are introduced, and the relationship between Quality-of-Service and traffic shaping, scheduling and call admission control is developed. The chapter includes a discussion of TCP and ATM congestion control.

Key Architectures and Advanced Topics

The third section shows how the fundamental networking concepts are embodied in two key network architectures, ATM and TCP/IP. The section also deals with the interworking of ATM and TCP/IP, as well as with enhancements to TCP/IP to provide secure and more responsive communications.

Chapter 8 presents a detailed discussion of TCP/IP protocols. We examine the structure of the IP layer and the details of IP addressing, routing, and fragmentation and reassembly. We discuss the motivation and present the features of IPv6. We introduce UDP, and examine in detail how TCP provides reliable stream service and flow control end-to-end across a connectionless packet network. RIP, OSPF, and BGP are introduced as protocols for synthesizing routing tables in the Internet. Multicast routing is also introduced.

Chapter 9 deals with the architecture of ATM networks. The ATM layer is explained, and Quality-of-Service and the ATM network service categories are presented. The various types of ATM adaptation layer protocols are discussed next. ATM signaling and PNNI routing are introduced.

Chapter 10 deals with the interworking of IP and ATM and with proposed enhancements to IP. We consider the various approaches for operating IP over

ATM networks. We then introduce Multiprotocol Label Switching which is the most promising example for operating IP over ATM and other link layer protocols. Finally we introduce RSVP, Integrated Services IP, and Differentiated Services IP which together provide mechanisms for providing Quality-of-Service over IP.

Chapter 11 provides an introduction to network security protocols. The various categories of threats that can arise in a network are used to identify various types of security requirements. Secret key and public key cryptography are introduced and their application to providing security is discussed. We develop protocols that provide security across insecure networks and we introduce protocols for establishing security associations and for managing keys. These general protocols are then related to the IP security protocols and to transport layer security protocols.

Chapter 12 deals with multimedia information and networking. We begin with an introduction to the properties of image, audio, and video signals. We discuss the various compression schemes that are applied to obtain efficient digital representations, and we describe the relevant compression standards. We then introduce the RTP protocol for transmitting real-time information across the Internet. Finally, we close the loop in the discussion of "plain old telephone service" by reviewing the various signaling protocols that are being developed to support multimedia communications in general, and IP telephony in particular, over the Internet.

The book ends with an Epilogue that discusses trends in network architecture and identifies several areas that are likely to influence the development of future networks.

Appendices

Appendix A deals with network performance models. Network performance is an integral part of network design and operation. In the text we use quantitative examples to illustrate the tradeoffs involved in various situations. We believe that an intuition for performance issues can be developed without delving into the underlying mathematics. Delay and loss performance results are introduced in the sections that deal with multiplexing, trunking, and medium access control. In these sections, the dynamics of the given problem are described and the key performance results are presented. The purpose of Appendix A is to develop the analysis of the performance models that are cited in the text. These analyses may be incorporated into more advanced courses on communication networks.

Appendix B provides an introduction to network management. The basic functions and structure of a network management system are introduced as well as the Simple Network Management Protocol (SNMP). We present the rules for describing management information, as well as the collection of objects, called Management Information Base, that are managed by SNMP. We also introduce remote monitoring (RMON) which offers extensive network diagnostic, planning, and performance information.

HOW TO USE THIS BOOK

The book was designed to support a variety of introductory courses on computer and communication networks. By appropriate choice of sections, the instructor can make adjustments to provide a desired focus or to account for the background of the students. Chapter 1 to Chapter 8 contain the core material (and more) that is covered in the typical introductory course on computer networks. For example, at the University of Toronto a 40 lecture-hour introductory undergraduate course in computer networks covers the following: Chapter 1 (all); Chapter 2 (all) including a series of lab exercises using sockets; Chapter 3 (sections 3.1, 3.2, 3.5, 3.6, 3.8.1 to 3.8.5); Chapter 4 (sections 4.1 to 4.3); Chapter 5 (all); Chapter 6 (sections 6.1 to 6.4, 6.6.1, 6.6.2); Chapter 7 (all); and Chapter 8 (sections 8.1 to 8.5). For courses that spend more time on the material in Chapter 8 or later, the material from Chapters 3 and 4 can be dropped altogether. The book contains enough material for a two-semester course sequence that provides an introductory course on computer networks followed by a course on emerging network protocols.

PEDAGOGICAL ELEMENTS

The book contains the following pedagogical elements:

- *Numerous Figures.* Network diagrams, time diagrams, performance graphs, state transition diagrams are essential to effectively convey concepts in networking. The 574 figures in the book are based on a set of Microsoft PowerPoint® course presentations that depend heavily on visual representation of concepts. A set of these presentation charts is available to instructors.
- *Numerous Examples.* The discussion of fundamental concepts is accompanied with examples illustrating the use of the concept in practice. Numerical examples are included in the text wherever possible.
- *Text Boxes.* Commentaries in text boxes are used to discuss network trends and interesting developments, to speculate about future developments, and to motivate new topics.
- *Problems.* The authors firmly believe that learning must involve problem solving. The book contains 589 problems. Each chapter includes problems with a range of difficulties from simple application of concepts to exploring, developing or elaborating various concepts and issues. Quantitative problems range from simple calculations to brief case studies exploring various aspects of certain algorithms, techniques, or networks. Simple programming exercises involving sockets and TCP/IP utilities are included where appropriate.
- An *Instructor's Solutions Manual* is available from McGraw-Hill.
- *Chapter Introductions.* Each chapter includes an introduction previewing the material covered in the chapter and in the context of the "big picture".

- *Chapter Summaries and Checklist of Important Terms.* Each chapter includes a summary that reiterates the most important concepts. A checklist of important terms will aid the student in reviewing the material.
- *References.* Each chapter includes a list of references. Given the introductory nature of the text, references concentrate on pointing to more advanced materials. Reference to appropriate Internet Engineering Taskforce (IETF) RFCs and research papers is made where appropriate, especially with more recent topics.
- *A web site.* The following Web site contains links to the on-line version of the solutions manual, the Powerpoint slides*, author information, and other related information: www.mhhe.com/leon-garcia.

ACKNOWLEDGMENTS

The material in the book was developed over many years in introductory as well as advanced courses in networking, both in regular undergraduate and graduate programs as well as in programs with an orientation towards professional practice. We acknowledge the feedback from the many students who participated in these courses and who used various versions of the manuscript. In particular we thank the students from CETYS University. We also acknowledge the input of the graduate students who served as teaching assistants in these courses, especially Dennis Chan, Yasser Rasheed, Mohamed Arad, Massoud Hashemi, Hasan Naser, and Andrew Jun.

We thank Anindo Banerjea, Raouf Boutaba, Michael Kaplan, and Gillian Woodruff for many exciting conversations on networking. Anindo and Raouf graciously provided some of the material that is presented in Chapter 2. We would also like to thank Anwar Elwalid and Debasis Mitra for their continued encouragement and interest in the book. We thank Yau-Ren Jenq for reviewing the fair queueing discussions in detail.

We are especially grateful to Irene Katzela for testing the manuscript in her courses. We also thank Ray Pickholtz for testing various versions of the text, including the beta version, and for his many valuable suggestions and his continued encouragement.

We thank the reviewers for their many useful comments on the various versions of the manuscript: Subrata Banerjee (Stevens Institute of Technology), John A. Copeland (Georgia Institute of Technology), Mario Gerla (UCLA), Rohit Goyal (Ohio State University), Gary Harkin (Montana State University), Melody Moh (San Jose State University), Kihong Park (Purdue University–West Lafayette), Raymond L. Pickholtz (The George Washington University), Chunming Qiao (SUNY Buffalo), Arunabha Sen

*The *Instructor's Solutions Manual* and the Powerpoint slides are password protected. See the website for information on how to obtain one.

(Arizona State University), Stuart Tewksbury (West Virginia University), and Zhi-li Zhang (University of Minnesota).

We would also like to acknowledge the many friends from Nortel Networks for showing us the many facets of networking. We thank Sidney Yip for opening the door to many years of interaction. We also thank Richard Vickers, Marek Wernik, and Jim Yan for many illuminating conversations over the years. We especially thank Tony Yuen for sharing his vast knowledge of the networking industry and for continuously showing how the big picture is actually bigger!

We thank Eric Munson from McGraw-Hill for persuading us to take the plunge with this project, and Betsy Jones, Executive Editor, for providing decisive support at key times. In addition we thank the production team at McGraw-Hill for their patience, ideas, and continued support, especially Kelley Butcher and Jim Labeots.

IW would like to thank to his wife Liesye for the constant encouragement and for putting up with him during the many nights and weekends spent writing the book, especially during the final stages.

Finally, ALG would like to thank his soulmate, Karen Carlyle, who went beyond the usual putting up with an author's neglect, to assuming the role of project manager, designer, transcriber and real-time editor for the book.

With the help of the many reviewers, professors, and students who have used early versions of this book we have tried to make the complex and fluid topic of network architecture as approachable, up-to-date and error-free as possible. We welcome all comments and suggestions on how to improve the text. Please contact us via the text's website with any ideas you may have.

Alberto Leon-Garcia
Indra Widjaja

CONTENTS