

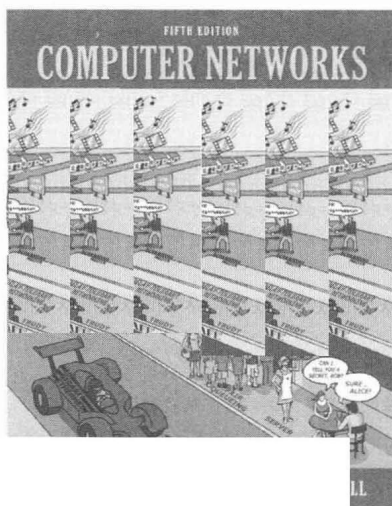


经 典 原 版 书 库

# 计算机网络

(英文版·第5版)

*Computer Networks*  
(Fifth Edition)



(荷) Andrew S. Tanenbaum  
阿姆斯特丹Vrije大学

(美) David J. Wetherall 著  
华盛顿大学西雅图分校



机械工业出版社  
China Machine Press

Original edition, entitled COMPUTER NETWORKS, 5E, 9780132553179 by TANENBAUM, ANDREW S.; WETHERALL, DAVID J., published by Pearson Education, Inc., publishing as Prentice Hall, Copyright © 2011, 2003, 1996, 1989, 1981.

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage retrieval system, without permission from Pearson Education, Inc.

China edition published by PEARSON EDUCATION ASIA LTD., and CHINA MACHINE PRESS, Copyright © 2011.

This edition is manufactured in the People's Republic of China, and is authorized for sale and distribution in the People's Republic of China exclusively (except Taiwan, Hong Kong SAR and Macau SAR).

本书英文影印版由Pearson Education Asia Ltd.授权机械工业出版社独家出版。未经出版者书面许可,不得以任何方式复制或抄袭本书内容。

仅限于中华人民共和国境内(不包括中国香港、澳门特别行政区和中国台湾地区)销售发行。本书封面贴有Pearson Education(培生教育出版集团)激光防伪标签,无标签者不得销售。

封底无防伪标均为盗版

版权所有,侵权必究

本书法律顾问 北京市展达律师事务所

本书版权登记号:图字:01-2011-5522

图书在版编目(CIP)数据

计算机网络(英文版·第5版)/(荷)塔嫩鲍姆(Tanenbaum, A. S.)等著. —北京:机械工业出版社, 2011.9

(经典原版书库)

书名原文:Computer Networks, Fifth Edition

ISBN 978-7-111-35925-8

I. 计… II. 塔… III. 计算机网络—英文 IV. TP393

中国版本图书馆CIP数据核字(2011)第191970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:迟振春

北京京师印务有限公司印刷

2011年10月第1版第1次印刷

170mm × 242mm • 59.5印张

标准书号:ISBN 978-7-111-35925-8

定价:99.00元

凡购本书,如有缺页、倒页、脱页,由本社发行部调换

客服热线:(010) 88378991; 88361066

购书热线:(010) 68326294; 88379649; 68995259

投稿热线:(010) 88379604

读者信箱:hzsj@hzbook.com

# 出版者的话

文艺复兴以降，源远流长的科学精神和逐步形成的学术规范，使西方国家在自然科学的各个领域取得了垄断性的优势；也正是这样的传统，使美国在信息技术发展的六十多年间名家辈出、独领风骚。在商业化的进程中，美国的产业界与教育界越来越紧密地结合，计算机学科中的许多泰山北斗同时身处科研和教学的最前线，由此而产生的经典科学著作，不仅擘划了研究的范畴，还揭示了学术的源变，既遵循学术规范，又自有学者个性，其价值并不会因年月的流逝而减退。

近年，在全球信息化大潮的推动下，我国的计算机产业发展迅猛，对专业人才的需求日益迫切。这对计算机教育界和出版界都既是机遇，也是挑战；而专业教材的建设在教育战略上显得举足轻重。在我国信息技术发展时间较短的现状下，美国等发达国家在其计算机科学发展的几十年间积淀和发展的经典教材仍有许多值得借鉴之处。因此，引进一批国外优秀计算机教材将对我国计算机教育事业的发展起到积极的推动作用，也是与世界接轨、建设真正的世界一流大学的必由之路。

机械工业出版社华章公司较早意识到“出版要为教育服务”。自1998年开始，我们就将工作重点放在了遴选、移译国外优秀教材上。经过多年的不懈努力，我们与Pearson, McGraw-Hill, Elsevier, MIT, John Wiley & Sons, Cengage等世界著名出版公司建立了良好的合作关系，从他们现有的数百种教材中甄选出Andrew S. Tanenbaum, Bjarne Stroustrup, Brian W. Kernighan, Dennis Ritchie, Jim Gray, Alfred V. Aho, John E. Hopcroft, Jeffrey D. Ullman, Abraham Silberschatz, William Stallings, Donald E. Knuth, John L. Hennessy, Larry L. Peterson等大师名家的一批经典作品，以“计算机科学丛书”为总称出版，供读者学习、研究及珍藏。大理石纹理的封面，也正体现了这套丛书的品位和格调。

“计算机科学丛书”的出版工作得到了国内外学者的鼎力襄助，国内的专家不仅提供了中肯的选题指导，还不辞劳苦地担任了翻译和审校的工作；而原书的作者也相当关注其作品在中国的传播，有的还专程为其书的中译本作序。迄今，“计算机科学丛书”已经出版了近百个品种，这些书籍在读者中树立了良好的口碑，并被许多高校采用为正式教材和参考书籍。其影印版“经典原版书库”作

#### 4 · 出版者的话

为姊妹篇也被越来越多实施双语教学的学校所采用。

权威的作者、经典的教材、一流的译者、严格的审校、精细的编辑，这些因素使我们的图书有了质量的保证。随着计算机科学与技术专业学科建设的不断完善和教材改革的逐渐深化，教育界对国外计算机教材的需求和应用都将步入一个新的阶段，我们的目标是尽善尽美，而反馈的意见正是我们达到这一终极目标的重要帮助。华章公司欢迎老师和读者对我们的工作提出建议或给予指正，我们的联系方法如下：

华章网站：[www.hzbook.com](http://www.hzbook.com)

电子邮件：[hzsj@hzbook.com](mailto:hzsj@hzbook.com)

联系电话：(010) 88379604

联系地址：北京市西城区百万庄南街1号

邮政编码：100037



华章教育

华章科技图书出版中心

*To Suzanne, Barbara, Daniel, Aron, Marvin, Matilde,  
and the memory of Bram, and Sweetie  $\pi$  (AST)*

*To Katrin, Lucy, and Pepper (DJW)*

This book is now in its fifth edition. Each edition has corresponded to a different phase in the way computer networks were used. When the first edition appeared in 1980, networks were an academic curiosity. When the second edition appeared in 1988, networks were used by universities and large businesses. When the third edition appeared in 1996, computer networks, especially the Internet, had become a daily reality for millions of people. By the fourth edition, in 2003, wireless networks and mobile computers had become commonplace for accessing the Web and the Internet. Now, in the fifth edition, networks are about content distribution (especially videos using CDNs and peer-to-peer networks) and mobile phones are small computers on the Internet.

### **New in the Fifth Edition**

Among the many changes in this book, the most important one is the addition of Prof. David J. Wetherall as a co-author. David brings a rich background in networking, having cut his teeth designing metropolitan-area networks more than 20 years ago. He has worked with the Internet and wireless networks ever since and is a professor at the University of Washington, where he has been teaching and doing research on computer networks and related topics for the past decade.

Of course, the book also has many changes to keep up with the: ever-changing world of computer networks. Among these are revised and new material on

- Wireless networks (802.12 and 802.16)
- The 3G networks used by smart phones
- RFID and sensor networks
- Content distribution using CDNs
- Peer-to-peer networks
- Real-time media (from stored, streaming, and live sources)
- Internet telephony (voice over IP)
- Delay-tolerant networks

A more detailed chapter-by-chapter list follows.

Chapter 1 has the same introductory function as in the fourth edition, but the contents have been revised and brought up to date. The Internet, mobile phone networks, 802.11, and RFID and sensor networks are discussed as examples of computer networks. Material on the original Ethernet—with its vampire taps—has been removed, along with the material on ATM.

Chapter 2, which covers the physical layer, has expanded coverage of digital modulation (including OFDM as widely used in wireless networks) and 3G networks (based on CDMA). New technologies are discussed, including Fiber to the Home and power-line networking.

Chapter 3, on point-to-point links, has been improved in two ways. The material on codes for error detection and correction has been updated, and also includes a brief description of the modern codes that are important in practice (e.g., convolutional and LDPC codes). The examples of protocols now use Packet over SONET and ADSL. Sadly, the material on protocol verification has been removed as it is little used.

In Chapter 4, on the MAC sublayer, the principles are timeless but the technologies have changed. Sections on the example networks have been redone accordingly, including gigabit Ethernet, 802.11, 802.16, Bluetooth, and RFID. Also updated is the coverage of LAN switching, including VLANs.

Chapter 5, on the network layer, covers the same ground as in the fourth edition. The revisions have been to update material and add depth, particularly for quality of service (relevant for real-time media) and internetworking. The sections on BGP, OSPF and CIDR have been expanded, as has the treatment of multicast routing. Anycast routing is now included.

Chapter 6, on the transport layer, has had material added, revised, and removed. New material describes delay-tolerant networking and congestion control in general. The revised material updates and expands the coverage of TCP congestion control. The material removed described connection-oriented network layers, something rarely seen any more.

Chapter 7, on applications, has also been updated and enlarged. While material on DNS and email is similar to that in the fourth edition, in the past few years there have been many developments in the use of the Web, streaming media and content delivery. Accordingly, sections on the Web and streaming media have been brought up to date. A new section covers content distribution, including CDNs and peer-to-peer networks.

Chapter 8, on security, still covers both symmetric and public-key cryptography for confidentiality and authenticity. Material on the techniques used in practice, including firewalls and VPNs, has been updated, with new material on 802.11 security and Kerberos V5 added.

Chapter 9 contains a renewed list of suggested readings and a comprehensive bibliography of over 300 citations to the current literature. More than half of these are to papers and books written in 2000 or later, and the rest are citations to classic papers.



### List of Acronyms

Computer books are full of acronyms. This one is no exception. By the time you are finished reading this one, the following should ring a bell: ADSL, AES, AJAX, AODV, AP, ARP, ARQ, AS, BGP, BOC, CDMA, CDN, CGI, CIDR, CRL, CSMA, CSS, DCT, DES, DHCP, DHT, DIFS, DMCA, DMT, DMZ, DNS, DOCSIS, DOM, DSLAM, DTN, FCFS, FDD, FDDI, FDM, FEC, FIFO, FSK, FTP, GPRS, GSM, HDTV, HFC, HMAC, HTTP, IAB, ICANN, ICMP, IDEA, IETF, IMAP, IMP, IP, IPTV, IRTF, ISO, ISP, ITU, JPEG, JSP, JVM, LAN, LATA, LEC, LEO, LLC, LSR, LTE, MAN, MFJ, MIME, MPEG, MPLS, MSC, MTSO, MTU, NAP, NAT, NRZ, NSAP, OFDM, OSI, OSPF, PAWS, PCM, PGP, PIM, PKI, POP, POTS, PPP, PSTN, QAM, QPSK, RED, RFC, RFID, RPC, RSA, RTSP, SHA, SIP, SMTP, SNR, SOAP, SONET, SPE, SSL, TCP, TDD, TDM, TSAP, UDP, UMTS, URL, VLAN, VSAT, WAN, WDM, and XML. But don't worry. Each will appear in **boldface type** and be carefully defined before it is used. As a fun test, see how many you can identify *before* reading the book, write the number in the margin, then try again *after* reading the book.

### How to Use the Book

To help instructors use this book as a text for courses ranging in length from quarters to semesters, we have structured the chapters into core and optional material. The sections marked with a "\*" in the table of contents are the optional ones. If a major section (e.g., 2.7) is so marked, all of its subsections are optional. They provide material on network technologies that is useful but can be omitted from a short course without loss of continuity. Of course, students should be encouraged to read those sections as well, to the extent they have time, as all the material is up to date and of value.

### Instructors' Resource Materials

The following protected instructors' resource materials are available on the publisher's Web site at [www.pearsonhighered.com/tanenbaum](http://www.pearsonhighered.com/tanenbaum). For a username and password, please contact your local Pearson representative.

- Solutions manual
- PowerPoint lecture slides

### Students' Resource Materials

Resources for students are available through the open-access Companion Web site link on [www.pearsonhighered.com/tanenbaum](http://www.pearsonhighered.com/tanenbaum), including

- Web resources, links to tutorials, organizations, FAQs, and more
- Figures, tables, and programs from the book
- Steganography demo
- Protocol simulators

### Acknowledgements

Many people helped us during the course of the fifth edition. We would especially like to thank Emmanuel Agu (Worcester Polytechnic Institute), Yoris Au (University of Texas at Antonio), Nikhil Bhargava (Aircom International, Inc.), Michael Buettner (University of Washington), John Day (Boston University), Kevin Fall (Intel Labs), Ronald Fulle (Rochester Institute of Technology), Ben Greenstein (Intel Labs), Daniel Halperin (University of Washington), Bob Kinicki (Worcester Polytechnic Institute), Tadayoshi Kohno (University of Washington), Sarvish Kulkarni (Villanova University), Hank Levy (University of Washington), Ratul Mahajan (Microsoft Research), Craig Partridge (BBN), Michael Piatek (University of Washington), Joshua Smith (Intel Labs), Neil Spring (University of Maryland), David Teneyuca (University of Texas at Antonio), Tammy VanDe-grift (University of Portland), and Bo Yuan (Rochester Institute of Technology), for providing ideas and feedback. Melody Kadenko and Julie Svendsen provided administrative support to David.

Shivakant Mishra (University of Colorado at Boulder) and Paul Nagin (Chimborazo Publishing, Inc.) thought of many new and challenging end-of-chapter problems. Our editor at Pearson, Tracy Dunkelberger, was her usual helpful self in many ways large and small. Melinda Haggerty and Jeff Holcomb did a good job of keeping things running smoothly. Steve Armstrong (LeTourneau University) prepared the PowerPoint slides. Stephen Turner (University of Michigan at Flint) artfully revised the Web resources and the simulators that accompany the text. Our copyeditor, Rachel Head, is an odd hybrid: she has the eye of an eagle and the memory of an elephant. After reading all her corrections, both of us wondered how we ever made it past third grade.

Finally, we come to the most important people. Suzanne has been through this 19 times now and still has endless patience and love. Barbara and Marvin now know the difference between good textbooks and bad ones and are always an inspiration to produce good ones. Daniel and Matilde are welcome additions to our family. Aron is unlikely to read this book soon, but he likes the nice pictures on page 884 (AST). Katrin and Lucy provided endless support and always managed to keep a smile on my face. Thank you (DJW).

ANDREW S. TANENBAUM

DAVID J. WETHERALL

**Andrew S. Tanenbaum** has an S.B. degree from M.I.T. and a Ph.D. from the University of California at Berkeley. He is currently a Professor of Computer Science at the Vrije Universiteit where he has taught operating systems, networks, and related topics for over 30 years. His current research is on highly reliable operating systems although he has worked on compilers, distributed systems, security, and other topics over the years. These research projects have led to over 150 refereed papers in journals and conferences.

Prof. Tanenbaum has also (co)authored five books which have now appeared in 19 editions. The books have been translated into 21 languages, ranging from Basque to Thai and are used at universities all over the world. In all, there are 159 versions (language/edition combinations), which are listed at [www.cs.vu.nl/~ast/publications](http://www.cs.vu.nl/~ast/publications).

Prof. Tanenbaum has also produced a considerable volume of software, including the Amsterdam Compiler Kit (a retargetable portable compiler), Amoeba (an early distributed system used on LANs), and Globe (a wide-area distributed system).

He is also the author of MINIX, a small UNIX clone initially intended for use in student programming labs. It was the direct inspiration for Linux and the platform on which Linux was initially developed. The current version of MINIX, called MINIX 3, is now focused on being an extremely reliable and secure operating system. Prof. Tanenbaum will consider his work done when no computer is equipped with a reset button and no living person has ever experienced a system crash. MINIX 3 is an on-going open-source project to which you are invited to contribute. Go to [www.minix3.org](http://www.minix3.org) to download a free copy and find out what is happening.

Tanenbaum is a Fellow of the ACM, a Fellow of the the IEEE, and a member of the Royal Netherlands Academy of Arts and Sciences. He has also won numerous scientific prizes, including:

- 2010 TAA McGuffey Award for Computer Science and Engineering books
- 2007 IEEE James H. Mulligan, Jr. Education Medal
- 2002 TAA Texty Award for Computer Science and Engineering books
- 1997 ACM/SIGCSE Award for Outstanding Contributions to Computer Science Education
- 1994 ACM Karl V. Karlstrom Outstanding Educator Award

His home page on the World Wide Web can be found at <http://www.cs.vu.nl/~ast/>.

**David J. Wetherall** is an Associate Professor of Computer Science and Engineering at the University of Washington in Seattle, and advisor to Intel Labs in Seattle. He hails from Australia, where he received his B.E. in electrical engineering from the University of Western Australia and his Ph.D. in computer science from M.I.T.

Prof. Wetherall has worked in the area of networking for the past two decades. His research is focused on network systems, especially wireless networks and mobile computing, the design of Internet protocols, and network measurement.

He received the ACM SIGCOMM Test-of-Time award for research that pioneered active networks, an architecture for rapidly introducing new network services. He received the IEEE William Bennett Prize for breakthroughs in Internet mapping. His research was recognized with an NSF CAREER award in 224, and he became a Sloan Fellow in 2004.

As well as teaching networking, Prof. Wetherall participates in the networking research community. He has co-chaired the program committees of SIGCOMM, NSDI and MobiSys, and co-founded the ACM HotNets workshops. He has served on numerous program committees for networking conferences, and is an editor for ACM Computer Communication Review.

His home page on the World Wide Web can be found at <http://djw.cs.washington.edu>.

<b>PREFACE</b>	<b>6</b>
<b>ABOUT THE AUTHORS</b>	<b>10</b>
<b>1 INTRODUCTION</b>	<b>23</b>
1.1 USES OF COMPUTER NETWORKS, 25	
1.1.1 Business Applications, 25	
1.1.2 Home Applications, 28	
1.1.3 Mobile Users, 32	
1.1.4 Social Issues, 36	
1.2 NETWORK HARDWARE, 39	
1.2.1 Personal Area Networks, 40	
1.2.2 Local Area Networks, 41	
1.2.3 Metropolitan Area Networks, 45	
1.2.4 Wide Area Networks, 45	
1.2.5 Internetworks, 50	
1.3 NETWORK SOFTWARE, 51	
1.3.1 Protocol Hierarchies, 51	
1.3.2 Design Issues for the Layers, 55	
1.3.3 Connection-Oriented Versus Connectionless Service, 57	
1.3.4 Service Primitives, 60	
1.3.5 The Relationship of Services to Protocols, 62	
1.4 REFERENCE MODELS, 63	
1.4.1 The OSI Reference Model, 63	
1.4.2 The TCP/IP Reference Model, 67	
1.4.3 The Model Used in This Book, 70	

- 1.4.4 A Comparison of the OSI and TCP/IP Reference Models, 71
- 1.4.5 A Critique of the OSI Model and Protocols, 73
- 1.4.6 A Critique of the TCP/IP Reference Model, 75
- 1.5 EXAMPLE NETWORKS, 76
  - 1.5.1 The Internet, 76
  - 1.5.2 Third-Generation Mobile Phone Networks, 85
  - 1.5.3 Wireless LANs: 802.11, 90
  - 1.5.4 RFID and Sensor Networks, 93
- 1.6 NETWORK STANDARDIZATION, 95
  - 1.6.1 Who's Who in the Telecommunications World, 97
  - 1.6.2 Who's Who in the International Standards World, 98
  - 1.6.3 Who's Who in the Internet Standards World, 100
- 1.7 METRIC UNITS, 102
- 1.8 OUTLINE OF THE REST OF THE BOOK, 103
- 1.9 SUMMARY, 104

## **2 THE PHYSICAL LAYER**

**109**

- 2.1 THE THEORETICAL BASIS FOR DATA COMMUNICATION, 110
  - 2.1.1 Fourier Analysis, 110
  - 2.1.2 Bandwidth-Limited Signals, 110
  - 2.1.3 The Maximum Data Rate of a Channel, 114
- 2.2 GUIDED TRANSMISSION MEDIA, 115
  - 2.2.1 Magnetic Media, 115
  - 2.2.2 Twisted Pairs, 116
  - 2.2.3 Coaxial Cable, 117
  - 2.2.4 Power Lines, 118
  - 2.2.5 Fiber Optics, 119
- 2.3 WIRELESS TRANSMISSION, 125
  - 2.3.1 The Electromagnetic Spectrum, 125
  - 2.3.2 Radio Transmission, 129
  - 2.3.3 Microwave Transmission, 130
  - 2.3.4 Infrared Transmission, 134
  - 2.3.5 Light Transmission, 134

- 2.4 COMMUNICATION SATELLITES, 136
  - 2.4.1 Geostationary Satellites, 137
  - 2.4.2 Medium-Earth Orbit Satellites, 141
  - 2.4.3 Low-Earth Orbit Satellites, 141
  - 2.4.4 Satellites Versus Fiber, 143
- 2.5 DIGITAL MODULATION AND MULTIPLEXING, 145
  - 2.5.1 Baseband Transmission, 145
  - 2.5.2 Passband Transmission, 150
  - 2.5.3 Frequency Division Multiplexing, 152
  - 2.5.4 Time Division Multiplexing, 155
  - 2.5.5 Code Division Multiplexing, 155
- 2.6 THE PUBLIC SWITCHED TELEPHONE NETWORK, 158
  - 2.6.1 Structure of the Telephone System, 159
  - 2.6.2 The Politics of Telephones, 162
  - 2.6.3 The Local Loop: Modems, ADSL, and Fiber, 164
  - 2.6.4 Trunks and Multiplexing, 172
  - 2.6.5 Switching, 181
- 2.7 THE MOBILE TELEPHONE SYSTEM, 184
  - 2.7.1 First-Generation (1G) Mobile Phones: Analog Voice, 186
  - 2.7.2 Second-Generation (2G) Mobile Phones: Digital Voice, 190
  - 2.7.3 Third-Generation (3G) Mobile Phones: Digital Voice and Data, 194
- 2.8 CABLE TELEVISION, 199
  - 2.8.1 Community Antenna Television, 199
  - 2.8.2 Internet over Cable, 200
  - 2.8.3 Spectrum Allocation, 202
  - 2.8.4 Cable Modems, 203
  - 2.8.5 ADSL Versus Cable, 205
- 2.9 SUMMARY, 206

## **3 THE DATA LINK LAYER**

**213**

- 3.1 DATA LINK LAYER DESIGN ISSUES, 214
  - 3.1.1 Services Provided to the Network Layer, 214
  - 3.1.2 Framing, 217
  - 3.1.3 Error Control, 220
  - 3.1.4 Flow Control, 221

- 3.2 ERROR DETECTION AND CORRECTION, 222
  - 3.2.1 Error-Correcting Codes, 224
  - 3.2.2 Error-Detecting Codes, 229
- 3.3 ELEMENTARY DATA LINK PROTOCOLS, 235
  - 3.3.1 A Utopian Simplex Protocol, 240
  - 3.3.2 A Simplex Stop-and-Wait Protocol for an Error-Free Channel, 241
  - 3.3.3 A Simplex Stop-and-Wait Protocol for a Noisy Channel, 242
- 3.4 SLIDING WINDOW PROTOCOLS, 246
  - 3.4.1 A One-Bit Sliding Window Protocol, 249
  - 3.4.2 A Protocol Using Go-Back-N, 252
  - 3.4.3 A Protocol Using Selective Repeat, 259
- 3.5 EXAMPLE DATA LINK PROTOCOLS, 264
  - 3.5.1 Packet over SONET, 265
  - 3.5.2 ADSL (Asymmetric Digital Subscriber Loop), 268
- 3.6 SUMMARY, 271

## **4 THE MEDIUM ACCESS CONTROL SUBLAYER 275**

- 4.1 THE CHANNEL ALLOCATION PROBLEM, 276
  - 4.1.1 Static Channel Allocation, 276
  - 4.1.2 Assumptions for Dynamic Channel Allocation, 278
- 4.2 MULTIPLE ACCESS PROTOCOLS, 279
  - 4.2.1 ALOHA, 280
  - 4.2.2 Carrier Sense Multiple Access Protocols, 284
  - 4.2.3 Collision-Free Protocols, 287
  - 4.2.4 Limited-Contention Protocols, 292
  - 4.2.5 Wireless LAN Protocols, 295
- 4.3 ETHERNET, 298
  - 4.3.1 Classic Ethernet Physical Layer, 299
  - 4.3.2 Classic Ethernet MAC Sublayer Protocol, 300
  - 4.3.3 Ethernet Performance, 304
  - 4.3.4 Switched Ethernet, 306

- 4.3.5 Fast Ethernet, 308
- 4.3.6 Gigabit Ethernet, 311
- 4.3.7 10-Gigabit Ethernet, 314
- 4.3.8 Retrospective on Ethernet, 316
  
- 4.4 WIRELESS LANS, 317
  - 4.4.1 The 802.11 Architecture and Protocol Stack, 317
  - 4.4.2 The 802.11 Physical Layer, 319
  - 4.4.3 The 802.11 MAC Sublayer Protocol, 321
  - 4.4.4 The 802.11 Frame Structure, 327
  - 4.4.5 Services, 329
  
- 4.5 BROADBAND WIRELESS, 330
  - 4.5.1 Comparison of 802.16 with 802.11 and 3G, 331
  - 4.5.2 The 802.16 Architecture and Protocol Stack, 332
  - 4.5.3 The 802.16 Physical Layer, 334
  - 4.5.4 The 802.16 MAC Sublayer Protocol, 335
  - 4.5.5 The 802.16 Frame Structure, 337
  
- 4.6 BLUETOOTH, 338
  - 4.6.1 Bluetooth Architecture, 338
  - 4.6.2 Bluetooth Applications, 339
  - 4.6.3 The Bluetooth Protocol Stack, 340
  - 4.6.4 The Bluetooth Radio Layer, 342
  - 4.6.5 The Bluetooth Link Layers, 342
  - 4.6.6 The Bluetooth Frame Structure, 343
  
- 4.7 RFID, 345
  - 4.7.1 EPC Gen 2 Architecture, 345
  - 4.7.2 EPC Gen 2 Physical Layer, 346
  - 4.7.3 EPC Gen 2 Tag Identification Layer, 347
  - 4.7.4 Tag Identification Message Formats, 349
  
- 4.8 DATA LINK LAYER SWITCHING, 350
  - 4.8.1 Uses of Bridges, 350
  - 4.8.2 Learning Bridges, 352
  - 4.8.3 Spanning Tree Bridges, 355
  - 4.8.4 Repeaters, Hubs, Bridges, Switches, Routers, and Gateways, 358
  - 4.8.5 Virtual LANs, 360
  
- 4.9 SUMMARY, 367



## 5 THE NETWORK LAYER

373

### 5.1 NETWORK LAYER DESIGN ISSUES, 373

- 5.1.1 Store-and-Forward Packet Switching, 374
- 5.1.2 Services Provided to the Transport Layer, 374
- 5.1.3 Implementation of Connectionless Service, 376
- 5.1.4 Implementation of Connection-Oriented Service, 377
- 5.1.5 Comparison of Virtual-Circuit and Datagram Networks, 379

### 5.2 ROUTING ALGORITHMS, 380

- 5.2.1 The Optimality Principle, 382
- 5.2.2 Shortest Path Algorithm, 384
- 5.2.3 Flooding, 386
- 5.2.4 Distance Vector Routing, 388
- 5.2.5 Link State Routing, 391
- 5.2.6 Hierarchical Routing, 396
- 5.2.7 Broadcast Routing, 398
- 5.2.8 Multicast Routing, 400
- 5.2.9 Anycast Routing, 403
- 5.2.10 Routing for Mobile Hosts, 404
- 5.2.11 Routing in Ad Hoc Networks, 407

### 5.3 CONGESTION CONTROL ALGORITHMS, 410

- 5.3.1 Approaches to Congestion Control, 412
- 5.3.2 Traffic-Aware Routing, 413
- 5.3.3 Admission Control, 415
- 5.3.4 Traffic Throttling, 416
- 5.3.5 Load Shedding, 419

### 5.4 QUALITY OF SERVICE, 422

- 5.4.1 Application Requirements, 423
- 5.4.2 Traffic Shaping, 425
- 5.4.3 Packet Scheduling, 429
- 5.4.4 Admission Control, 433
- 5.4.5 Integrated Services, 436
- 5.4.6 Differentiated Services, 439

### 5.5 INTERNETWORKING, 442

- 5.5.1 How Networks Differ, 443
- 5.5.2 How Networks Can Be Connected, 444
- 5.5.3 Tunneling, 447