

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

---

# The Principles of Computer Networking

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

*Also in this series*

- 1 An Introduction to Logical Design of Digital Circuits  
*C. M. Reeves 1972*
- 2 Information Representation and Manipulation in a Computer  
*E. S. Page and L. B. Wilson, Second Edition 1978*
- 3 Computer Simulation of Continuous Systems  
*R. J. Ord-Smith and J. Stephenson 1975*
- 4 Macro Processors  
*A. J. Cole, Second Edition 1981*
- 5 An Introduction to the Uses of Computers  
*Murray Laver 1976*
- 6 Computing Systems Hardware  
*M. Wells 1976*
- 7 An Introduction to the Study of Programming Languages  
*D. W. Barron 1977*
- 8 ALGOL 68 – A first and second course  
*A. D. McGettrick 1978*
- 9 An Introduction to Computational Combinatorics  
*E. S. Page and L. B. Wilson 1979*
- 10 Computers and Social Change  
*Murray Laver 1980*
- 11 The Definition of Programming Languages  
*A. D. McGettrick 1980*
- 12 Programming via Pascal  
*J. S. Rohl and H. J. Barrett 1980*
- 13 Program Verification using Ada  
*A. D. McGettrick 1982*
- 14 Simulation Techniques for Discrete Event Systems  
*I. Mitrani 1982*
- 15 Information Representation and Manipulation using Pascal  
*E. S. Page and L. B. Wilson 1983*
- 16 Writing Pascal Programs  
*J. S. Rohl 1983*
- 17 An Introduction to APL  
*S. Pommier 1983*
- 18 Computer Mathematics  
*D. J. Cooke and H. E. Bez 1984*
- 19 Recursion via Pascal  
*J. S. Rohl 1984*
- 20 Text Processing  
*A. Colin Day 1984*
- 21 Introduction to Computer Systems  
*Brian Molinari 1985*
- 22 Program Construction  
*R. G. Stone and D. J. Cooke 1987*
- 23 A Practical Introduction to Denotational Semantics  
*Lloyd Allison 1987*
- 24 Modelling of Computer and Communication Systems  
*I. Mitrani 1987*

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

---

25 Cambridge Computer Science Texts

# The Principles of Computer Networking

D. Russell

*Computing Laboratory, University of Newcastle upon Tyne*



**CAMBRIDGE**  
**UNIVERSITY PRESS**

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

CAMBRIDGE UNIVERSITY PRESS

Cambridge, New York, Melbourne, Madrid, Cape Town,  
Singapore, São Paulo, Delhi, Tokyo, Mexico City

Cambridge University Press

The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by

Cambridge University Press, New York

[www.cambridge.org](http://www.cambridge.org)

Information on this title: [www.cambridge.org/9780521339926](http://www.cambridge.org/9780521339926)

© Cambridge University Press 1989

This publication is in copyright. Subject to statutory exception  
and to the provisions of relevant collective licensing agreements,  
no reproduction of any part may take place without the written  
permission of Cambridge University Press.

First published 1989

Reprinted 1991, 1997

*A catalogue record for this publication is available from the British Library*

ISBN 978-0-521-32795-4 Hardback

ISBN 978-0-521-33992-6 Hardback

Cambridge University Press has no responsibility for the persistence or  
accuracy of URLs for external or third-party internet websites referred to in  
this publication, and does not guarantee that any content on such websites is,  
or will remain, accurate or appropriate. Information regarding prices, travel  
timetables, and other factual information given in this work is correct at  
the time of first printing but Cambridge University Press does not guarantee  
the accuracy of such information thereafter.

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

---

To my parents

For more than I can ever know

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

---

# Contents

<b>1</b>	<b>Data Transmission</b>	<b>1</b>
1.1	Character Representation	1
1.2	Principles of Transmission	5
1.3	Fourier Analysis	6
1.4	Noise	9
1.5	Limits of Data Transmission	9
1.6	Real Data Transmission	11
1.7	Asynchronous Communication	13
1.8	Synchronous Communication	15
1.9	Signal Encoding	17
1.10	Clock Recovery	21
1.11	Data Coding and Modulation	22
1.12	Modem Signals	22
1.13	Other Modem Signals	24
1.14	Automatic Answering	25
1.15	Null Modems	27
1.16	Local Loopback or Cross-Connection?	29
1.17	Plugs and Sockets	30
1.18	Originating Dialed Calls	31
1.19	Character and Record Structure	32
1.20	Bit Stuffing	35
1.21	Errors	36
<b>2</b>	<b>Error Detection and Recovery</b>	<b>37</b>
2.1	Error Detection	37
2.2	Hamming Distance	38
2.3	Error-Correcting Codes	38
2.4	Hamming Single-Error-Correcting Code	40
2.5	Burst Errors	42
2.6	Checksum Error Detection	43
2.7	Cyclic Redundancy Checks	43
2.8	CRC Analysis	44
2.9	Back-to-Back Blocks	46
2.10	Error Analysis	47
2.11	CRC Computation by Program	48
2.12	Choice of Method	50
2.13	Forward and Reverse Error Correction	51

viii **Contents**

2.14	Reverse Error Correction Protocol	51
2.15	Parallel Exercise	52
2.16	Protocol Representation	52
2.17	Protocol Evaluation	53
2.18	Protocol Representation Again	55
2.19	A Minimal Link Protocol	57
2.20	A Real Link Level Protocol—The HDLC Family	58
2.21	The Notion of State	58
2.22	Multiple Packets—Windows	60
2.23	Querying the Send State Variable	65
2.24	Remote Procedure Calls	65
2.25	Forward or Reverse Error Correction?	67
2.26	Acceptable Error in an Imperfect World	68
2.27	Summary	70
<b>3</b>	<b>Shared Media</b>	<b>71</b>
3.1	Why Share a Medium?	71
3.2	Time and Frequency Division Multiplexing	73
3.3	Contention Access	76
3.4	Throughput	79
3.5	Other Aloha Disciplines	87
3.6	Aloha Models	88
3.7	Aloha Summary	88
3.8	Carrier Sense Multiple Access	88
3.9	Ethernets	90
3.10	CSMA Summary	94
3.11	Rings	94
3.12	The Slotted Ring	96
3.13	The Monitor Station	99
3.14	Slotted Ring Summary	101
3.15	The Token Ring	101
3.16	Token Ring Priority	104
3.17	Token Ring Errors	109
3.18	The FDDI Ring	109
3.19	Other Types of Ring	111
3.20	Contention Rings	113
3.21	Ring Summary	114
3.22	Token Bus	115
3.23	Token Bus Summary	117
3.24	Summary	118
<b>4</b>	<b>Flow Control</b>	<b>119</b>
4.1	Examples of Flow Control	119



4.2	Record Oriented Flow Control	122
4.3	Bandwidth, Throughput, and Delay Time	124
4.4	Flow Control Mechanisms	126
4.5	M and N Pacing	126
4.6	Flow Control Windows	128
4.7	Windows and Cyclic Numbering	129
4.8	The Mental Picture of a Window Mechanism	130
4.9	Implications of Window Mechanisms	130
4.10	Credit Mechanisms	132
4.11	Credits and Sliding Window Protocols	133
4.12	Do We Really Need Flow Control?	134
4.13	Flow Control in Real Life	134
<b>5</b>	<b>Network Routing and Congestion</b>	<b>139</b>
5.1	Network Addresses, Routes and Topology	139
5.2	Datagrams and Virtual Calls	141
5.3	Routing Datagrams	142
5.4	Dynamic Routing	147
5.5	Load Balancing	150
5.6	Re-Routing	151
5.7	Congestion and Deadlock	151
5.8	Virtual Call Networks	157
5.9	Hybrid Networks	162
5.10	Broadcasts and Multicasts	163
5.11	Source Routing	165
5.12	Summary	166
<b>6</b>	<b>Network Service and Interface</b>	<b>168</b>
6.1	X.25	168
6.2	The X.25 Protocol	171
6.3	Packet Format in X.25	171
6.4	Call Connection in X.25	172
6.5	Data Transfer in X.25	174
6.6	Flow Control in X.25	176
6.7	Expedited Data in X.25	179
6.8	RESET in X.25	179
6.9	Disconnection in X.25	180
6.10	Connections Over Datagrams—The ARPANET TCP	181
6.11	Sequence Numbers in TCP	181
6.12	Connection Management in TCP	183
6.13	Call Disconnection in TCP	187
6.14	The Actual TCP/IP Protocol	188
6.15	The Internet Protocol	189

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

<b>x</b>	<b>Contents</b>	
6.16	The ISO Transport Service	192
6.17	ISO Transport across Heterogeneous Networks	195
6.18	The ISO Transport Checksum	196
6.19	ISDN	197
6.20	Signalling System Number 7	198
6.21	Facilities on ISDN	199
6.22	ISDN and Computer Communications	200
6.23	Summary	201
<b>7</b>	<b>Terminal Support</b>	<b>203</b>
7.1	Supporting Simple Character Terminals—Triple-X	203
7.2	Virtual Terminals—TELNET	213
7.3	Screen Based Terminals	219
7.4	Supporting Bitmapped Terminals—X and NeWS	224
7.5	The X-Window System	225
7.6	NeWS	229
7.7	A Comparison of NeWS and X	231
7.8	Summary	232
<b>8</b>	<b>Presentation</b>	<b>233</b>
8.1	Data Representation	233
8.2	Compression and Encryption	239
8.3	Encryption	243
8.4	Abstract Syntax Notation 1—ASN.1	245
8.5	General	253
<b>9</b>	<b>File Transfer and Access</b>	<b>254</b>
9.1	File Structure	254
9.2	File Transfer Protocol	257
9.3	File Types	258
9.4	ISO File Transfer Access and Manipulation Protocol	260
9.5	Virtual and Real File Structures	260
9.6	Document Types	262
9.7	File Access	265
9.8	File Transfer “In The Large”	265
9.9	Checkpoint Recovery	271
9.10	Summary	272
<b>10</b>	<b>Network Mail</b>	<b>273</b>
10.1	Computer Messages	274
10.2	Forwarding, Relaying and Address Structures	283
10.3	Domain Structure	285
10.4	Other Mail Networks	289

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

xi

10.5	X.400 Mail Systems	290
10.6	X.400 Mail Protocols	292
10.7	Conferencing	297
10.8	Human Factors	299
10.9	Summary	300
<b>11</b>	<b>Application Level Services</b>	<b>301</b>
11.1	CASE Standards	301
11.2	Remote Operations	306
11.3	Upper Layer Architecture	309
11.4	Directory Services	313
11.5	Maintaining the Database	318
11.6	Summary	320
<b>12</b>	<b>Performance and System Issues</b>	<b>322</b>
12.1	Lightweight Protocols	322
12.2	Remote Procedure Calls	323
12.3	General Performance and Cost Issues	330
12.4	Packet Handling Costs	330
12.5	Single Byte Interactions	334
12.6	Multiple Packet Interactions	335
12.7	Hardware Checksum Calculation	337
12.8	The Cost of Heavyweight Protocols	340
12.9	The Task Switching Overhead—Back-to-Back Blocks	341
12.10	The Impact of Transmission Errors on Throughput	347
12.11	Non-Sequential Protocols	348
12.12	Error Recovery and Network Congestion	350
12.13	Summary	351
<b>13</b>	<b>Network Management</b>	<b>352</b>
13.1	Error Monitoring	352
13.2	Traffic and Congestion	354
13.3	Dynamic Reconfiguration	357
13.4	Distributing and Loading New Network Software	357
13.5	Software Integrity	364
13.6	Topology of Shared Media	365
13.7	Backbones	370
13.8	General Discussion	371
13.9	Size	371
13.10	Summary	373
<b>14</b>	<b>Security and Authentication</b>	<b>374</b>
14.1	The Need for Security	374

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

xii	<b>Contents</b>	
14.2	Physical Security	375
14.3	A Potted History of Cryptology	377
14.4	Rotor Machines	384
14.5	The DES Standard	388
14.6	The DES Controversy	391
14.7	Public Key Encryption	392
14.8	The Knapsack Algorithm	394
14.9	The RSA Algorithm	395
14.10	Digital Signatures	398
14.11	Weaknesses of Current Public Key Algorithms	400
14.12	Network Applications of Encryption	401
14.13	Equivalence of Secure Channels and Authentication	401
14.14	Key Management	401
14.15	Formal Protocol Analysis	406
14.16	Confidentiality Using Public Key Encryption	406
14.17	Public vs Private Key Authentication	407
14.18	Summary	408
<b>15</b>	<b>Gateways</b>	<b>411</b>
15.1	Addressing Domains	412
15.2	Third Party Addressing	414
15.3	Hierarchical Naming	416
15.4	Administrative Gateways	417
15.5	Transparent Gateways	420
15.6	Protocol Mapping	421
15.7	Mapping at the Packet Level—Packet Sizes	421
15.8	Packet-Level Addressing	424
15.9	Network-Level Gateways	425
15.10	Network-Level Packet Sizes	425
15.11	Datagram or Virtual Call?	425
15.12	Internetwork Services	427
15.13	Higher Level Gateways	429
15.14	Store and Forward Gateways	431
15.15	Gateway, Router, Switch, Bridge, or Repeater?	433
15.16	Summary	433
<b>16</b>	<b>Standards</b>	<b>435</b>
16.1	The Need for Standards	435
16.2	The Standards Makers	439
16.3	Communications Models	443
16.4	IEEE Project 802	448
16.5	TOP and MAP	450
16.6	Functional Standards	451

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

---

		xiii
16.7	Protocol Description	451
16.8	Testing Protocol Definitions and Implementations	460
16.9	Summary	463
	<b>Glossary</b>	465
	<b>Further Reading and References</b>	481
	Further Reading	481
	References	483
	<b>Index</b>	489

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

---

## Preface

This book is intended to cover the whole of the field of computer communications. Even with such a wide ranging ambition, there must be limits to the coverage. Roughly these are drawn at the lower end of the spectrum by assuming the properties of transmission media, and at the top end by stopping short of discussing truly distributed processing. In between, the aim has been to give an overall understanding of the principles involved.

Computer communications is such a vast and fast moving field that it is quite impossible to cover the details of any complete architecture within the confines of one book. However, that was never my intention. The real aim is to try to extract some of the *principles* that emerge in computer networking, sometimes over and over again. One prime example is the topic of flow control. The principles of flow control can be extracted independently of context, and this book devotes Chapter 4 to just that. Similarly, in Chapter 3 we look at what is at first sight a bewildering range of ways of sharing a medium. However, it soon emerges that most of their number can be reduced by asking two orthogonal questions—is the topology a bus or a ring, and is the access by contention or by token? Once these two principles have been understood, the other aspects are of secondary importance. Again, the addressing and routing principles that we discuss in Chapter 6 in relation to the techniques of providing the network service, crop up again when looking at network mail in Chapter 10, and Gateways in Chapter 15.

In overall plan the book starts at the bottom and works upwards. Thus, the early chapters through Chapter 6 explain how raw, error-prone communications media can be built into a reliable end-to-end communications service. However, the subject of communications has only just started by this time. For successful communication to take place, agreements have to be made about what the bits on this reliable pipe actually mean. This brings us to the consideration of presentation issues which are concerned with a consistent representation of the same semantic information across diverse systems. We also go into considerable detail in describing how various applications of computer connections actually work, including computer mail, terminal support, and file transfer and access. The application level tools provided by ISO, and in particular the remote operations service are explained.

As well as the “traditional” kinds of protocol with which this book is mainly concerned, a chapter is devoted to looking at so-called *lightweight protocols*, and the performance and system issues involved in

Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)**xvi Preface**

the efficient implementation of communications architectures. In addition, since networks have grown so big, they need to be managed, and some of the management issues are also discussed.

Perhaps unusually, a whole chapter is devoted to Security, Authentication, and Encryption. This topic was given such treatment because the author perceives that current attitudes show a huge ignorance of what can and can't be done in this area. Computer networks are insecure, and becoming more so. However, many people either seem to be very ignorant of what can be achieved by encryption, or, naively, seem to be ready to put complete trust into encryption techniques. In 1978, Needham and Schroeder showed how, through the use of encryption techniques, two mutually unknown network entities could authenticate themselves, one to the other through the agency of a third, trusted, authentication server. This is independent of "hostile" agents observing all the messages, and inserting, corrupting, or replaying messages. Most people are very surprised by this ability, and it is surprisingly poorly known even 10 years after its first publication. On the other hand, some people put an unquestioning trust in encryption, apparently oblivious of the consistent history of broken cyphers. In addition, the interesting properties of public key encryption, together with their present disappointing position is also presented. Chapter 14 aims to give an up-to-date review of what can and cannot be done in this area.

Finally, Chapter 16 tries to summarise the need for standards, and the processes, political and technical, by which standards are produced and imposed. In addition to discussing the various political bodies that produce standards, Chapter 16 also discusses some of the techniques by which standards are described and analysed. Natural human language is inadequate and leads to ambiguity and misunderstanding, and Chapter 16 indicates some of the improved tools that are beginning to appear.

Throughout the book, the principles are illustrated by examples taken from real computer architectures. The emphasis is always on generally agreed standards, and so the examples come mainly from the ISO and ARPANET suites of protocols. The attempt has been to avoid proprietary architectures wherever possible, and the choice of the ISO and ARPANET suites is for two main reasons. One is that they are publicly and widely available, and the other is that they often have quite different approaches to solving the problems in hand. When different approaches are used on the same problem, then a careful analysis of where differences lie often illuminates the real character of the problem and reveals the principles involved.

A book like this owes much to the efforts of others. Perhaps the most help have been those with whom the author has come into contact



Cambridge University Press

978-0-521-33992-6 - 25 Cambridge Computer Science Texts: The Principles of  
Computer Networking

D. Russell

Frontmatter

[More information](#)

xvii

over the long years that he has worked in designing and implementing networks. I have been privileged to encounter many luminaries, and it would be invidious to mention any individually since at least ten times as many would of necessity not be mentioned. However, I hope I may be allowed the indulgence of mentioning just two. I was privileged to know Bob Husak of the Merit Computer Network. Bob had a deep and encyclopaedic knowledge of networks at all levels, and was a good friend. His early death saddened all who knew him. In my undergraduate life as a physicist, Thomas Littlefield taught me how to get a feel for complex physical processes by employing simple mental pictures. It is an approach I have valued ever since.

Directly involved in the production of this book have been Harry Whitfield who fooled me into starting the project in the first place, and pointed out many silly mistakes, Quentin Campbell, Jill Foster, Isi Mitrani, and especially Ian Doak have read various drafts and given suggestions. From CUP, Ernest Kirkwood, Tim Bradshaw, and David Tranah have supported me during the preparation of this book.

I shall not break with the worthy tradition of thanking the typist Denis Russell for typing and revising endless revisions of the manuscript, with only the occasional hint of dissatisfaction with his lot. In addition, he typeset the text using T<sub>E</sub>X†, produced all the drawings in PostScript‡, and produced camera ready copy. Of course this leaves even less room than normal for the author to disclaim responsibility for errors. More to the point, various tools were used including text editors on several operating systems (even including UNIX§), micros, workstations and mainframes too numerous to mention, and communications systems including most of those described between these covers.

Finally, and most of all, I would like to thank my wife Marion, and the kids for putting up both with me and without me during the excessively protracted gestation period of this book. I can only hope it was worth their efforts.

---

† T<sub>E</sub>X is a trademark of the American Mathematical Society

‡ PostScript is a trademark of Adobe Systems Incorporated

§ UNIX is a trademark of Bell Laboratories