

Table of Contents

1. Introduction	1
1.1 The Emergence of Parallel Systems	1
1.2 Theoretical Research in Parallel Computing	2
1.3 History of Routing	4
1.4 Research Areas related to Routing	8
1.4.1 Parallel Sorting	8
1.4.2 Shop Scheduling	9
1.4.3 Multicommodity Flow	10
1.4.4 Network Emulations	10
1.4.5 Shared Memory Simulations	11
1.4.6 Load Balancing	12
1.5 Main Contributions of this Book	13
2. Communication Mechanisms Used in Practice	15
2.1 Multiplexing	15
2.2 Switching Elements	16
2.2.1 Circuit Switches	16
2.2.2 Packet Switches	17
2.3 Local Area Networks (LAN)	18
2.3.1 The Ethernet	18
2.3.2 The Fibre Distributed Data Interface (FDDI)	19
2.4 Wide Area Networks (WAN)	20
2.4.1 The Synchronous Digital Hierarchy (SDH)	20
2.4.2 The Asynchronous Transfer Mode (ATM)	21
2.5 Communication Systems for Parallel Computers	23
2.5.1 Non-scalable Parallel Computers	23
2.5.2 Scalable Parallel Computers	24
2.6 The OSI Model	24
3. Terminology	27
3.1 Basic Definitions and Inequalities	27
3.2 Basic Definitions in Probability Theory	28
3.3 Basic Definitions in Graph Theory	29
3.4 Basic Definitions in Routing Theory	30

3.4.1	The Hardware Model	31
3.4.2	The Routing Problem	34
3.4.3	Message Passing Models	35
3.4.4	Routing Strategies	36
3.4.5	Space-Efficient Routing	38
4.	Introduction to Store-and-Forward Routing	41
4.1	History of Store-and-Forward Routing	41
4.1.1	Routing in Specific Networks	42
4.1.2	Universal Routing	43
4.2	Optimal Networks for Permutation Routing	44
4.2.1	Optimal Networks for Randomized Routing	45
4.2.2	Optimal Networks for Deterministic Routing	45
5.	The Routing Number	47
5.1	Existence of Efficient Path Systems	48
5.2	Valiant's Trick	50
5.3	The Routing Number of Specific Networks	52
5.4	Routing Number vs. Expansion	53
5.5	Computing Efficient Path Systems	54
5.5.1	An Algorithm for Arbitrary Networks	54
5.5.2	An Algorithm for Node-Symmetric Networks	55
5.6	Summary of Main Results	55
6.	Offline Routing Protocols	57
6.1	Keeping the Routing Time Low	58
6.2	Keeping the Buffer Size Low	62
6.3	Applications	67
6.3.1	Network Emulations Using 1–1 Embeddings	67
6.3.2	Network Emulations Using 1–Many Embeddings	68
6.4	Summary of Main Results	70
7.	Oblivious Routing Protocols	73
7.1	The Random Delay Protocol	73
7.1.1	Description of the Protocol	73
7.1.2	Applications	75
7.1.3	Limitations	75
7.2	The Random Rank Protocol	75
7.2.1	Description of the Protocol	75
7.2.2	Applications	78
7.2.3	Limitations	80
7.3	Ranade's Protocol	82
7.3.1	Description of the Protocol	82
7.3.2	Applications	84
7.3.3	Limitations	84

7.4	The Growing Rank Protocol	84
7.4.1	Description of the Protocol	85
7.4.2	Applications	89
7.4.3	Limitations	90
7.5	The Extended Growing Rank Protocol	91
7.5.1	Description of the Protocol	91
7.5.2	Applications	95
7.5.3	Limitations	98
7.6	The Trial-and-Failure Protocol	98
7.6.1	Description of the Protocol	99
7.6.2	Applications	101
7.6.3	Limitations	102
7.7	The Duplication Protocol	102
7.7.1	Description of the Protocol	103
7.7.2	Applications	105
7.7.3	Limitations	106
7.8	The Protocol by Rabani and Tardos	106
7.8.1	Description of the Protocol	106
7.8.2	Applications	110
7.8.3	Limitations	110
7.9	The Protocol by Ostrovsky and Rabani	111
7.9.1	Description of the Protocol	111
7.9.2	Applications	111
7.9.3	Limitations	112
7.10	Summary of Main Results	112
8.	Adaptive Routing Protocols	115
8.1	Deterministic Routing in Multibutterflies	116
8.1.1	The r -replicated s -ary Multibutterfly	116
8.1.2	Description of the Simple Protocol	117
8.1.3	Analysis of the Simple Protocol	118
8.1.4	Description of the Global Protocol	129
8.1.5	Analysis of the Global Protocol	131
8.2	Universal Adaptive Routing Strategies	134
8.2.1	Greedy Routing Strategies	134
8.2.2	Routing via Sorting	135
8.2.3	Routing via Simulation	135
8.3	Summary of Main Results	138
9.	Compact Routing Protocols	139
9.1	History of Compact Routing	139
9.1.1	Relationship between Space and Stretch Factor	139
9.1.2	Relationship between Space and Slowdown	142
9.2	The “Routing via Simulation” Strategy	143
9.2.1	Selecting Suitable Routing Structures	143

9.2.2	Space-Efficient Perfect Hashing	145
9.2.3	Design of Compact Routing Tables	145
9.3	Randomized Compact Routing	147
9.3.1	The (s, d, k) -Butterfly	147
9.3.2	The Simulation Strategy	148
9.3.3	Bounding the Congestion and Dilation	151
9.3.4	Applications	154
9.4	Deterministic Compact Routing	155
9.4.1	The Simulation Strategy	157
9.4.2	Applications	160
9.5	Summary of Main Results	160
10.	Introduction to Wormhole Routing	163
10.1	History of Wormhole Routing	164
10.1.1	Routing in Specific Networks	164
10.1.2	Universal Routing	165
10.2	Upper and Lower Bounds	166
11.	Oblivious Routing Protocols	167
11.1	The Trial-and-Failure Protocol	167
11.1.1	Wormhole Routing in Meshes and Tori	168
11.1.2	Wormhole Routing in Butterflies	169
11.1.3	Further Applications	175
11.2	The Duplication Protocol	176
11.3	Summary of Main Results	177
12.	Protocols for All-Optical Networks	179
12.1	An All-Optical Hardware Model	179
12.2	Overview on All-Optical Routing	180
12.3	A Simple, Efficient Protocol	182
12.3.1	Applications	185
12.4	Proof of Theorems 12.3.1 and 12.3.3	186
12.4.1	The Upper Bound	186
12.4.2	The Lower Bound	193
12.5	Proof of Theorem 12.3.2	201
12.5.1	The Upper Bound	201
12.5.2	The Lower Bound	207
13.	Summary and Future Directions	209
13.1	Store-and-Forward Routing	209
13.1.1	Path Selection	210
13.1.2	Offline Routing	210
13.1.3	Oblivious Routing	211
13.1.4	Adaptive Routing	212
13.1.5	Compact Routing	212

13.2	Wormhole Routing	213
13.3	Future Directions	214
13.3.1	Dynamic Routing	214
13.3.2	Routing in Faulty and Dynamic Networks	216
13.3.3	Scheduling	218
	References	221
	Index	233