Table of Contents

Part I. Introduction and Motivation

1. Introduction 3

2. Modern Telecommunication Networks 9
2.1 Common Channel Signaling 10
2.1.1 CCSN Objectives 11
2.1.2 Signaling System Number 7 11
2.2 Intelligent Networks 12
2.2.1 Service Provision 13
2.2.2 The IN Conceptual Model 15
2.2.3 Discussion 15
2.3 The TINA Approach 17
2.3.1 TINA and the IN Concept 18
2.3.2 The TINA Computing Architecture 19
2.3.3 Discussion 21
2.4 Guiding the Network Design Process 22
2.4.1 Impact of Network Architectures on Performance Analysis 23
2.4.2 Requirements 24
2.5 Summary and Concluding Remarks 26

3. The View from Industry: First Modeling Approaches 27
3.1 Modeling and Evaluation Requirements: The Practitioner's View 28
3.2 A First Modeling Approach 30
3.2.1 Model Description 30
3.2.2 Model Evaluation 32
3.3 Application Example 35
3.3.1 System Description 35
3.3.2 Analysis 38
3.4 Relation to Other Approaches 44
3.4.1 Single System Evaluation Approaches 44
3.4.2 Approaches Dealing with the Mapping Problem 46
3.4.3 Discussion 47

3.5 Summary and Concluding Remarks 47

Part II. Node Analysis

4. Quasi-Birth-and-Death Processes 51
4.1 Definition 52
4.1.1 State Space and Transition Structure 52
4.1.2 Generator Matrix and Steady-State Characterization . 53
4.2 Matrix-Geometric Solution Methods 56
4.2.1 Preliminaries 56
4.2.2 The Successive Substitution (SS) Method 58
4.2.3 The Logarithmic Reduction (LR) Approach 59
4.2.4 Naoumov's Improved LR Algorithm 61
4.3 Transform Methods 63
4.3.1 The Cyclic Reduction Method 63
4.3.2 The Invariant Subspace Approach 64
4.3.3 The Spectral Expansion Method 66
4.4 Non-Skip-Free QBDs 72
4.4.1 Reduction to Standard QBD Processes 72
4.4.2 Approaches for Direct Solution 75
4.5 Numerical Comparison of Solution Methods 76
4.5.1 Candidate Solution Algorithms 77
4.5.2 The Model under Investigation 78
4.5.3 Numerical Results 79
4.5.4 Conclusion 93
4.6 QBD Extensions 94
4.6.1 Approximate Analysis 94
4.6.2 Buffer Resets 96
4.6.3 Quasi-Stationary Solution 98
4.6.4 Multi-Dimensional QBD Processes 99
4.7 Summary and Concluding Remarks 100

5. High-Level System Specification with iSPNs 103
5.1 The iSPN Modeling Environment 103
5.1.1 High-Level Modeling Approaches 104
5.1.2 Basic Idea and Related Approaches 105
5.1.3 Formal Definition of iSPNs 106
5.1.4 An Example iSPN Model 109
5.2 Equivalence to QBD Markov chains 111
5.2.1 Preliminaries 111
5.2.2 The Simple Case: Two Successive Submarking-Equivalent j-Sets 113
5.2.3 The General Case: All iSPNs Lead to QBD Processes . 116
5.2.4 Coverage of all QBDs by iSPNs 121

5.3 Implementation Issues 125
5.3.1 Tightly Choosing $j_{\min}$ 125
5.3.2 State Space Generation 130
5.3.3 Accounting for Immediate Transitions 135
5.3.4 Modeling Batch Arrivals and Departures 138
5.4 Extensions for Buffer Resets and Quasi-Stationary Models . . . 139
5.5 Summary and Concluding Remarks 140

6. Application Examples: Node Analysis 143
6.1 Connection Management for Video Traffic 143
6.1.1 System Description 144
6.1.2 Model Development 145
6.1.3 Parameterization 146
6.1.4 Numerical Results 146
6.1.5 Conclusion 153
6.2 WWW Traffic and TCP/IP Congestion Control 153
6.2.1 System Description 154
6.2.2 Model Development 156
6.2.3 Parameterization 161
6.2.4 Numerical Results 164
6.2.5 Conclusion 170
6.3 Accounting for Self-Similar Traffic 171
6.3.1 Self-Similar Stochastic Processes 172
6.3.2 Self-Similar Traffic Models 174
6.3.3 Parameterization 178
6.3.4 Numerical Results 179
6.3.5 Conclusion 181
6.4 Summary and Concluding Remarks 183

Part III. Network Analysis

7. Queueing Network Analysis Techniques 187
7.1 Main Problems and Existing Work 188
7.1.1 Main Issues 188
7.1.2 Parametric Decomposition Approaches 190
7.1.3 Conclusion 193
7.2 The Queueing Network Analyzer 194
7.2.1 Basic QNA 195
7.2.2 Finite Buffers 200
7.2.3 From QNA Nodes to QBD Nodes 204
7.2.4 Using QBDs to Improve QNA 206
7.2.5 Conclusion 212
7.3 Embedding iSPNs 212
7.3.1 Job Arrivals 214

7.3.2 Departure Process Derivation 216
7.3.3 Conclusion 225
7.4 Splitting and Merging Traffic Streams 225
7.4.1 Splitting 225
7.4.2 Merging 227
7.4.3 Dealing With the Distributional Explosion 228
7.4.4 Conclusion 231
7.5 Summary and Concluding Remarks 233

8. Conclusions and Outlook 235

A. Linear Algebra and Probability Theory Primer 239
A.1 Polynomial Eigenvalue Problems 239
A.1.1 Definition 239
A.1.2 Linearization 239
A.1.3 Other Solution Approaches 243
A.2 Phase-Type Distributions 243
A.3 Markovian Arrival Processes 244

B. Tool Description 247
B.1 User Interface 247
B.1.1 Model Specification 247
B.1.2 Execution Control 252
B.1.3 Output Format 252
B.2 Implementation 254

C. Model Specifications 255
C.1 An IN Model Based on M|G|1 Node Models 255
C.2 A Checkpointing Transaction Processing System 256
C.2.1 Parameterization 257
C.2.2 Variable Definitions 257
C.2.3 Petri Net Specification 258
C.2.4 Definition of Reward-Based Measures 259
C.3 Connection Management for Video Traffic 260
C.3.1 Variable Definitions 260
C.3.2 Petri Net Specification 260
C.3.3 Definition of Reward-Based Measures 262
C.4 WWW Traffic and TCP/IP Congestion Control 262
C.4.1 Variable Definitions 262
C.4.2 Petri Net Specification 263
C.4.3 Definition of Reward-Based Measures 266
C.5 Pseudo-Self-Similar Arrival Processes 266
C.5.1 Variable Definitions 267
C.5.2 Petri Net Specification 267
C.5.3 Definition of Reward-Based Measures 268

Notation and Abbreviations 269

Bibliography 273

Index 285