

# Contents

<b>Preface .....</b>	v
<b>Acknowledgements .....</b>	vii
<b>Acronyms .....</b>	xv
<b>1 Motivation and Basics</b>	
<i>Torsten Braun and Thomas Staub .....</i>	1
1.1 Quality of Service and its Parameters .....	1
1.1.1 Delay and Delay Variations in End-to-End Packet Delivery .....	2
1.1.2 Bandwidth and Packet Loss Ratio .....	3
1.2 Applications' QoS Requirements .....	4
1.2.1 Types of Network Applications .....	5
1.2.2 QoS Requirements of Applications .....	6
1.3 Packet Scheduling in Network Elements .....	8
1.3.1 (Non)Work-Conserving Scheduling Disciplines .....	8
1.3.2 Fairness .....	9
1.3.3 Scheduling Disciplines .....	10
1.3.4 Packet Dropping .....	11
1.4 Quality-of-Service Architectures .....	12
1.4.1 Integrated Services .....	12
1.4.2 Differentiated Services .....	14
1.4.3 End-to-End QoS Mechanisms .....	16
1.5 Implementation and Performance of QoS-aware Applications .....	17
1.5.1 Prerequisites for Successful QoS Applications .....	17
1.5.2 Media Scaling .....	18
1.5.3 Applications' Performance Gain Due to QoS .....	19

1.5.4 Summary .....	20
1.6 Structure of the Book .....	21
<b>2 QoS Measurements in IP-based Networks</b>	
<i>René Serral-Gracià, Jordi Domingo-Pascual, Andrzej Bęben and Philippe Owezarski .....</i> 23	
2.1 Introduction .....	23
2.2 Measurement Metrics .....	24
2.2.1 Network Level .....	24
2.2.2 Call level .....	28
2.2.3 User Level .....	29
2.3 Measurement Techniques .....	33
2.3.1 Previous Considerations .....	33
2.3.2 Base Techniques .....	36
2.3.3 Active Measurements .....	39
2.3.4 Passive Measurements .....	44
2.4 Conclusions .....	48
<b>3 Traffic Engineering</b>	
<i>Luciano Lenzini, Enzo Mingozi and Giovanni Stea .....</i> 49	
3.1 Introduction .....	49
3.2 A Motivating Example .....	50
3.3 Multi-Protocol Label Switching Architecture .....	52
3.3.1 The Forwarding Component .....	53
3.3.2 The Control Component .....	54
3.3.3 MPLS Optimisation .....	56
3.4 MPLS-Based Traffic Engineering .....	58
3.4.1 Constraint-Based Routing .....	58
3.4.2 Explicit Route Signalling .....	61
3.4.3 Traffic Engineering Practices .....	64
3.5 Traffic Engineering and Quality of Service .....	66
3.5.1 QoS Support over MPLS .....	67
3.5.2 Traffic Engineering Extensions for DiffServ .....	70
3.6 Conclusions .....	73
<b>4 Signalling</b>	
<i>Ilaria Marchetti, Antonio Pietrabissa, Massimiliano Rossi, Fernando Boavida, Luís Cordeiro, Edmundo Monteiro and Marilia Curado .....</i> 75	
4.1 Introduction .....	75
4.2 Session Initiation Protocol (SIP) .....	76
4.2.1 SIP and Its Value Propositions .....	76
4.2.2 Protocol Components .....	77
4.2.3 SIP Messages .....	80
4.2.4 Session Description .....	82
4.2.5 Establishment of an SIP Session .....	83

4.2.6 SIP's Extension .....	86
4.3 The Next Steps In Signalling (NSIS) .....	86
4.3.1 Background and Main Characteristics .....	86
4.3.2 Overview of Signalling Scenarios and Protocol Structure .....	89
4.3.3 The NSIS Layer Transport Protocol .....	91
4.4 Common Open Policy Service (COPS) .....	98
4.4.1 COPS Overview .....	98
4.4.2 Basic Model .....	99
4.4.3 COPS Protocol .....	100
4.4.4 COPS Messages .....	102
4.4.5 Common Operation .....	106
4.4.6 Using Examples: COPS for RSVP .....	107
4.5 Conclusions .....	109

## **5 Enhanced Transport Protocols**

*Nicolas Wambeke, Ernesto Exposito, Guillaume Jourjon and*

<i>Emmanuel Lochin .....</i>	111
5.1 Introduction .....	111
5.2 State of the Art of Transport Protocols .....	112
5.2.1 TCP and UDP .....	113
5.2.2 TCP Evolution .....	113
5.2.3 SCTP .....	116
5.2.4 DCCP .....	117
5.2.5 Discussion .....	117
5.3 Transport Mechanisms .....	118
5.3.1 Overview .....	118
5.3.2 Congestion-Control Mechanisms .....	119
5.3.3 Reliability Mechanisms .....	120
5.3.4 Discussion .....	122
5.4 Enhanced Transport Protocol Mechanisms .....	122
5.4.1 TFRC and gTFRC, a QoS-Aware Congestion Control .....	122
5.4.2 Application-Aware Transport Mechanisms .....	123
5.5 Conclusions .....	129

## **6 The EuQoS System**

<i>Michel Diaz, José Enríquez-Gabeiras, Laurent Barresse, Andrzej Beben, Wojciech Burakowski, María Ángeles Callejo-Rodríguez, Jorge Carapinha, Olivier Dugeon, Ernesto Exposito, Mathieu Gineste, Enzo Mingozi, Edmundo Monteiro, Antonio Pietrabissa, Florin Racaru, Jarosław Śliwiński, Giovanni Stea, Halina Tarasiuk, Nicolas Wambeke and Markus Wulff .....</i>	131
6.1 Introduction .....	132
6.2 Architecture .....	133
6.2.1 Goals and Requirements .....	133
6.2.2 Functional Blocks and their Main Functions .....	134
6.2.3 Control Plane Elements: RM and RA .....	137

<b>6.3 Provisioning, Invocation, and Operation, Administration and Management</b>	<b>139</b>
6.3.1 Provisioning Process .....	140
6.3.2 Invocation Process .....	145
6.3.3 Operation, Administration and Management .....	149
<b>6.4 End-to-End Classes of Service in Heterogeneous Networks</b>	<b>149</b>
6.4.1 End-to-end Classes of Service in EuQoS .....	150
6.4.2 QoS Mechanisms and Algorithms for Specification of e2e Classes of Service .....	153
6.4.3 Implementation of e2e Classes of Service in Underlying Technologies.....	155
<b>6.5 EuQoS Enhanced Transport Protocol</b>	<b>161</b>
6.5.1 Introduction .....	161
6.5.2 Enhanced Transport Protocol Services for EuQoS .....	161
6.5.3 Services for Streaming/Nonstreaming Applications .....	162
<b>6.6 Multicast</b>	<b>163</b>
6.6.1 Application Layer Multicast .....	165
6.6.2 Application Layer Multicast in the EuQoS System .....	166
6.6.3 Multicast Middleware .....	168
6.6.4 Introducing QoS to Multicast Middleware .....	170
<b>6.7 Telemedicine Application</b>	<b>172</b>
6.7.1 Telemedicine—the Case for Application-Driven QoS .....	172
6.7.2 Overview of Medigraf .....	173
6.7.3 Medigraf Adaptation to EuQoS .....	174
<b>6.8 Conclusions</b>	<b>176</b>
<b>7 Summary and Outlook</b>	
<i>Torsten Braun and Thomas Staub</i> .....	179
<b>Appendix A: Implementing Protocols on Network Simulators</b>	<b>..</b>
<i>Thomas Staub, Jana Krähenbühl and Torsten Braun</i> .....	181
<b>A.1 Main Simulation Terms and Concepts</b>	<b>181</b>
A.1.1 Simulation Process .....	182
A.1.2 Simulation Types .....	182
<b>A.2 Network Simulation</b>	<b>183</b>
A.2.1 Parallel/Distributed versus Serial Execution of Simulations .....	183
A.2.2 Packet-Level, Fluid-Based and Hybrid Model Simulation .....	184
A.2.3 Simulation Speedup .....	185
A.2.4 Network Simulation in Research .....	185
A.2.5 Simulation for Education Purposes .....	186
<b>A.3 Network Simulators</b>	<b>187</b>
A.3.1 GloMoSim and Qualnet .....	187
A.3.2 JiST/SWANS .....	187
A.3.3 Scalable Simulation Framework (SSF) and SSFNet .....	188
A.3.4 OMNeT++ and OMNEST .....	188

A.4 The Network Simulator ns-2 .....	188
A.4.1 The Language Concept .....	189
A.4.2 Hierarchical Structure .....	189
A.4.3 First Steps—Simulation Script Template .....	190
A.4.4 Nodes, Links and Traffic .....	191
A.4.5 Wireless Networks .....	193
A.4.6 Implementing Protocols with ns-2 .....	196
A.4.7 Advice for Running ns-2 Simulations .....	214
A.4.8 Analysing Methods .....	215

## **Appendix B: Network Emulation Focusing on QoS-Oriented Satellite Communication**

<i>Laurent Dairaine, Mathieu Gineste and Hervé Thalmensy</i> .....	217
B.1 Network Emulation Basics .....	217
B.1.1 Introduction to Network Emulation .....	217
B.1.2 What is Network Emulation? .....	219
B.1.3 Why Use Network Emulation? .....	222
B.1.4 Requirements for Emulation Systems .....	223
B.1.5 Network Emulation System Approaches .....	226
B.2 Case Study: Emulation of QoS-oriented Satellite Communication .....	236
B.2.1 Introduction .....	236
B.2.2 DVB Satellite Communications .....	236
B.2.3 QoS Support for Satellite Network Systems .....	238
B.2.4 Emulation of a DVB-S, DVB-RCS Satellite System .....	239
B.3 Conclusions .....	247
<b>References</b> .....	249
<b>Index</b> .....	261