

# Table of Contents

<b>Introduction.....</b>	<b>1</b>
--------------------------	----------

---

## **Part I**

---

<b>Introduction (Part I).....</b>	<b>5</b>
-----------------------------------	----------

<b>1 Novel Transponder Interfaces: Novel Modulation Formats .....</b>	<b>7</b>
1.1 Introduction.....	7
1.2 Transmission of 8-Level 240 Gb/s RZ-DQPSK-ASK .....	9
1.3 Four Bits per Symbol 16-ary Transmission Experiments .....	11
1.4 Optical Rate Conversion Units.....	13
1.4.1 Optical Packet Compression and Expansion.....	13
1.4.2 Optical Compression/Expansion Loop .....	14
1.4.3 Optical Delay Line Structure .....	15
1.4.4 Scalable Packet Compression/Expansion Units.....	17
1.4.5 Transmission Efficiency .....	20
References.....	21
<b>2 Electronic Channel Equalization Techniques.....</b>	<b>23</b>
2.1 Introduction.....	23
2.2 Electronic Equalizers .....	24
2.3 Fundamental Limits of MLSE Performance with Large Number of States.....	27
2.3.1 No PD-Filter, 8 Samples/Bit.....	28
2.3.2 With PD-Filter, 2 Samples/Bit.....	29
2.3.3 Large Optical Filter, 2 Samples/Bit .....	30
2.3.4 Large Optical Filter, 1 Sample/Bit.....	30
2.3.5 Compensation of SPM Using MLSE.....	31
2.4 Nonlinear Electrical Equalization for Different Modulation Formats .....	33
2.4.1 Introduction of NL-FFE-DFE.....	34
2.4.2 System Setups and Parameters.....	35
2.4.3 EDC Performance for Different Modulation Formats .....	37
2.5 Optical Single Sideband Modulation .....	41
2.5.1 Compensation of Optical Dispersion .....	41

2.5.2	Reduction of Nonlinear Transmission Effects .....	42
2.6	Enhancing the Performance DML Transmitters .....	43
2.7	Conclusions.....	45
	References.....	45
<b>3</b>	<b>Optical Signal Processing Techniques for Signal Regeneration and Digital Logic.....</b>	<b>49</b>
3.1	Optical Regeneration and Wavelength Conversion .....	49
3.1.1	640 Gbit/s Wavelength Conversion Based on XPM in HNLF.....	49
3.1.2	Wavelength Conversion and Regeneration Based on Supercontinuum Generation .....	53
3.1.3	Multi-Wavelength Conversion at 10 Gb/s and 40 GHz Using a Hybrid Integrated SOA Mach-Zehnder Interferometer .....	58
3.1.4	All-Optical Multi-Wavelength Regeneration Based on Quantum-Dot Semiconductor Optical Amplifiers for High Bit Rates.....	63
3.2	Optoelectronic Clock Recovery, Retiming and OTDM Demultiplexing.....	66
3.2.1	320 Gbit/s Clock Transmission and Channel Identification .....	66
3.2.2	Filtering-Assisted Cross-Phase Modulation in a Semiconductor Optical Amplifier Enabling 320 Gb/s Clock Recovery.....	70
3.2.3	640 Gbit/s Data Transmission and Clock Recovery Using an Ultra-Fast Periodically Poled Lithium Niobate Device.....	74
3.2.4	All-Optical Clock Extraction Circuit Based on a Mode-Locked Ring Laser Comprising SOA and FP Filter .....	77
3.2.5	OTDM Demux Based on Induced Modulation on an Auxiliary Carrier by Means of Super-Continuum Generation.....	80
3.2.6	160 Gb/s Retiming Using Rectangular Pulses Generated Using a Superstructured Fibre Bragg Grating.....	86
3.2.7	Timing Jitter Tolerant 640 Gb/s Demultiplexing Using a Long-Period Fibre Grating-Based Flat-Top Pulse Shaper .....	90
	References.....	94
<b>4</b>	<b>Evolution of Optical Access Networks .....</b>	<b>97</b>
4.1	Introduction: FTTX Developments .....	97
4.1.1	FTTX Architectures.....	99
4.1.2	Current Standard PON Deployment Worldwide.....	101
4.2	Emerging Standards for 100 Gbit Ethernet Access and Beyond.....	101
4.2.1	Introduction – Why Higher Speed Ethernet?.....	101

4.2.2	100 Gbit Ethernet Challenges .....	102
4.2.3	Transparent Optical Transmission For 100 Gbit Ethernet .....	103
4.2.4	Future Directions .....	104
4.3	Interoperability of TDM and WDM PONs .....	104
4.3.1	Introduction.....	104
4.3.2	Network Architecture .....	104
4.3.3	Network Routing Performance .....	105
4.3.4	Conclusions.....	107
4.4	3G Radio Distribution over Fibre.....	107
4.4.1	Introduction.....	107
4.5	Optical Wireless for Last Mile Access.....	110
4.5.1	Introduction.....	110
4.5.2	FSO Networks .....	111
4.5.3	Propagation Results .....	112
4.5.4	Conclusions.....	114
4.6	Dynamic Bandwidth Allocation Protocols over GPONs .....	114
4.6.1	Introduction.....	114
4.6.2	Dynamic Bandwidth Allocation Protocols.....	115
4.6.3	Conclusions.....	117
4.7	Innovative Architecture and Control Plane for Metro-Access Convergence .....	117
4.7.1	Motivation for Metro-Access Convergence.....	117
4.7.2	Unified Metro-Access Networks Criteria .....	117
4.7.3	A Few Examples of Unified Metro-Access Networks (UMAN) .....	118
4.7.4	The Success + Network .....	119
4.7.5	The Success + Network Topology .....	120
4.7.6	The Success + UMAN Control Plane .....	120
4.7.7	Conclusion .....	121
4.8	Protection Schemes for PONs.....	121
4.8.1	Evolution of PON Protection Schemes .....	121
4.8.2	Recent PON Protection Architectures.....	122
4.8.3	Hybrid WDM/TDM PON .....	123
4.8.4	Reliability Performance Evaluation .....	124
	References.....	126
<b>5</b>	<b>Novel Switch Architectures .....</b>	<b>133</b>
5.1	Introduction.....	133
5.2	Application of Quantum-Dot SOAs for the Realization of All- Optical Buffer Architectures up to 160 Gb/s.....	136
5.3	Multiwavelength Optical Buffers.....	142
5.3.1	New Buffer Architectures .....	142

5.3.2	Scheduling Algorithms .....	143
5.3.3	Performance Evaluation.....	145
5.4	Multi-Stage Optical Switches with Optical Recirculation Buffers .....	146
5.4.1	The Switching Fabric Architecture .....	146
5.4.2	Scheduling Algorithms for the Single-Stage Shared FDL Switch .....	148
5.4.3	Scheduling Algorithms for the Three-Stage Shared FDL Optical Clos-Network Switch .....	149
5.4.4	Simulation Experiments.....	150
5.5	Optical Asynchronous Packet Switch Architectures .....	152
5.5.1	All-Optical Buffer Technologies .....	152
5.5.2	Node Architectures .....	154
5.5.3	Performance Evaluation.....	156
5.6	Conclusions.....	157
	References.....	158
	<b>Future Outlook (Part I).....</b>	<b>161</b>

---

## Part II

---

	<b>Introduction (Part II) .....</b>	<b>165</b>
<b>6</b>	<b>Cross-Layer Optimization Issues for Realizing Transparent Mesh Optical Networks.....</b>	<b>167</b>
6.1	An Impairment Aware Networking Approach for Transparent Mesh Optical Networks.....	167
6.1.1	Introduction.....	167
6.1.2	Transparent Optical Network Challenges .....	168
6.1.3	Proposed Approach.....	169
6.2	Mutual Impact of Physical Impairments and Traffic Grooming Capable Nodes with Limited Number of O/E/O .....	176
6.2.1	Motivation.....	176
6.2.2	Modelling the Physical Layer Impairments .....	177
6.2.3	The Routing Model.....	179
6.2.4	Simulation Results .....	181
6.3	Conclusion .....	187
	References.....	187
<b>7</b>	<b>Performance Issues in Optical Burst/Packet Switching.....</b>	<b>189</b>
7.1	Introduction.....	189
7.2	OBS/OPS Performance .....	192

7.2.1	Introduction and State-of-the-Art.....	192
7.2.2	On the Use of Balking for Estimation of the Blocking Probability for OBS Routers with FDL Lines.....	193
7.2.3	A Performance Comparison of Synchronous Slotted OPS Switches.....	196
7.2.4	A Performance Comparison of OBS and OpMiGua Paradigms .....	197
7.3	Burstification Mechanisms.....	201
7.3.2	Delay-Throughput Curves for Timer-Based OBS Burstifiers with Light Load.....	203
7.3.3	Performance Evaluation of Adaptive Burst Assembly Algorithms in OBS Networks with Self-Similar Traffic Sources.....	206
7.4	QoS Provisioning .....	209
7.4.1	Introduction and State-of-the-Art.....	209
7.4.2	Performance Overview of QoS Mechanisms in OBS Networks.....	211
7.4.3	Evaluation of Preemption Probabilities in OBS Networks with Burst Segmentation.....	214
7.5	Routing Algorithms.....	216
7.5.1	Introduction and State-of-the-Art.....	216
7.5.2	Optimization of Multi-Path Routing in Optical Burst Switching Networks.....	218
7.6	TCP over OBS Networks .....	220
7.6.1	Introduction and State-of-the-Art.....	220
7.6.2	Burst Reordering Impact on TCP over OBS Networks .....	221
7.7	Conclusions.....	227
	References.....	228
<b>8</b>	<b>Multi-layer Traffic Engineering (MTE) in Grooming Enabled ASON/GMPLS Networks .....</b>	<b>237</b>
8.1	Introduction.....	237
8.2	Routing and Grooming in Multi-layer Networks .....	238
8.2.1	Basic Schemes .....	239
8.2.2	Adaptive Integrated Multi-layer Routing.....	239
8.2.3	Simulation Study .....	242
8.3	Improvements for Multi-layer Routing and Grooming Schemes .....	246
8.3.1	Online Optimization at Connection Teardown .....	247
8.3.2	Admission Control for Improving Fairness .....	248
8.4	Evaluation of Traffic and Network Patterns.....	249
	References.....	251

<b>9</b>	<b>Network Resilience in Future Optical Networks.....</b>	<b>253</b>
9.1	Introduction.....	253
9.2	Terminology.....	254
9.3	Basic Resilience Techniques and Failure Management .....	256
9.4	Resilient Network Performance Improvement, Evaluation	
	Methods and Parameters .....	257
9.4.1	Availability Calculation in Optical Network .....	257
9.4.2	Recovery Time.....	262
9.4.3	Network Performance Improvement through Differentiated Survivability .....	264
9.5	Security Issues in Transparent Optical Networks .....	270
9.6	Multilayer Resilience .....	272
9.6.1	Single Layer Recovery in Multilayer Networks .....	273
9.6.2	Interworking between Layers .....	275
9.6.3	Multilayer Survivability Strategies .....	278
9.6.4	Logical Topology Design .....	281
9.7	Conclusions.....	282
	References.....	283
<b>10</b>	<b>Optical Storage Area Networks .....</b>	<b>285</b>
10.1	Introduction.....	285
	10.1.1 Storage Area Networks (SANS) .....	286
	10.1.2 Data Mirroring Techniques.....	287
10.2	Network Architectures .....	287
10.3	Proposed Mirroring Technique .....	290
10.4	Performance Evaluation.....	291
	10.4.1 Single Section Ring Architecture.....	291
	10.4.2 Two Sections Ring Architecture.....	299
10.5	Conclusions.....	301
	References.....	302
	<b>Future Outlook (Part II) .....</b>	<b>303</b>

---

**Part III**


---

<b>Introduction (Part III)</b> .....	<b>307</b>
<b>11 Software Tools and Methods for Modelling Physical Layer Issues</b> .....	<b>309</b>
11.1 Modelling of Optoelectronic Components (Lasers and Semiconductor Optical Amplifiers) .....	309
11.1.1 Introduction.....	309
11.1.2 Frequency-Domain Approaches .....	309
11.1.3 Time-Domain Models.....	310
11.1.4 Lumped-Element Models.....	311
11.1.5 Distributed Time-Domain Models.....	312
11.1.6 Modeling of Hybrid Mode-Locked Lasers .....	313
11.1.7 Modelling of Travelling-Wave Semiconductor Optical Amplifiers .....	314
11.2 Simulation Tool MOVE-IT.....	317
11.3 Numerical Models for Simulation of Transient Effect in Raman Fibre Amplifiers.....	320
11.4 Split-Step-Fourier-Method in Modeling of WDM Links.....	325
11.4.1 Pre-simulated Local Errors S-SSMF.....	326
11.4.2 Results .....	327
11.4.3 Conclusions.....	328
References.....	329
<b>12 Software Tools and Methods for Research and Education in Optical Networks</b> .....	<b>331</b>
12.1 Models and Simulations.....	331
12.1.1 Modelling.....	332
12.1.2 Simulation Techniques .....	333
12.1.3 Simulation and Model Verification.....	334
12.1.4 Summary on Modelling .....	334
12.2 Tool Integration Perspectives.....	335
12.2.1 Integration: Definitions.....	336
12.2.2 Obstacles to Integration and Possible Diversions .....	337
12.2.3 Conclusions and Future Outlook .....	338
12.3 Modelling with OPNET: A Practical Example .....	339
12.3.1 OPNET Domains .....	339
12.3.2 The OPNET Project Editor .....	340
12.3.3 Developing Models with OPNET: Conclusion.....	343
12.4 Simulation of ASON/GMPLS Using OMNET++ Simulator.....	344
12.4.1 The OMNET Simulator and the INET Framework .....	345

12.4.2 IP/MPLS over ASON/GMPLS Simulator .....	347
12.4.3 Conclusions.....	349
12.5 WDM Network Planning: The MatPlanWDM Tool .....	350
12.5.1 Distinctions Between Planning Problems .....	350
12.5.2 Integrated Tool.....	352
12.5.3 Extension of the Tool.....	352
12.6 The Javanco Environment.....	354
12.6.1 History and Predecessors .....	354
12.6.2 General Architecture.....	355
12.6.3 Utilisations.....	359
12.6.4 Future Developments and Conclusion .....	359
12.7 IKR Simulation Library .....	359
12.7.1 Conceptual Structure.....	360
12.7.2 Libraries .....	361
12.7.3 Application of the Simulation Library .....	361
12.7.4 Summary .....	362
References.....	362
<b>Future Outlook (Part III).....</b>	<b>365</b>
<b>Future Outlook.....</b>	<b>367</b>