

ATM & MPLS Theory & Application

Foundations of Multi-Service Networking

- Get details on current standards within ATM, frame relay, and IP (MPLS) technology
- Solve network and application problems with speed and precision
- Understand how MPLS supports cost-effective IP networking
- Preview the future role of multi-service ATM and MPLS networks

DAVID E. MCDYSAN AND DAVE PAW

CONTENTS

Introduction	xix
------------------------	-----

Part I

▼ 1	Introduction to ATM and MPLS and Overview of the Book	3
	Overview of This Book	6
	Review	12
▼ 2	Background and Motivation for ATM and MPLS Networking	13
	A Brief History of Communications	14
	Recurring Trends in Encoding and Relaying	14
	Data Networking: Enabling Computers to Communicate.	15
	Changing Organizations of People and Networks	16
	Defining the Demand for Communications	17
	Residential and Commercial Users	17
	Applications and Networks Change Faster Than Behavior	18
	Geographical Aspects of Networking	18
	The End Result: Tremendous Internet and Data Traffic Growth	19
	Technology Trends	19
	Processor and Memory Cost Trends: Moore's Law	19
	Distributed Computer Communications Protocols	20
	Modernization of Transmission Infrastructures	20
	Faster and Farther, but Never Free	21

The Accelerating Bandwidth Principle	21
Worldwide Cooperation for Standards	22
Review	24
▼ 3 ATM- and MPLS-Related Standards Bodies	25
ATM- and MPLS-Related Standards Bodies	26
International Telecommunications Union (ITU)	27
ATM Forum	27
Internet Engineering Task Force (IETF)	28
Frame Relay Forum	29
MPLS Forum	29
DSL Forum	30
Other B-ISDN/ATM Standards Bodies	30
Creating Standards: The Players	30
Vendors	30
Users	31
Network Service Providers	31
Creating Standards: The Process	32
Charter and Work Plan	33
Meetings and Contributions	33
Drafting and Review	33
Approval and Consensus	34
User Acceptance and Interoperability	34
Other Aspects of Standards	35
Business and Politics	35
Measures of Success and Proven Approaches	35
Predicting the Future of Standardization	36
Review	36

Part II

▼ 4 Networks, Circuits, Multiplexing, and Switching	39
General Network Topologies	40
Point-to-Point	41
Multipoint and Broadcast	42
Star	44
Ring	45
Mesh	46
Data Communications and Private Lines	47
Simplex, Half-Duplex, and Full-Duplex Transmission	47
DTE-to-DCE Connections	48
Private Lines	50
Data Transmission Methods	50
Asynchronous and Synchronous Data Transmission	51
Asynchronous Versus Synchronous Transfer Modes	52
Principles of Multiplexing and Switching	53
Multiplexing Methods Summarized	54
Space Division Multiplexing (SDM)	54
Frequency Division Multiplexing (FDM)	54
Time Division Multiplexing (TDM)	55
Address or Label Multiplexing	55

Code Division Multiple Access (CDMA)	55
Point-to-Point Switching Functions	56
Point-to-Multipoint Switching Functions	56
Examples of Multiplexing	57
Examples of Switching	62
Review	67
▼ 5 Basic Protocol Concepts	69
A Brief History of Packet Switching	70
Early Reasons for Packet Switching	71
Principles of Packet Switching	71
Darwin's Theory and Packet-Switching Evolution	73
Basic Protocol Layering Concepts	75
Open Systems Interconnection Reference Model	77
Layers of the OSI Reference Model	81
Physical Layer	81
Data Link Layer	82
Network Layer	83
Transport Layer	83
Session Layer	84
Presentation Layer	84
Application Layer	84
Mapping of Generic Devices to OSI Layers	84
Layered Data Communication Architectures	85
Internet Protocol (IP) Architecture	85
IBM's Systems Network Architecture (SNA)	86
IEEE 802.X Series (LAN/MAN/WAN)	87
Integrated Services Digital Network Protocol Architecture	89
Network Service Paradigms	91
Connection-Oriented Network Service (CONS)	91
Connectionless Network Services (CLNS)	92
Connection-Oriented Versus Connectionless	
Services Analogy	94
Review	94
▼ 6 Time Division Multiplexing and the Narrowband Integrated Services Digital Network	95
Circuit Switching	96
History of Circuit Switching	96
Digitized Voice Transmission and Switching	97
Digital Data Circuit Switching	98
Private-Line Networks	100
Private (Leased)-Line Characteristics	100
Private-Line Networking	100
Permanent Versus Switched Circuits	103
Digital Time Division Multiplexing (TDM)	104
Plesiochronous Digital Hierarchy (PDH)	104
SONET and the Synchronous Digital Hierarchy (SDH)	106
Basic SONET Frame Format	110
Basics and History of Narrowband ISDN (N-ISDN)	113
Narrowband ISDN Basics	113
BRI and PRI Service and Protocol Structures	115
ISDN D-Channel Signaling	117
Review	119

▼ 7	Connection-Oriented Protocols—X.25 and Frame Relay	121
	Packet Switching	122
	Origins of X.25	122
	Protocol Structure	123
	Networking Context	124
	SDLC, HDLC, and X.25's Link Layer Protocol	125
	Packet Layer Format and Protocol	131
	Control Functions	133
	Example of X.25 Operation	133
	Traffic and Congestion Control Aspects of X.25	135
	Service Aspects of X.25	137
	Frame Relay—Overview and User Plane	137
	Origins of Frame Relay	137
	Frame Relay Protocol Structure	138
	Frame Relay Networking Context	139
	Frame Format	140
	Frame Relay Functions	142
	Example of Frame Relay Operation	143
	Traffic and Congestion Control Aspects of Frame Relay	144
	Service Aspects of Frame Relay	147
	Frame Relay—Control Plane	149
	Frame Relay Control Protocol Networking Context	149
	Frame Relay Standards and Specifications	150
	Frame Relay PVC Status Signaling	152
	Frame Relay PVC Status Signaling Example	155
	Multilink Frame Relay	157
	Frame Relay Service Level Agreements (SLAs)	159
	Frame Relay Operations, Administration, and Maintenance	161
	Frame Relay Fragmentation and Compression	164
	Frame Relay Privacy	166
	Frame Relay Switched Virtual Connections (SVCs)	168
	Example of Frame Relay SVC Operation	168
	Frame Relay Signaling Message Information Elements	169
	Review	174
▼ 8	Connectionless Protocols—IP and SMDS	175
	The Internet Protocol SUITE, TCP/IP	176
	Origins of TCP/IP	176
	TCP/IP Protocol Structure	177
	TCP/IP Networking Context	178
	Generic Link Layer Protocols for IP	180
	IP Version 4 (IPv4) Packet Format	182
	Internet Protocol (IP) Addressing	183
	Next Generation IP—IPv6	184
	Quality of Service in IP Networks	186
	Transmission Control Protocol (TCP)	190
	User Datagram Protocol (UDP)	196
	Real-Time Transport Protocol (RTP)	196
	Service Aspects of TCP/IP	198
	Switched Multimegabit Data Service (SMDS)	198
	Origins of SMDS	198
	SMDS/IEEE 802.6 Protocol Structure	199
	SMDS/802.6 Protocol Data Unit (PDU) Formats	199

DQDB and SMDS Operation	202
Example of SMDS over DQDB Operation	204
Traffic and Congestion Control Aspects of DQDB and SMDS	204
Service Aspects of SMDS	205
Review	206

▼ 9 LANS, Bridging, and Routing	207
Bridging, Routing, and Internetworking	208
Basic Terminology	208
Address Assignment and Resolution	210
Routing, Restoration, and Reconfiguration	211
IEEE Local Area Networking (LAN) Standards	212
Layered LAN Protocol Model	213
Typical LLC and MAC Sublayer Implementations	213
The Logical Link Control (LLC) Sublayer	214
The Media Access Control (MAC) Sublayer	215
Ethernet and the CSMA/CD 802.3 MAC Sublayer	217
Ethernet User Priority and VLANs	219
Token Ring	220
100 Mbps Fast Ethernet	222
100VG-AnyLAN	223
Gigabit and 10 Gbps Ethernet	224
Fiber Distributed Data Interface (FDDI)	224
Basic Fiber Distributed Data Interface (FDDI)	225
Hybrid Ring Control (FDDI-II)	228
Bridging Concepts, Systems, and Protocols	229
Bridging Context	230
A Taxonomy of Bridges	231
Spanning Tree Protocol	232
Source Routing Protocol	233
Bridge Network Design	234
Routing Concepts, Systems, and Protocols	235
Packet-Forwarding and Routing Protocol Functions	235
Link-State Routing Protocols Defined	238
Routing and Logical IP Subnetworks (LISs)	242
Address Resolution Protocol (ARP)	245
Bridging and Routing Systems Design	247
Review	249

Part III

▼ 10 Introduction to ATM and MPLS	253
Introduction to ATM and B-ISDN	254
B-ISDN Protocol Reference Model	254
B-ISDN Architecture	255
Overview of the Application of ATM	256
ATM as a Technology	257
ATM as a Protocol	257
ATM as an Interface	258
ATM as Integrated Access	259

ATM as an End-to-End Service	261
ATM as a Scalable Infrastructure	261
Origins of MPLS: Reinventing IP over ATM	263
Ipsilon's IP Switching	265
Toshiba's Cell Switching Router (CSR)	267
Cisco's Tag Switching	267
IBM's Aggregate Route-Based IP Switching (ARIS)	270
Early IETF Multiprotocol Label Switching (MPLS)	272
Introduction to MPLS	274
Traffic Engineering of IP Networks	275
Network-Based IP VPN using MPLS Tunneling	276
Multi-Service MPLS Tunneling	276
Considerations in the Choice of Cells Versus Frames	277
Effect of Link Speed on Packet Performance	277
Rationale for the Choice of ATM Cell Size	278
Hardware Price-Performance Trade-offs	279
Review	280

▼ 11 ATM and MPLS: Physical Layer and Label Switching Functions	281
Overview of Physical, ATM, and AAL Layer Functions	282
B-ISDN Protocol Layer Structure	283
Hardware and Software Implementations of B-ISDN Layers	284
ATM Physical Layer	285
Physical Medium-Dependent Sublayer	285
Transmission Convergence (TC) Sublayer	287
TC Header Error Check (HEC) Functions	288
TC Cell Rate Decoupling	290
Inverse Multiplexing over ATM	290
xDSL Physical Layer for ATM	292
ATM Layer	296
ATM UNI and NNI Defined	296
ATM Virtual Paths and Channels (VPs and VCs)	297
The ATM Cell	302
ATM-Layer QoS and Service Categories	306
Multiprotocol Label Switching (MPLS)	308
IP over MPLS Architecture and Terminology	308
MPLS Forwarding Operations	309
Example of MPLS Forwarding of IP Packets	312
MPLS Encapsulation Standards	312
MPLS Shim Header	312
MPLS over ATM	315
MPLS over Frame Relay	317
Review	318
▼ 12 ATM Adaptation and MPLS Tunneling Protocols	319
ATM Adaptation Layer (AAL)	320
ATM Adaptation Layer (AAL)—Protocol Model	320
AAL Protocol Structure Defined	321
Key AAL Attributes	322
ATM Adaptation Layer 1 (AAL1)	323
AAL1 Segmentation and Reassembly (SAR) Sublayer	324
AAL1 Convergence Sublayer Functions	325

Structured Data Transfer (SDT) Convergence Sublayer	327
Unstructured Mode Convergence Sublayer	329
AAL1 Clock Recovery Methods	330
ATM Adaptation Layer 2 (AAL2)	332
AAL2 Protocol Structure and PDU Formats	333
Example of AAL2 Operation	335
ATM Adaptation Layer 3/4 (AAL3/4)	337
AAL3/4 SAR Sublayer	337
AAL3/4 CPCS Sublayer	338
Example of AAL3/4 Operation	339
AAL3/4 Multiplexing Example	340
ATM Adaptation Layer 5 (AAL5)	340
AAL5 Segmentation and Reassembly (SAR) Sublayer	342
AAL5 Common Part Convergence (CPCS) Sublayer	342
Example of AAL5 Operation	343
AAL5 Multiplexing Example	344
Multi-Service Tunneling over MPLS (and Other Protocols)	346
General Concept of Protocol Tunneling	346
ATM Forum's ATM over MPLS Network Interworking	348
IETF Pseudo Wire Emulation Edge to Edge (PWE3)	350
"Martini" Multi-Service Encapsulation	351
Review	352
▼ 13 Higher-Level User and Control Plane Protocols	353
Overview of Higher-Layer ATM and MPLS Protocols	354
Circuit Emulation Voice, Video, and WAN Data Protocols	354
Local Area Networking and IP-Based Applications	356
ATM Service Category and AAL Support for Applications	358
Overview of ATM and MPLS Control Plane Protocols	358
Generic Control Plane Functions	359
Switched and Permanent ATM Virtual Connections	359
ATM Control Plane Protocols	360
MPLS Control Plane Protocols	361
ATM Control Plane Structure and AAL	361
ITU-T B-ISDN Signaling Protocols	362
Types of Signaling Channel Association	363
Layered Signaling AAL Model	365
Service Specific Coordination Function (SSCF)	365
Service Specific Connection-Oriented Protocol (SSCOP)	366
ATM User-Network Interface (UNI) Signaling	368
Base Signaling Functions: Q.2931 and UNI 3.1	368
ATM Forum UNI Signaling 4.0 and ITU-T Standards	368
ATM Forum UNI Signaling 4.1 and ITU-T Standards	370
UNI 4.1 Signaling Message Types	371
Signaling Message Information Elements	372
Examples of ATM Signaling Procedures	373
ATM Control Plane Addressing	378
Control Plane Addressing Levels	378
ATM Level Addressing	379
ATM Addressing Formats	379
ATM Forum ATM End System Address (AESA) Formats	381
Group Addresses and Anycast	382

ILMI Address Registration	383
Bi-Level Addressing	384
ATM Name Service (ANS)	384
Review	385
▼ 14 MPLS Signaling and Routing Protocols	387
MPLS Control Plane Architecture	388
MPLS Control and Forwarding Plane Model	388
Motivation for Constraint-Based Routing	389
MPLS Label Distribution Control Protocol Attributes	391
MPLS Label Distribution Signaling Protocols	397
Label Distribution Protocol (LDP)	397
RSVP Traffic Engineering (RSVP-TE)	400
Constraint-Based Routing LDP (CR-LDP) Extensions	404
Use of BGP for Label Distribution	405
IGP Traffic Engineering Extensions: OSPF and IS-IS	407
General Modifications for Traffic Engineering	407
Specific Modifications for IS-IS TE	408
Specific Modifications for OSPF-TE	408
Open Issues and Challenges Ahead	409
Example Applications of MPLS in IP Networks	409
Traffic Engineering in an IP Backbone	409
Label Distribution in Support of Other Services	411
MPLS Connectivity Across Multiple Providers	412
Review	413
▼ 15 ATM NNI Signaling and Routing Protocols	415
Interim Interswitch Signaling Protocol (IISP)	416
Private Network-Network Interface (PNNI)	416
Architecture and Requirements	417
Network Addressing Philosophy	418
A Tale of Two Protocols	419
PNNI Routing Hierarchy and Topology Aggregation	420
Beyond Connectivity to Quality and Bandwidth	427
Soft Permanent Virtual Connections (SPVCs)	431
Minimum Interoperable PNNI 1.1 Subset	432
Broadband InterCarrier Interface (B-ICI)	433
B-ISDN User Services Part (BISUP)	433
B-ICI's Replacement: ATM Inter-Network Interface (AINI)	434
Extended PNNI and AINI Routing and Signaling Capabilities	436
Review	439

Part IV

▼ 16 Enabling Voice, TDM, and Video Over ATM and MPLS	443
Packet Voice Networking	444
General Network Architecture	445
Media Gateway Functions	446
Packet Voice Encoding Standards	446
Quality Considerations	448

Voice Trunking Using ATM and MPLS	449
Voice over ATM (VoATM) Trunking	450
Voice over MPLS (VoMPLS) Trunking	457
Broadband Local Loop Emulation Using AAL2	459
Circuit Emulation Using ATM and MPLS	463
AAL1-Based Circuit Emulation Service (CES)	463
Circuit Emulation over MPLS	466
Video over ATM and Packet Networks	467
Commonly Used Video Coding Standards	467
MPEG-2 Video Over ATM and Packet Networks	468
QoS Considerations Related to Video	471
Review	472
▼ 17 Connection-Oriented Protocol Support	473
Interworking, Access, and Trunking	474
Overview of Frame Relay/ATM Interworking	477
Frame Relay/ATM Network Interworking	478
FR Service-Specific Convergence Sublayer (FR-SSCS)	479
Status Signaling Conversion	480
Congestion Control and Traffic Parameter Mapping	480
Frame Relay/ATM Service Interworking	481
Status Signaling Interworking	482
Address Resolution Protocol Interworking	483
FR/ATM SVC Service Interworking	484
FR/ATM Interworking Applied	486
ATM Access to SMDs	488
Frame-Based Interfaces Supporting ATM	489
ATM Data Exchange Interface (DXI)	489
Frame-Based User-Network Interface (FUNI)	493
Frame-Based ATM over SONET/SDH Transport (FAST)	496
Frame-Based ATM Transport over Ethernet (FATE)	497
MPLS-Based Support for Link Layer Protocols	498
Pseudo-Wire and Service Emulation Considerations	499
Martini Encapsulation and Transport of FR, AAL5, ATM, and HDLC	500
FR over MPLS Network Interworking	502
Review	503
▼ 18 ATM and MPLS Support for LAN Protocols	505
Multiprotocol Encapsulation over AAL5	506
Protocol Encapsulation	506
VC-Based Multiplexing	508
Considerations in the Selection of Multiplexing Method	510
ATM Forum LAN Emulation (LANE)	511
Hardware and Software in an Emulated LAN	511
LANE Components and Connection Types	514
Summary of LANE Operation	514
LANE and Spanning Tree	518
LANE Implementation Considerations	519
Ethernet over MPLS	520
Martini Encapsulation of Ethernet over MPLS	520
Virtual Private LAN Service (VPLS)	521

VPLS and Access to the Internet	525
Interworking Network Layer Protocols over MPLS	526
Metropolitan and Wide Area Ethernet over MPLS Networking	528
Review	530

▼ 19 ATM and MPLS Support of Enterprise-Level IP Networks	531
IP over ATM Virtual Private Networks	533
Classical IP over ATM	533
Multiprotocol over ATM (MPOA)	537
IP Multicast over ATM	542
IP Virtual Private Networks (VPN) over MPLS or IP Tunnels	545
General Virtual Private Network (VPN) Terminology and Concepts	545
Network-Based IP VPN Concepts	548
Aggregated Routing Network-Based VPNs Using Tunnels	550
Virtual Router Network-Based VPNs using Tunnels	554
Considerations and Trade-offs with Network-Based IP VPNs	556
Considerations Regarding Choice of Tunnel Type	557
VPN Representations and Configuration Complexity	558
IP Path Maximum Transfer Unit (MTU) Discovery	560
MTU Path Discovery over AAL5	560
MTU Path Discovery over MPLS	561
Review	562

Part V

▼ 20 The Traffic Contract and Quality of Service (QoS)	565
The Traffic Contract	566
Reference Models	567
Generic Allocation of Impairments Model	567
ATM Equivalent Terminal Model	568
Diffserv Per-Hop and Per-Domain Behavior Models	569
Quality Of Service	571
Application QoS Requirements	571
ATM QoS Parameters	573
IP Performance Metrics (IPPM)	578
Traffic Parameters and Conformance Definitions	579
ATM Traffic Descriptor	579
IP Traffic Descriptor	582
ATM Conformance Definitions	583
IP Traffic Conformance Definitions	585
Classes of Service	586
ATM Forum QoS Classes and Service Categories	586
ITU-T ATM QoS Classes	588
Mapping Between ATM Forum and ITU-T QoS Definitions	591
Diffserv Per-Hop Behaviors (PHBs)	594
MPLS Support for Diffserv	595

Comparison of ATM and IP QoS and TrafficParameters	596
ATM Service Categories Optimized for Packet Switching	597
Guaranteed Frame Rate (GFR)	597
Switch Modifications to Support GFR	601
UBR with BSC and MDCR	603
Use of Differentiated UBR to Support Diffserv	604
Use of Differentiated UBR to Support IEEE 802.x	605
UBR Service Category with Optional MDCR Parameter	605
Review	607
▼ 21 Traffic Control, QoS Mechanisms, and Resource Management	609
Achieving Conformance	610
Checking Conformance: Policing	612
ATM Policing	613
Examples of Leaky Bucket Policing	613
Generic Cell Rate Algorithm (GCRA) and	
Virtual Scheduling	619
IP and MPLS Policing	620
Ensuring Conformance: Shaping	624
Overview of Possible Shaping Methods	625
Leaky Bucket Buffering	626
Token Bucket Shaping	627
Delivering QoS: Prioritization, Queuing, and Scheduling	630
Prioritized Queuing and Scheduling	630
Priority Discard Thresholds	631
Performance Implications of Priority Control	632
Overview of Weighted Scheduling Algorithms	633
Meeting the Traffic Contract: Resource Management	634
Admission Control	634
ATM VPs and Label Stacked MPLS LSPs	638
Review	640
▼ 22 Congestion Control	641
Congestion: A Familiar Phenomenon	642
The Nature of Congestion	642
Busy Seasons, Days, and Hours	643
Impact of Congestion	644
Examples of Congestion in a Network	644
Congestion Control: A Range of Solutions	645
Open- and Closed-Loop Congestion Control	645
Impact of Congestion on Performance	646
Categorization of Congestion Control Approaches	649
Congestion Management	652
Resource Allocation	652
Network Engineering	652
Congestion Avoidance	653
Congestion Indication	653
Policing and Tagging	654
Connection Blocking	654
Closed-Loop Flow Control	654
Generic Closed-Loop Flow Control Methods	655
ATM Generic Flow Control (GFC)	656

Available Bit Rate	657
The Great Rate Versus Credit Debate	659
Congestion Recovery	667
Selective Discard	667
Early/Partial Packet Discard (EPD/PPD)	668
Dynamic Usage Parameter Control (UPC)	670
Disconnection and/or Rerouting	670
Operational Procedures	671
Review	671

Part VI

▼ 23 Basic Communications Engineering	675
Philosophy	676
Communications Channel Model	676
Deterministic Versus Random Modeling	677
Probability Theory	677
Randomness in Communications Networks	677
Random Trials and Bernoulli Processes	678
The Normal/Gaussian Distribution	678
Common Digital Signals and Their Spectra	679
The Telegraph Pulse: Binary On/Off Keying	680
A Better Way: Pulse Shaping	681
Pushing the Envelope: Quadrature Amplitude Modulation	681
Error Models and Channel Capacity	685
Typical Communications Channel Error Models	685
Shannon's Channel Capacity	686
Error Performance of Common Modulation Methods	688
Error-Detecting and -Correcting Codes	689
Simple Parity Check Schemes	689
Cyclical Redundancy Check (CRC) Codes	690
Performance of ATM's HEC	691
Undetected Error Performance of HDLC and AAL5	694
Data Compression	694
Review	696
▼ 24 Traffic Engineering	697
Philosophy	698
Source Model Traffic Parameter Characteristics	698
Modeling Accuracy	699
Overview of Queuing Theory	699
General Source Model Parameters	699
Poisson Arrivals and Markov Processes	702
Queuing System Models	705
Call Attempt Rates, Blocking, and Queuing	708
Statistical Model for Call Attempts	708
Erlang's Blocked Calls Cleared Formula	709
Erlang's Blocked Calls Held Formula	711
Performance of Buffering Methods	713
Input Versus Output Queuing Performance	713

Output Buffer Overflow Probability	714
Shared Buffer Performance	716
Deterministic Constant Rate Performance	718
Equivalent Capacity	720
Fluid Flow Approximation	721
Statistical Multiplex Gain Model	722
Equivalent Capacity Approximation	726
Priority Queuing Performance	728
Review	730

▼ 25 Design Considerations	731
Impacts of Delay, Loss, and Delay Variation	732
Impact of Delay	732
Impact of Loss	735
Impact of Delay Variation	738
TCP Performance Considerations	742
TCP Window Size Impact on Throughput	742
TCP over ATM: UBR and ABR	742
TCP/IP Performance in a Congested Scenario	743
Voice and Data Integration	745
Voice Traffic Model	745
Statistically Multiplexing Voice Conversations	746
Voice/Data Integration Savings	747
Overview of the Network Planning and Design Process	748
Network Design Approaches and Modeling Philosophy	749
Measuring Traffic and Performance Data	750
Analyzing and Simulating Candidate Networks	
and Technology	751
Practice Makes Perfect	752
Network Design and Modeling Tools	753
Design Tool Graphical User Interface (GUI)	753
Specifying Design Scenarios	754
Modeling Network-Specific Capabilities	755
Displaying and Comparing Results	755
Review	756

Part VII

▼ 26 Operational Philosophy and Network Management Architectures	759
OAM&P Philosophy	760
Administration	760
Provisioning	761
Operations	762
Maintenance	762
Unique Challenges Created by ATM	763
Unique Challenges Created by MPLS	763
Network Management Architectures	764
Centralized Versus Distributed Network Management	764
OSI Network Management Functional Model	765

ITU Telecommunications Management Network (TMN)	766
ITU-T Generic Transport Network Architecture	769
ATM Forum Network Management Architecture	772
Review	773
▼ 27 Network Management Protocols and Management Information Bases (MIBs)	775
Network Management Protocols	776
IETF Simple Network Management Protocol (SNMP)	776
ITU-T Common Management Interface Protocol (CMIP)	780
Proprietary Network Management Protocols	781
Considerations on Choice of Network Management Protocol	782
ATM Management Information Bases (MIBs)	782
ATM Forum Integrated Local Management Interface (ILMI)	783
IETF AToM MIBs	786
Other ATM MIBs	787
MPLS Management Information Bases (MIBs)	787
Label Switch Router (LSR) and Related MIBs	788
Traffic Engineering (TE) MIBs	789
Multiservice PPVPN and PWE3 MIBs	789
IP-Based Management Tools for MPLS	790
ICMP PING and Traceroute	790
Vendor-Proprietary ICMP Extensions for MPLS	791
IETF Direction for IP-Based MPLS Management	792
Review	793
▼ 28 ATM and MPLS Management and Performance Measurement	795
ATM OAM Flow Reference Architecture	796
ATM OAM Cell Formats	798
ATM OAM Fault Management	800
AIS and RDI Theory and Operation	800
Loopback Operation and Diagnostic Usage	802
Continuity Check (CC)	806
ATM Protection Switching	806
ATM Performance Specification and Measurement	810
Network Performance and Quality of Service	810
ATM Performance Measurement (PM)	810
NP/QoS Parameter Estimation	814
MPLS OAM Status and Direction	819
Overview of ITU Direction for MPLS OAM	819
MPLS Protection Switching and Fast Rerouting	820
Review	820
Part VIII	
▼ 29 Design Considerations for ATM and MPLS Networks	825
Efficiency Analysis	826
Circuit Emulation Efficiency	826
Packetized Voice Efficiency	828
Efficiency of Cells Versus Frames for Packet Switching	829

IP/ATM, IP/MPLS, and IP/SONET Efficiency	831
Packet Video Efficiency	834
Multiservice Efficiency Comparison	835
Scalability Analysis	837
Addressing and Hierarchy	837
Supported User and Routing Table Growth	838
Packet Forwarding and Moore's Law	839
Connection-Oriented Versus Connectionless Paradigms	840
Support for a Wide Range of Interfaces and Speeds	841
Capacity Bottlenecks	842
Complexity Analysis	842
To Switch or Not to Switch? An Answer to This Question	842
Keep It Simple to Succeed	843
Hardware Is Hard, but Software Is Harder	843
Are QoS and Bandwidth Reservation Really Necessary?	844
Reliability, Availability, and Stability	846
Supportability and Operability	847
Security	847
Review	848
▼ 30 Future Directions and Applications Involving MPLS and ATM	851
Future Directions and Applications of ATM	852
Multiservice Backbone Network Infrastructure	852
Convergence and Integrated Access	853
Lessons Learned from ATM for Multiservice Networking	853
Don't Operate at the Per-Flow Level	853
Use Basic QoS and Traffic Management on Aggregates	854
Use Bandwidth Reservation for Constraint-Based Routing	854
Assume a Heterogeneous Underlying Network	854
Future Applications and Directions of MPLS (and IP)	855
Next Generation Multiservice Network Infrastructure	855
Optical Networking for Scalability	855
Generalized MPLS (GMPLS)	857
Separation of Forwarding and Control	860
Possible Future of Multiservice Networking	861
What Will Continue the Internet's Explosive Growth?	861
Will MPLS Become the Ubiquitous Multiservice Network?	862
Will GMPLS Effectively Control Next-Generation Backbones?	863
What Will Happen to ATM?	863
Review	863
▼ A Acronyms and Abbreviations	865
▼ B References	881
▼ Index	913