

Contents

Telcordia SR-5237-Documentation Information

1 Introduction

| | |
|---|-----|
| 1.1 Purpose and Scope | 1-2 |
| 1.2 Organization of This Document | 1-3 |

2 Current Optical Networks and Reasons to Evolve

| | |
|--|-----|
| 2.1 Looking Back | 2-1 |
| 2.2 Optical Networks Today | 2-2 |
| 2.3 Looking Forward – Trends in Technology and Networks | 2-6 |
| 2.4 Network Operator Reasons for Optical Network Evolution | 2-7 |
| 2.5 Selecting an Evolution Path for an Optical Network | 2-9 |

3 Optical Technologies and Networks – Roadmap

| | |
|---|------|
| 3.1 Optical Technologies – The Building Blocks | 3-3 |
| 3.1.1 Long-Haul Technologies | 3-3 |
| 3.1.1.1 Dense Wavelength Division Multiplexing (DWDM) | 3-5 |
| 3.1.1.2 Ultra Long-Haul DWDM | 3-7 |
| 3.1.1.3 OC-768 | 3-8 |
| 3.1.1.4 ITU-T Optical Transport Network (OTN) | 3-9 |
| 3.1.1.4.1 The OPU/ODU Layer | 3-10 |
| 3.1.1.4.2 The OTU Layer | 3-11 |
| 3.1.1.4.3 OCh Layer | 3-11 |
| 3.1.1.4.4 OMS Layer | 3-12 |
| 3.1.1.4.5 OTS Layer | 3-12 |
| 3.1.1.4.6 The Physical Media Layer | 3-13 |
| 3.1.1.5 Cross-Connects for Optical Networks | 3-15 |
| 3.1.2 Metro Technologies and Network Elements | 3-19 |
| 3.1.2.1 Metro DWDM and Coarse Wavelength Division Multiplexing (CWDM) | 3-21 |
| 3.1.2.2 Optical Add-Drop Multiplexers (OADM) | 3-23 |
| 3.1.2.2.1 Static OADMs | 3-25 |
| 3.1.2.2.2 Reconfigurable OADMs | 3-25 |
| 3.1.2.3 Next Generation SONET/SDH | 3-26 |
| 3.1.2.3.1 Multiservice Provisioning Platform (MSPP) | 3-27 |
| 3.1.2.3.2 SONET/SDH Virtual Concatenation | 3-28 |
| 3.1.2.3.3 SONET/SDH Link Capacity Adjustment Scheme (LCAS) | 3-31 |
| 3.1.2.3.4 Generic Framing Procedure (GFP) | 3-32 |
| 3.1.2.4 Gigabit Ethernet (GbE) | 3-34 |
| 3.1.2.5 Asynchronous Transfer Mode (ATM) | 3-36 |
| 3.1.2.6 Multiprotocol Label Switching (MPLS) | 3-37 |
| 3.1.2.7 Packet Over SONET/SDH (POS) | 3-38 |
| 3.1.2.8 Resilient Packet Rings (RPR) | 3-41 |
| 3.1.2.9 Layer 2/3 Switching | 3-43 |

| | |
|--|------|
| 3.1.2.10 Metro Technology Summary | 3-44 |
| 3.1.3 Access Network Technologies | 3-48 |
| 3.1.3.1 Access Node | 3-50 |
| 3.1.3.2 Access Rings | 3-51 |
| 3.1.3.3 Fiber In The Loop (FITL) | 3-52 |
| 3.1.3.4 Passive Optical Network (PON) | 3-53 |
| 3.1.3.4.1 Broadband PON (BPON) and ATM PON (APON) | 3-55 |
| 3.1.3.4.2 Ethernet PON (EPON) | 3-59 |
| 3.1.3.4.3 BPON/EPON Comparison | 3-61 |
| 3.1.3.4.4 Gigabit PON (GPON) | 3-63 |
| 3.1.3.5 Free Space Optics | 3-64 |
| 3.1.3.6 Other Technologies | 3-65 |
| 3.1.3.6.1 Wavelength-Division Multiplexing (WDM) | 3-65 |
| 3.1.3.6.2 Multiprotocol Label Switching (MPLS) | 3-66 |
| 3.1.3.6.3 1/10 Gigabit Ethernet (GbE) | 3-66 |
| 3.1.3.6.4 Multiple Service Provisioning Platform (MSPP) | 3-67 |
| 3.1.3.6.5 Resilient Packet Rings (RPR) | 3-67 |
| 3.1.4 Control and Signaling for Optical Networks | 3-68 |
| 3.1.5 Advanced Technologies Enabling Optical Networking | 3-72 |
| 3.1.5.1 Fiber Types | 3-72 |
| 3.1.5.2 Dispersion Management | 3-73 |
| 3.1.5.3 PMD Compensation | 3-74 |
| 3.1.5.4 Optical Amplifiers | 3-75 |
| 3.1.5.5 RZ Modulation and Soliton Transmission | 3-76 |
| 3.1.5.6 Tunable Lasers | 3-77 |
| 3.1.5.7 Very Short Reach (VSR) Interfaces | 3-78 |
| 3.1.6 Optical Developments and Concepts for the Longer Term | 3-79 |
| 3.2 Optical Networks – The Architecture Paradigms | 3-79 |
| 3.2.1 Legacy (Non-IP) Services | 3-80 |
| 3.2.2 IP Services | 3-80 |
| 3.2.2.1 PMO – IP/ATM/SONET/DWDM | 3-82 |
| 3.2.2.2 IP/SONET/DWDM | 3-83 |
| 3.2.2.3 IP/Ethernet/DWDM | 3-83 |
| 3.2.2.4 IP/Ethernet and IP/PPP over SONET/DWDM | 3-84 |
| 3.2.2.5 IP/RPR over GFP/SONET/DWDM or over Ethernet PHY/DWDM | 3-84 |

4 Technology Issues and Considerations for Network Operators

| | |
|---|-----|
| 4.1 Issues Context and Classification | 4-1 |
| 4.2 Next Generation SONET/SDH (MSPP) Issues | 4-5 |
| 4.3 Cross-Connect Issues for Optical Networks | 4-6 |
| 4.3.1 Scalability of Optical Cross-Connect (OXC) Matrices | 4-6 |
| 4.3.2 Scalability of Overall Network Bandwidth | 4-6 |
| 4.3.3 Transparency Issues for Optical Cross-Connects | 4-7 |
| 4.4 Access Issues | 4-8 |
| 4.4.1 FTTx Issues | 4-8 |
| 4.4.2 PON Issues | 4-9 |

| | | |
|------------|--|------|
| 4.4.3 | Access Prove-In Issues | 4-10 |
| 4.5 | Switching and Control Plane Issues for Optical Networks | 4-11 |
| 4.5.1 | Legacy SONET/SDH Products | 4-11 |
| 4.5.2 | Next Generation SONET/SDH – MSPP | 4-12 |
| 4.5.3 | Switching and Control Plane Functionality for Access Products | 4-12 |
| 4.5.4 | Switching and Control Plane Issues for Cross-Connect Products | 4-13 |
| 4.5.5 | Impact of Control Plane on Network Management Systems | 4-15 |
| 4.6 | Packet versus Circuit Boundary Issues | 4-17 |
| 4.6.1 | Packet over SONET/SDH | 4-17 |
| 4.6.2 | Packet Ring Technology (ATM VP and RPR) | 4-18 |
| 4.6.3 | GbE Networking | 4-19 |
| 4.6.4 | Other Issues - ATM and MPLS | 4-21 |
| 4.7 | Protection and Restoration Issues | 4-22 |
| 4.7.1 | Mesh Design versus Ring Design Tradeoffs | 4-22 |
| 4.7.2 | Coordinated Restoration/Protection Across Layers | 4-23 |
| 4.8 | Service Availability for New Optical Networks | 4-23 |
| 4.8.1 | Service Assurance Issues/SLA Support | 4-24 |
| 4.9 | Functionality and Compatibility Issues for Future Products | 4-24 |
| 4.9.1 | Maintaining Functionality while Consolidating/Collapsing Layers | 4-24 |
| 4.9.2 | Evolving Network Elements in an Integrated/Collapsed Hierarchy | 4-25 |
| 4.9.3 | Interoperability of Products | 4-26 |
| 4.9.4 | Backward Compatibility for Investment Protection | 4-27 |
| 4.10 | Network Planning and Design Issues | 4-27 |
| 4.11 | Process Issues and Considerations | 4-28 |
| 4.11.1 | Network Design | 4-28 |
| 4.11.2 | Service Development | 4-28 |
| 4.11.3 | Service Fulfillment | 4-30 |
| 4.12 | Standards Status | 4-31 |
| 4.12.1 | ANSI Standards Committee T1 Telecommunications | 4-32 |
| 4.12.2 | international Telecommunication Union – Telecommunications Standardization Sector (ITU-T) | 4-33 |
| 4.12.2.1 | Optical Control Plane | 4-33 |
| 4.12.2.2 | OTN Transport Plane (G.709) | 4-34 |
| 4.12.2.3 | GFP and Data over SONET | 4-35 |
| 4.12.2.4 | Broadband Passive Optical Network | 4-35 |
| 4.12.3 | Optical Internetworking Forum (OIF) | 4-36 |
| 4.12.3.1 | Optical Control Plane Signaling | 4-36 |
| 4.12.3.2 | Tunable Laser | 4-37 |
| 4.12.3.3 | OC-768/STM-256 | 4-38 |
| 4.12.4 | Internet Engineering Task Force (IETF) | 4-38 |
| 4.12.5 | ATM Forum | 4-38 |
| 4.12.6 | Institute of Electrical and Electronics Engineers (IEEE) | |
| | 802 LAN/MAN Standards Committee | 4-39 |
| 4.12.6.1 | IEEE 802.3 Working Group | 4-39 |
| 4.12.6.1.1 | Ethernet in the First Mile (EFM) IEEE P802.3ah | 4-39 |
| 4.12.6.1.2 | 10-Gigabit Ethernet IEEE P802.3ae | 4-40 |
| 4.12.6.2 | IEEE 802.17 Resilient Packet Ring Working Group (RPRWG) | 4-41 |

- 4.12.6.3 Metro Ethernet Forum 4-42
- 4.12.6.4 Other Optical Alliances 4-42
 - 4.12.6.4.1 Free Space Optic (FSO) Alliance 4-42
 - 4.12.6.4.2 Full Service Access Network 4-43
 - 4.12.6.4.3 10 Gigabit Ethernet Alliance (10GEA) 4-44

5 Management Considerations and Relationship to Control Plane

- 5.1 Foundational Network Management Concepts 5-1
 - 5.1.1 NM Architecture Concepts 5-1
 - 5.1.2 NM Standards 5-2
 - 5.1.3 NM Systems 5-3
 - 5.1.4 Overview of NM Protocols 5-4
 - 5.1.5 Overview of NM Information Models 5-5
- 5.2 Summary of NM Standards Focused on Optical Networks 5-6
 - 5.2.1 TM Forum Multitechnology Network Management (MTNM) Effort 5-7
 - 5.2.2 CORBA Framework 5-10
 - 5.2.3 Other Optical NM Standards 5-11
- 5.3 Improving Operations Flow-Through 5-14
 - 5.3.1 Reasons for Breaks in Flow-Through 5-14
 - 5.3.2 Maximizing Flow-Through via Automated Control Plane and OSS 5-16
 - 5.3.3 Summary of the Issue 5-18
- 5.4 Establishing ASTN Connections 5-18
 - 5.4.1 Management of Different Connection Establishment Techniques Within a Single Network 5-21
 - 5.4.2 Relationship Between Subnetworks and ASTN Administrative Domains 5-22
 - 5.4.3 Management of Control Plane in Support of ASTN 5-24
 - 5.4.4 Additional Strategic Considerations 5-25
- 5.5 Provisioning Optical Networks 5-26
 - 5.5.1 Management System Based Options 5-27
 - 5.5.1.1 EMS Route Design 5-27
 - 5.5.1.2 NMS Route Design 5-29
 - 5.5.2 Optical Network Control Plane Based Options 5-30
 - 5.5.2.1 ASTN Soft Permanent Connection 5-31
 - 5.5.2.2 ASTN Switched Connections 5-32
- 5.6 Management Support for Optical Cross-Connects (OXC) 5-33
- 5.7 Protection and Restoration – Management Perspective 5-40
 - 5.7.1 Protection Cardinality 5-40
 - 5.7.2 Optical Layer Protection 5-41
 - 5.7.2.1 Relationship Between Connection and Protection Management 5-41
 - 5.7.2.2 Management of Protection Schemes for Basic Topologies 5-42
 - 5.7.2.3 Management of Protection Schemes over Complex Topologies 5-43
 - 5.7.2.4 Management of Mesh Protection 5-44
 - 5.7.3 Multilayer Protection 5-44
 - 5.7.3.1 Coordination of Protection Across Multiple Technology Layers 5-44
 - 5.7.3.2 Coordination of Protection Across GMPLS Layers 5-46

| | | |
|----------|--|------|
| 5.8 | Surveillance and Service Level Agreements | 5-49 |
| 5.8.1 | General Concepts | 5-50 |
| 5.8.1.1 | Overview of Surveillance | 5-50 |
| 5.8.1.2 | Motivation for SLAs | 5-50 |
| 5.8.1.3 | Network Performance and QoS | 5-51 |
| 5.8.1.4 | Network Performance | 5-52 |
| 5.8.2 | Optical Network Performance Monitoring | 5-53 |
| 5.9 | Integration with Established Network (Large LEC) | 5-57 |
| 5.9.1 | Analysis of Management Gaps | 5-57 |
| 5.9.2 | Integration with Existing OSSs | 5-58 |
| 5.9.3 | Role of Customer Network Management (CNM) | 5-59 |
| 5.10 | Optical Ethernet Operations | 5-60 |
| 5.10.1 | GbE Architecture Alternatives | 5-60 |
| 5.10.2 | GbE Operations Issues and Challenges | 5-63 |
| 5.10.2.1 | Capacity Management | 5-63 |
| 5.10.2.2 | Service Provisioning and Service Assurance | 5-64 |
| 5.10.2.3 | Integrated Operations Support Systems (OSSs) | 5-65 |

6 Business Drivers and Considerations

| | | |
|-----------|--|------|
| 6.1 | Services and the Use of Optical Technologies | 6-1 |
| 6.1.1 | Service for Optical Networks | 6-1 |
| 6.1.1.1 | Data Transport Lines | 6-1 |
| 6.1.1.2 | Point to Point (WAN, MAN) Connectivity | 6-3 |
| 6.1.1.2.1 | Frame Relay and ATM | 6-3 |
| 6.1.1.2.2 | Native Mode LAN Interconnection | 6-3 |
| 6.1.1.3 | Wholesale Transport Services | 6-3 |
| 6.1.1.4 | Internet Access Services | 6-4 |
| 6.1.1.5 | Video Services | 6-4 |
| 6.1.1.5.1 | Video Conferencing | 6-5 |
| 6.1.1.5.2 | Training and Distance Learning | 6-5 |
| 6.1.1.5.3 | Residential Broadcast Video | 6-5 |
| 6.1.1.5.4 | Video on Demand | 6-5 |
| 6.1.2 | Other Services Impacting Optical Networks | 6-6 |
| 6.1.2.1 | Virtual Private Network (VPN) Services | 6-6 |
| 6.1.2.2 | Residential and Business Telephony Services | 6-7 |
| 6.1.3 | Application and Service Requirements on Networks | 6-8 |
| 6.2 | Business and Strategic Considerations for Network Operators | 6-10 |
| 6.2.1 | Criteria for Network Operators | 6-10 |
| 6.2.2 | Implications Due to Current Telecommunications Business Environment | 6-13 |
| 6.2.3 | Build Versus Lease | 6-15 |
| 6.2.4 | Impact of Wireless and Satellite Broadband Solutions | 6-16 |
| 6.2.5 | Single Supplier Solutions Versus Interoperable Solutions | 6-17 |
| 6.3 | Implications of Regulations on Optical Deployment | 6-18 |
| 6.3.1 | Broadband Unbundling | 6-18 |
| 6.3.2 | Regulatory Uncertainty | 6-19 |
| 6.3.3 | Other Trends in Regulations | 6-19 |

7 Strategies for Network Operators

| | | |
|---------|--|------|
| 7.1 | Introduction | 7-1 |
| 7.2 | Large Incumbent Local Exchange Carrier | 7-2 |
| 7.2.1 | Assumptions | 7-2 |
| 7.2.1.1 | Services | 7-2 |
| 7.2.1.2 | Markets | 7-3 |
| 7.2.1.3 | Geographical Coverage | 7-3 |
| 7.2.1.4 | Regulations | 7-3 |
| 7.2.1.5 | Industry Structure | 7-4 |
| 7.2.1.6 | Technologies and Standards | 7-4 |
| 7.2.1.7 | Strategy | 7-5 |
| 7.2.2 | Current View | 7-5 |
| 7.2.3 | Optical Networking Evolution: Step 1 | 7-7 |
| 7.2.4 | Optical Networking Evolution: Step 2 | 7-12 |
| 7.3 | Long-Haul Carrier | 7-16 |
| 7.3.1 | Assumptions | 7-16 |
| 7.3.1.1 | Services | 7-16 |
| 7.3.1.2 | Markets | 7-17 |
| 7.3.1.3 | Geographical Coverage | 7-17 |
| 7.3.1.4 | Regulations | 7-17 |
| 7.3.1.5 | Industry Structure | 7-17 |
| 7.3.1.6 | Technologies and Standards | 7-17 |
| 7.3.1.7 | Strategy | 7-17 |
| 7.3.2 | Current View | 7-18 |
| 7.3.3 | Optical Networking Evolution: Step 1 | 7-18 |
| 7.3.4 | Optical Networking Evolution: Step 2 | 7-19 |
| 7.4 | Data-Centric Carrier | 7-19 |
| 7.4.1 | Assumptions | 7-19 |
| 7.4.1.1 | Services | 7-19 |
| 7.4.1.2 | Markets | 7-19 |
| 7.4.1.3 | Geographical Coverage | 7-19 |
| 7.4.1.4 | Regulations | 7-19 |
| 7.4.1.5 | Industry Structure | 7-19 |
| 7.4.1.6 | Technologies and Standards | 7-20 |
| 7.4.1.7 | Strategy | 7-20 |
| 7.4.2 | Current View | 7-20 |
| 7.4.3 | Optical Networking Evolution: Step 1 | 7-22 |
| 7.4.4 | Optical Networking Evolution: Step 2 | 7-23 |
| 7.5 | New Entrant | 7-24 |
| 7.5.1 | Assumptions | 7-24 |
| 7.5.1.1 | Services | 7-24 |
| 7.5.1.2 | Markets | 7-24 |
| 7.5.1.3 | Geographical Coverage | 7-24 |
| 7.5.1.4 | Regulations | 7-24 |
| 7.5.1.5 | Industry Structure | 7-25 |
| 7.5.1.6 | Technologies and Standards | 7-25 |

| | |
|---|------|
| 7.5.1.7 Strategy | 7-25 |
| 7.5.2 Optical Network Build: Step 1 | 7-25 |
| 7.5.3 Optical Network Build: Step 2 | 7-26 |
| 7.6 Strategic Planning | 7-27 |
| 7.6.1 Scenario Analysis | 7-28 |
| 7.6.2 Risk Management | 7-29 |
| 7.6.3 Technology Acceleration | 7-30 |
| 7.7 Recommendations | 7-31 |

8 Conclusions

Appendix A: Optical Networking Standards Document Status

Appendix B: SONET/SDH Terminology

Appendix C: References

Appendix D: Acronyms

List of Figures

| | | |
|-------------|--|------|
| Figure 2-1 | Typical Network Hierarchy | 2-3 |
| Figure 2-2 | Impact of Network Hierarchy of Functional Needs | 2-4 |
| Figure 2-3 | Illustrative Metro Optical Network | 2-5 |
| Figure 3-1 | Technology Field-of-Use Map | 3-2 |
| Figure 3-2 | Transmission Capacity Trends | 3-4 |
| Figure 3-3 | Schematic Representation of DWDM Transmission | 3-5 |
| Figure 3-4 | The DWDM Advantage | 3-6 |
| Figure 3-5 | FEC Comparisons | 3-8 |
| Figure 3-6 | Digital OTN Layer Networks with Example NEs | 3-10 |
| Figure 3-7 | OTUk Frame Structure | 3-11 |
| Figure 3-8 | Information Containment in the Digital OTN [G.709] | 3-13 |
| Figure 3-9 | Core OTN Recommendations [G.871] | 3-14 |
| Figure 3-10 | Cross-Connect Categories and Their Major Attributes | 3-16 |
| Figure 3-11 | General Overview of Metro Technologies | 3-21 |
| Figure 3-12 | Proposed Grid for Coarse WDM Transmission | 3-22 |
| Figure 3-13 | Linear Chain WDM System with OADM at Intermediate Sites | 3-24 |
| Figure 3-14 | Optical Ring Network | 3-24 |
| Figure 3-15 | STS-1-Xv Structure | 3-29 |
| Figure 3-16 | VT1.5-Xv Structure | 3-30 |
| Figure 3-17 | GFP Relationship to Client Signals and Transport Paths | 3-32 |
| Figure 3-18 | GFP Mapping Into OTN Optical Channel Payload Unit | 3-33 |
| Figure 3-19 | POS Layering | 3-39 |
| Figure 3-20 | POS Flow | 3-39 |
| Figure 3-21 | High-Performance Router Interconnection Using POS | 3-40 |
| Figure 3-22 | Total and Partial RPR Overlay on a SONET Network | 3-43 |
| Figure 3-23 | Service Aggregation and Bandwidth Efficiency | 3-45 |
| Figure 3-24 | Physical Access Network Options | 3-49 |
| Figure 3-25 | Example Remote Access Node – Then and Now | 3-50 |
| Figure 3-26 | Access Ring Applications | 3-51 |
| Figure 3-27 | Generic FITL System Overview | 3-53 |
| Figure 3-28 | PON Architecture | 3-55 |
| Figure 3-29 | BPON Frame Structure | 3-56 |
| Figure 3-30 | BPON Wavelength Allocation | 3-58 |
| Figure 3-31 | BPON Protection Network | 3-59 |
| Figure 3-32 | EPON Frame Structure | 3-60 |
| Figure 3-33 | Schematic of FSO System (Single Direction Shown for Clarity) | 3-64 |
| Figure 3-34 | Relationships and Interfaces Between ASTN Entities | 3-70 |
| Figure 3-35 | Multiservice Telecommunication Network Options | 3-80 |
| Figure 3-36 | Transport Alternatives for IP | 3-81 |
| Figure 5-1 | Telecommunications Management Network (TMN) Functional Layers | 5-2 |
| Figure 5-2 | Organizations Related to Optical Network Management | 5-3 |
| Figure 5-3 | TMN Functional Layers and Operations Systems | 5-4 |
| Figure 5-4 | Network Management Protocols Applicable to Optical Networks | 5-5 |

| | | |
|-------------|--|------|
| Figure 5-5 | Information Models | 5-6 |
| Figure 5-6 | Vendor Product Types – EMS | 5-8 |
| Figure 5-7 | Vendor Product Types – NMS | 5-9 |
| Figure 5-8 | ASTN Planes | 5-20 |
| Figure 5-9 | Connection Establishment over Subnetworks Supporting Different Setup Techniques | 5-21 |
| Figure 5-10 | Subnetworks, EMS Management Domains, and ASTN Administrative Domains | 5-23 |
| Figure 5-11 | EMS Route Design Example | 5-28 |
| Figure 5-12 | NMS Route Design Example | 5-30 |
| Figure 5-13 | OChSPRING Interconnection Using OADMs | 5-34 |
| Figure 5-14 | SNC Types Defined by TM Forum MTNM Interface (Not a Complete Listing) | 5-36 |
| Figure 5-15 | OChSPRING Interconnection Using OXCs | 5-37 |
| Figure 5-16 | OChSPRING Interconnection Using Same-Side Routing | 5-39 |
| Figure 5-17 | Protocol Stack – Technology Layers | 5-45 |
| Figure 5-18 | GMPS Layered Architecture | 5-46 |
| Figure 5-19 | GMPLS Restoration: Local (Span) Restoration | 5-48 |
| Figure 5-20 | GMPLS Restoration: End-to-End (Path) Restoration | 5-48 |
| Figure 5-21 | Performance Monitoring – Opaque Networks | 5-54 |
| Figure 5-22 | Monitoring within SONET Layers | 5-55 |
| Figure 5-23 | Monitoring in Transparent Network Elements | 5-56 |
| Figure 5-24 | Switched Gigabit Ethernet Architecture | 5-61 |
| Figure 5-25 | ILEC MSPP Implementation | 5-62 |
| Figure 7-1 | Factors Influencing Optical Networking Decisions | 7-1 |
| Figure 7-2 | Data Will Dominate the Traffic in the Network | 7-3 |
| Figure 7-3 | Overview of ILEC Network | 7-5 |
| Figure 7-4 | Example of Current ILEC Metro Network | 7-6 |
| Figure 7-5 | Example of Current ILEC Access Network | 7-7 |
| Figure 7-6 | Example of Phase 1 Evolution of ILEC Long-Haul Network | 7-9 |
| Figure 7-7 | Example of Phase 1 Evolution of ILEC Metro Network | 7-10 |
| Figure 7-8 | Example of Phase 1 Evolution of ILEC Access Network | 7-11 |
| Figure 7-9 | Example of Phase 2 Evolution of ILEC Long-Haul Network | 7-13 |
| Figure 7-10 | Example of Phase 2 Evolution of ILEC Metro Network | 7-14 |
| Figure 7-11 | Example of Phase 2 Evolution of ILEC Access Network | 7-15 |
| Figure 7-12 | Example of RPR Metro Overlay Network | 7-16 |
| Figure 7-13 | Example of Current IXC Network | 7-18 |
| Figure 7-14 | Example of Current DCC Network | 7-21 |
| Figure 7-15 | Example of Phase 1 Evolution of DCC Core Network | 7-22 |
| Figure 7-16 | Example of Phase 2 Evolution of DCC Core Network | 7-23 |
| Figure 7-17 | Example of Phase 1 Build of New Entrant Network | 7-26 |
| Figure 7-18 | Example of Phase 2 Build of New Entrant Network | 7-27 |
| Figure 7-19 | Factors Influencing the Future | 7-29 |

List of Tables

| | | |
|-----------|---|------|
| Table 3-1 | Major Network Characteristics | 3-1 |
| Table 3-2 | CWDM Wavelengths and Their Possible Application | 3-23 |
| Table 3-3 | Comparison of SONET/SDH SPE/VC Bandwidth and Common Data Bit Rates | 3-26 |
| Table 3-4 | Technology Comparison for Carrying IP or Ethernet Traffic Over SONET/SDH | 3-46 |
| Table 3-5 | GbE, ATM, and RPR Comparison | 3-47 |
| Table 3-6 | Summary of Network Characteristics for BPON and EPON | 3-62 |
| Table 3-7 | Services Consideration for GPON | 3-63 |
| Table 3-8 | Major Optical Fiber Types | 3-72 |
| Table 3-9 | PMD Limited Regeneration Span | 3-75 |
| Table 4-1 | Technology Relationships to Legacy SONET/SDH Equipment | 4-3 |
| Table 4-2 | Typical Functions Across Network Layers | 4-25 |
| Table 5-1 | ITU-T OTN Transport Plane Recommendations | 5-13 |
| Table 5-2 | ITU-T OTN Control Plane Recommendations | 5-13 |
| Table 5-3 | Modeling of Ring Interconnection Using OADMs | 5-35 |
| Table 5-4 | Modeling of Ring Interconnection Using OXCs | 5-38 |
| Table 5-5 | Feature Groups (For Management Purposes) | 5-58 |
| Table 6-1 | Sample Bandwidth Requirements for Services | 6-9 |
| Table 6-2 | Generic Criteria for Network Deployment and Evolution | 6-12 |
| Table B-1 | SONET/SDH Layer Comparison | B-1 |
| Table B-2 | Line Rates for SONET/SDH Interface Signals | B-1 |
| Table B-3 | SONET/SDH Path Signals | B-2 |
| Table B-4 | SONET/SDH Protection Mechanism Comparison | B-2 |