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NATIONAL COMMUNICATIONS SYSTEM

TECHNICAL INFORMATION BULLETIN 03-3

INTERNET PROTOCOL OVER OPTICAL TRANSPORT NETWORKS

December 2003

OFFICE OF THE MANAGER
NATIONAL COMMUNICATIONS SYSTEM
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Internet Protocol over Optical Transport Networks

Office of the Manager
National Communications System

December 2003

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FOREWORD

Among the responsibilities assigned to the National Communications System, is the management of the Federal Telecommunications Standards Program. Under this program, the NCS, with the assistance of the Federal Telecommunications Standards Committee identifies, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunications systems or to the achievement of a compatible and efficient interface between computer and telecommunications systems. In developing and coordinating these standards, a considerable amount of effort is expended in initiating and pursuing joint standards development efforts with appropriate technical committees of the International Organization for Standardization, the International Telecommunication Union-Telecommunications Standardization Sector, and the American National Standards Institute. This Technical Information Bulletin presents an overview of an effort which is contributing to the development of compatible Federal and national standards in the area of national security and emergency preparedness (NS/EP). It has been prepared to inform interested Federal and industry activities. Any comments, inputs or statements of requirements which could assist in the advancement of this work are welcome and should be addressed to:

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INTERNET PROTOCOLS OVER OPTICAL TRANSPORT NETWORKS

Abstract

The goal of this Technical Information Bulletin (TIB) is to examine the issues, technology, and standards associated with the use of the Internet Protocol (IP) over Optical Transport Networks (OTN), and how they may be used by the NCS in support of National Security and Emergency Preparedness (NS/EP) communications. A number of multi-protocol multi-layered architectures suitable for integrated operation of IP over OTN are described. An analysis of the relevant characteristics of these protocols and associated technologies are presented. The strengths, weaknesses and applicability of the architecture models for optimal transmission of IP over OTN, and the applicability of these models to the operation of the communications network to be used by NCS are also discussed. The technology evolution needed for optimal convergence of IP and OTN is identified. The status of National, International, and Industry standards relating to OTN is presented. Finally, recommendations for NCS actions with respect to the emergence of OTNs and their application in an NS/EP environment will be presented.

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Executive Summary

The National Communications System (NCS), in support of its National Security and Emergency Preparedness (NS/EP) mission, requires a secure and survivable large-scale data communication infrastructure that provides variable bandwidth on demand for differentiated services with a defined Qualities of Service, e.g., small delay time and minimal low packet loss. An Internet Protocol (IP) network infrastructure with enhanced capabilities in conjunction with an Optical Transport Network (OTN) might meet most of the NCS' requirements.

This Technical Information Bulletin (TIB) discusses a number of technologies in the design of such a communications infrastructure. It begins with a brief analysis of a number of multiprotocol, multilayered architectures suitable for integrated operation of IP over OTN, and an analysis of the relevant characteristics of these protocols and technologies. Discussions focus on flow and congestion control in Transport Control Protocol, Internet Protocol versions 4 and 6 (IPv4 and IPv6), Internet intra-domain and inter-domain routing protocols and Multiprotocol Label Switching/Generalized Multiprotocol Label Switching. In addition, the following areas are addressed:

- The operation and functions provided by the Asynchronous Transfer Mode (ATM), and Synchronous Optical Network (SONET)
- The architectures proposed for transmission of IP over Optical Transport Network
- The operation and functions of the sublayers of OTN, namely, Optical Channel, Optical Multiplex Subsection and Optical Transmission Subsection

This TIB focuses on the strengths, weaknesses and applicability of three architecture models for transmission of IP over OTN. These are the Peer model, the Overlay model and the Augmented model. The effects of OTN reconfiguration time scale on the stability of IP routing protocols and Transmission Control Protocol congestion control protocols are analyzed. Methods of connecting OTN to legacy systems such as ATM, SONET and gigabit IP routers, and low bit rate Time Division Multiplex systems are presented. Finally, the technology evolution needed for convergence of IP and OTN are identified and addressed. Standards for IP over OTN and related technologies are also discussed. Economic conditions and a lack of approved OTN standards have hindered implementation of OTN based networks. In addition, it is recommended that NCS become more involved in the OTN standards groups and development process.

1. Introduction

The National Communications System (NCS) was established through a Presidential Memorandum in 1963, and augmented by Executive Order (E.O.) 12472, Assignment of National Security and Emergency Preparedness (NS/EP) Telecommunications Functions, which broadened the mission and focus of the National Communications System.

As part of this mission, the NCS identifies new technologies that enhance NS/EP communications capabilities and ensures key NS/EP features such as priority access, interoperability, reliability, availability, and security are supported by emerging standards. In concert with this approach, the N2 manages the Federal Telecommunications Standards Program. Additionally, the N2 division directs efforts in both NS/EP management and applications services.

National Security and Emergency Preparedness requirements fall into the areas **[1] [2]** as shown in Table 1-1, and are identified in the Convergence Task Force Report **[3].**

Functional Requirement	Description
Enhanced Priority Treatment	Voice and data services supporting NS/EP missions should be provided preferential treatment over other traffic
Secure Networks	These services ensure the availability and survivability of the network, prevent corruption of or unauthorized access to the data, and provide for expanded encryption techniques and user authentication
Restorability	Should a service disruption occur, voice and data services must be capable of being reprovisioned, repaired, or restored to required service levels on a priority basis
International Connectivity	Voice and data services must provide access to and egress from international carriers
Interoperability	Voice and data services must interconnect and interoperate with other government or private facilities, systems, and networks
Mobility	The ability of voice and data infrastructure to support transportable, redeployable, or fully mobile voice and data communications (i.e., Personal Communications Service (PCS), cellular, satellite, High Frequency (HF) radio)
Nationwide Coverage	Voice and data services must be readily available to support the National security leadership and inter- and intra- agency emergency operations, wherever they are located
Survivability	Voice and data services must be robust to support surviving users under a broad range of circumstances, from the widespread damage of a natural or manmade disaster up to and including nuclear war

Functional Requirement	Description
Voice Band Service	The service must provide voice band service in support of presidential communications
Scaleable Bandwidth	NS/EP users must be able to manage the capacity of the communications services to support variable bandwidth requirements
Addressability	Addressability is the ability to easily route voice and data traffic to NS/EP users regardless of user location or deployment status. Means by which this may be accomplished include "follow me" or functional numbering, call forwarding, and functional directories.
Affordability	The service must leverage new Public Network (PN) capabilities to minimize cost. Means by which this may be accomplished favor the use of Commercial Off-The-Shelf (COTS) technologies and services and existing infrastructure.
Reliability	The capability of an information or telecommunications system to perform consistently and precisely according to its specifications and design requirements, and to do so with high confidence

Table 1-1: Matrix of NE/EP Requirements

This TIB addresses issues, which need to be considered in order to ensure that IP over OTNs can meet many or all of the NS/EP requirements set forth in Table 1-1.

1.1 Optical Transport Network

The major underlying technology for today's transport networks is Synchronous Optical NETwork (SONET)/Synchronous Digital Hierarchy (SDH). SONET/SDH is equipped with performance monitoring, fault isolation, protection switching, interleaving, and scaling capabilities in addition to its standards based interoperability feature. SONET/SDH was optimized to serve voice-based traffic with a strict Time Division Multiplexing (TDM) scheme. SONET/SDH is not efficient for variable length data traffic. With the ever-growing Internet and other data-oriented traffic usage, a new scheme was needed to meet the demands for network scalability and manageability. Like SONET/SDH, OTN is standards based (ITU-T G.709), insuring interoperability among various equipment interfaces. Whereas the SONET/SDH protocol was designed for managing single wavelength (λ) transmissions, OTN is designed to manage multiple wavelength transmissions on individual fiber paths. This is the basis for Dense Wave Division Multiplexing (DWDM) systems.

SONET/SDH based networks have played a crucial role in addressing the network capacity demands and will continue to do so for a foreseeable future. But with its limitations and the changing bandwidth requirements, tomorrow's networks will demand the capabilities of

OTN. See “Optical Transport Network: Solution to Network Scalability and Manageability” by Joon Choi, Danny Lahav from Optix Networks. **[15]**

An Optical Transport Network is composed of a set of Optical Network Elements connected by optical fiber links, able to provide functionality of transport, multiplexing, routing, management, supervision, and survivability of optical channels carrying client signals (Recommendation G.872[1]). 0 OTN design seeks to unify the data plane (transport layer) and the control plane (signaling and management layer). Figure 1-1 provides a conceptual representation of this idea.

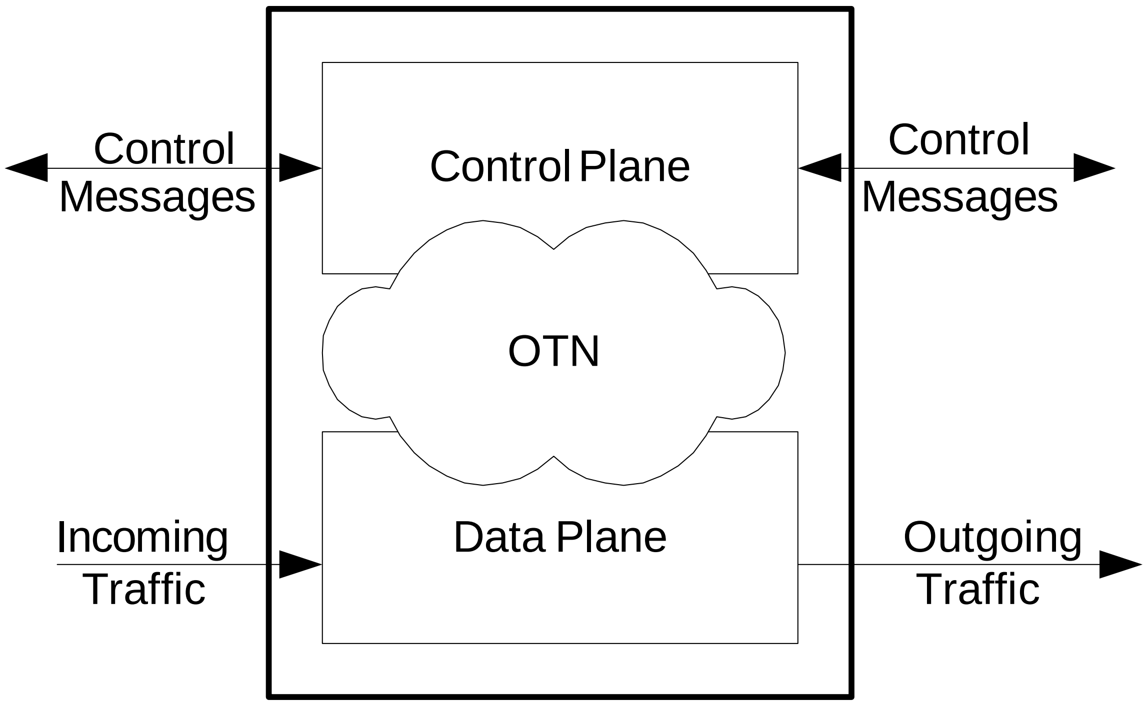


Figure 1-1: The Control and the Data Plane [5]

The Internet Protocol is a leading candidate **[10]** for deployment in OTN due its wide deployment within Government and industry. An IP over OTN communications infrastructure could provide high bandwidth on demand and flexible and scalable support for Quality of Service (QoS) for transmission of multimedia services with small delay time and low packet loss. It also represents a potential solution that meets many of the NCS service requirements previously identified.

The current Transmission Control Protocol/Internet Protocol (TCP/IP) network infrastructure is pervasive worldwide and provides reliable communication service to millions of users. Simultaneously, development of Dense Wavelength Division Multiplexing (DWDM) based optical transport networks have led to the availability of extremely high capacity light-paths in fiber optic based transport infrastructure. DWDM is a leading technology that appears to be able to meet the demand for the type of high capacity needed by the NCS based upon the

[1] ITU-T Study Group 15 definition.

NS/EP requirements at the present time or in the foreseeable future. It provides the high bandwidth light-paths needed for transmission of multimedia signals. As the optical transmission network matures to provide many of the services currently provided by ATM and SONET, these layers can be eliminated and more optimized architectures can be developed. Several such architectures are discussed in Section 4 of this TIB. Thus, a multi-layer IP over OTN network could provide NCS with a worldwide communication infrastructure that could satisfy its current and future communication needs with many desirable and necessary features.

1.2 IP over Optical Transport Networks Issues

This TIB addresses the following IP over OTN issues:

- A comparative analysis of the various protocol layer architectures is required to determine the optimal integration of IP and optical layers
- Of prime importance is the development of integrated network management system for proper integrated operation of the IP and optical layers
- The impact of OTN reconfiguration time on IP routing
- The ability to connect legacy equipment to OTN
- Identification of the necessary technology evolution needed to implement such systems
- Development of appropriate standards to insure interoperability among different manufacturers

Further research and development (R&D) work is needed.

1.3 TCP/IP Overview

TCP/IP is an industry-standard suite of protocols designed for large-scale inter-networks that span Local Area Networks (LAN) and Wide Area Networks (WAN) environments. Figure 1-2 shows a timeline of the origins of TCP/IP, which began in 1969, when the Advanced Research Projects Agency Network (ARPANET) was commissioned by the U.S. Department of Defense (DoD.)

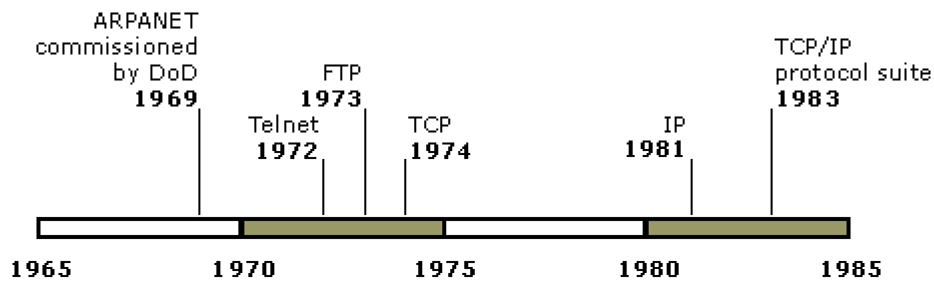
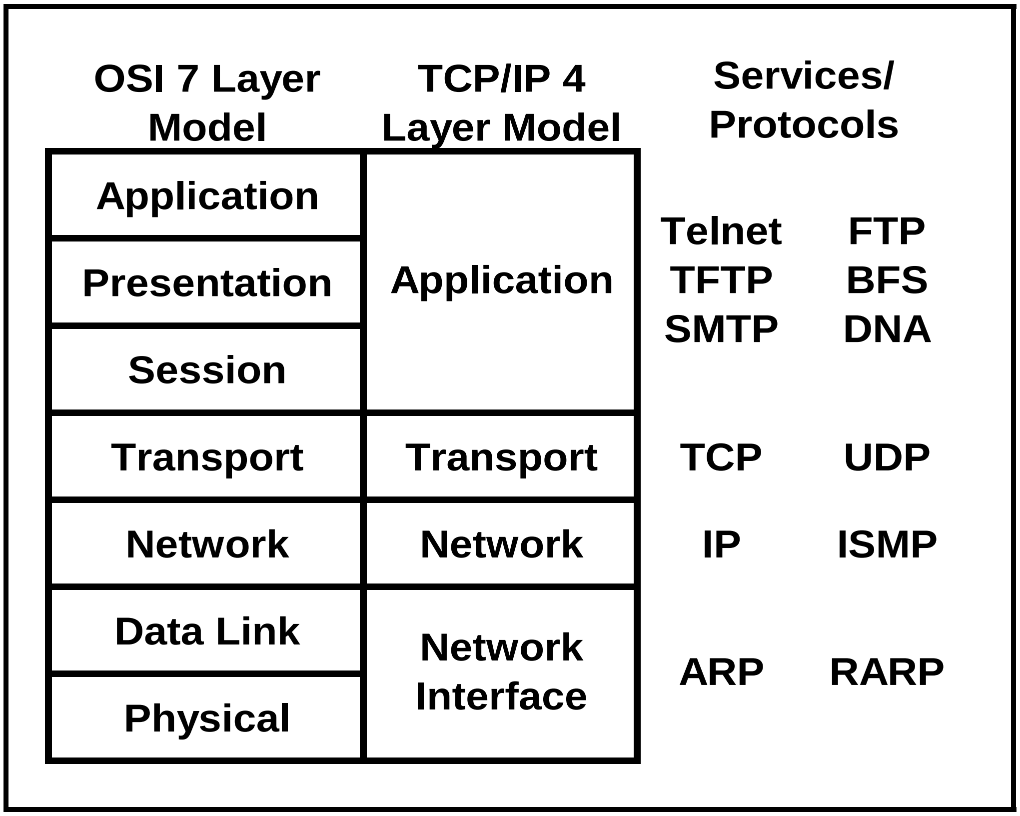


Figure 1-2: TCP/IP Timeline

The ARPANET was the result of a resource-sharing experiment. The purpose was to provide high-speed network communication links between various supercomputers located at various regional sites within the United States. Early protocols such as Telnet (for virtual terminal emulation) and File Transfer Protocol (FTP) were first developed to specify basic utilities needed for sharing information across the ARPANET. As the ARPANET grew in size and scope, two other important protocols appeared:

TCP was introduced in 1974 as a draft specification that described how to build a reliable, host-to-host data transfer service over a network. IP was introduced in 1981 in draft form and described how to implement an addressing standard and route packets between interconnected networks. On January 1, 1983, ARPANET began to require standard use of the TCP and IP protocols for all network traffic and essential communication. From this date forward, ARPANET started to become more widely known as the Internet, and its required protocols started to become more widely known as the TCP/IP protocol suite.

The TCP/IP model provides all the benefits of the 7 Layer Open Systems Interconnect (OSI) model in 4 layers. The OSI model has been somewhat displaced by TCP/IP due its selection by the Federal Government and Internet Service Providers (ISPs) as the internetworking protocol of choice. Figure 1-3 shows the relationship of the OSI model and the TCP/IP model.



Legend
Telnet – Terminal-remote host protocol developed for the ARPANET
TFTP – Trivial File Transfer Protocol
SMTP – Simple Mail Transfer Protocol
FTP – File Transfer Protocol
NFS – Network File System
DNA – Digital Network Architecture
UDP – User Datagram Protocol
ICMP – Internet Control Message Protocol
ARP – Address Resolution Protocol
RARP – Reverse Address Resolution Protocol

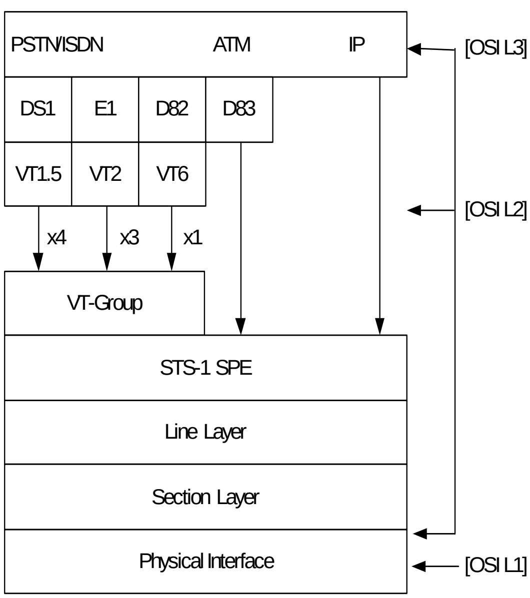
Figure 1-3: Comparison of the OSI Model to the IP Model [6]

2. Evolution Toward Optical Transport Network

The OTN is considered by industry as the successor to SONET/SDH, which is the current standard for voice and data traffic in the Public Switched Network (PSN). This section will examine the current standard and provide advantages and disadvantages. We also will examine the Optical Transport Network and identify its advantages and disadvantages.

2.1 Overview of SONET/SDH

Synchronous Optical Network is an optical transmission interface for high-speed transmission over optical fiber. In 1985, Committee T1X1 began the development of the SONET Standard. The phase 1 standard was issued in March 1988. The standard came about as a result of a request by MCI to ECSA (now ATIS). SONET is intended to attain the following objectives: multi-vendor internetworking, to be cost effective for existing services on an end-to-end basis, to create an infrastructure to support new broad band services, and for enhanced operation, administration, maintenance, and provisioning (OAM&P). SONET is an optical interface standard that allows interworking of transmission products from multiple vendors. It is a TDM technology. SONET and SDH Recommendations and industry standards are shown in Appendix C.



Identifier	Definition
DS1	Digital Signal Level 1-1.544 Mbps
E1	European Equivalent for US DS1, but 2.048 Mbps
DS2	Digital Signal Level 2-6.312 Mbps
DS3	Digital Signal Level 3-44.736 Mbps
VT1.5	Virtual Tributary[2] 1.5-1.544 Mbps
VT2	Virtual Tributary 2-2.048 Mbps
VT6	Virtual Tributary 6-SONET Sub Rate channel of 6.912 Mbps that carries a DS2
VT-Group	A logical grouping of virtual tributaries
STS-1	Synchronous Transport Signal Level 1-51.84 Mbps
SPE	Synchronous Payload Envelope-SONET term describing the envelope that carries the user data, or payload

Legend

Figure 2-1: The SONET Layer Model [7]

[2] Virtual Tributary is a struc ture designed for transport and switching of sub-DS3 payloads. These are measures of speed in SONET.

The SONET architecture specifies a multiplexing hierarchy, whose basic building block is the SONET Transport Service (STS-1) frame. Figure 2-1 is a representation of the SONET layer model. Any number of STS-1 frames are multiplexed to form higher data rate frames.

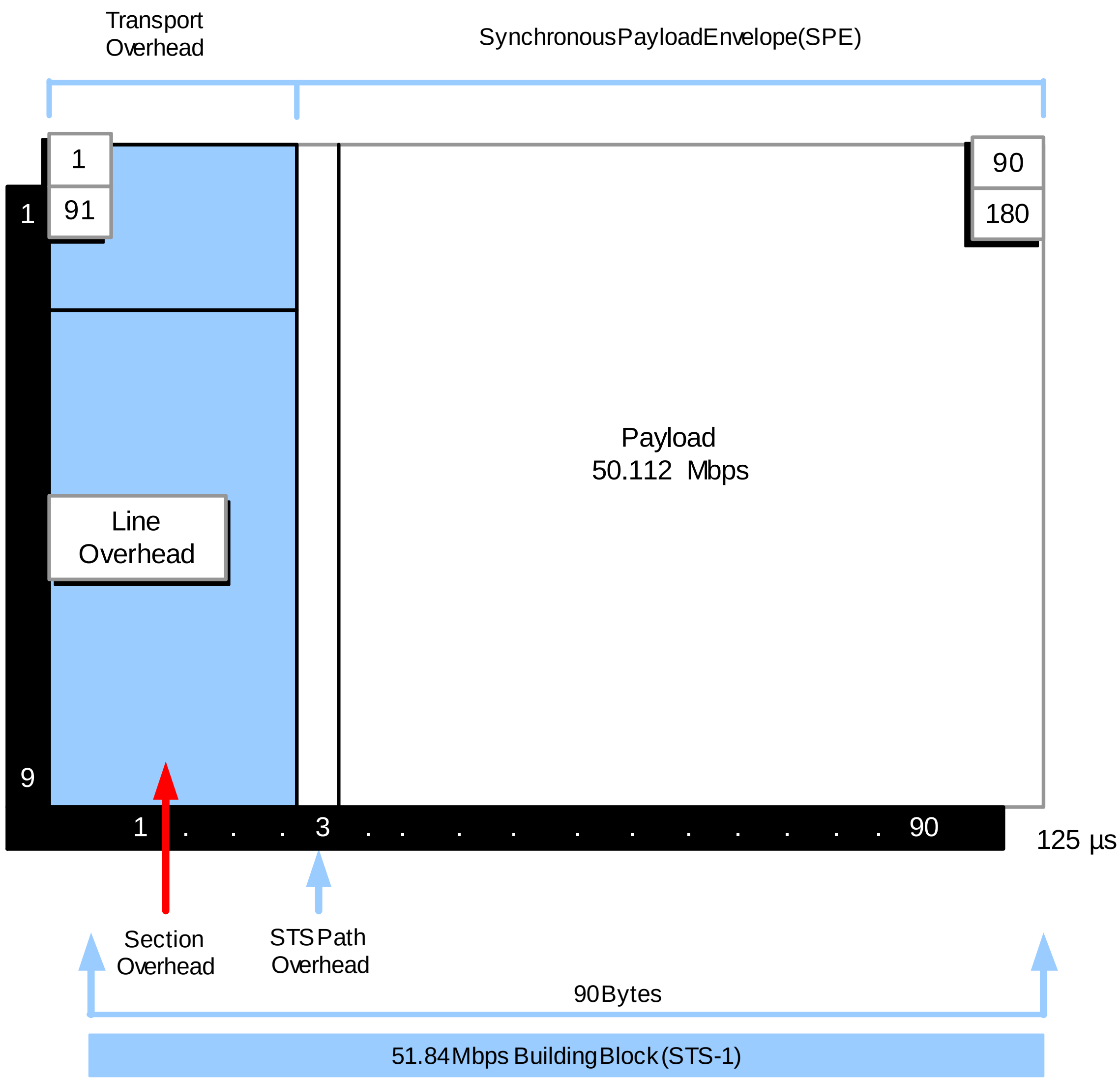


Figure 2-2: STS-1 Frame Format [8]

Each frame is transmitted in 125 µs. The frame format of the basic STS-1 frame is shown in Figure 2-2.

The frame itself is depicted as a segmented rectangle 90 columns wide by 9 rows deep. It consists of 9 bytes of section overhead, 18 bytes of line overhead, and 783 bytes of data. The overhead bytes provide, among other things, framing, parity, and data communications channel for alarms, control, and maintenance and administration functions between sections. The line rate is 51.84 Mbps and payload rate is 50.112 Mbps. A number of these STS-1 frames are multiplexed to obtain higher rates. Some of the higher data rates are as shown in Table 2-1.

Optical Level	SONET Level	Line Rate (Mbps)	Payload Rate (Mbps)
OC-1	STS-1	51.84	50.112
OC-3	STS-3	155.520	150.336
OC-12	STS-12	622.080	601.344
OC-24	STS-24	1244.160	1202.688
OC-48	STS-48	2488.320	2405.376
OC-96	STS-96	4976.640	4810.752
OC-192	STS-192	9953.280	9621.504

Table 2-1: Hierarchy of SONET Speeds

2.1.1 Advantages of SONET

Some of the advantages of SONET are:

- Currently used by all major Telecommunications Carriers (such as MCI (WorldCom), Qwest Communications, American Telephone and Telegraph (AT&T), and Verizon)
- Very well-developed standards, both international and domestic
- Synchronous multiplexing format that greatly simplified interfacing to other equipment
- Precise performance monitoring and fault detection, facilitating centralized fault isolation
- Creation of a set of generic standards to interconnect different vendors' equipment

2.1.2 Disadvantages of SONET

Some of SONET's disadvantages are:

- Limited flexibility to provide lines of varying speeds. For example, if a client needs 70 Megabits of capacity, SONET can only provide either 51 Megabits or 103 Megabits based on concatenation of STS-1 frames. The client would be required to purchase more then he actually needs.
- Requires significant equipment, at the carriers' premises, to make the network run
- Slow provisioning of the network elements often adds weeks to the completion of circuits

2.2 Optical Transport Networks

OTN is composed of a set of optical network elements connected by optical fiber links known as Optical Cross-Connects (OXC). The fiber links contain optical amplifiers and are interconnected through Optical Add-Drop Multiplexers (OADM). OXCs switch wavelength channels between their input and output fibers, and are used to establish optical light paths. In addition, some cross-connects may have the capability of wavelength conversion. OTN consists of two defined hierarchies; Digital Transport Hierarchy, which is beyond the scope of this TIB, and the Optical Transport Hierarchy. Appendix D contains the current list of OTN related standards and industry agreements along with their publication dates where applicable.

Optical Transport Hierarchy can be divided as follows:

- Optical Channel Layer
- The Optical Physical Section

The Optical Channel Layer consists of:

- The Optical Channel Layer (OCh)
- Optical channel multiplexing

The Optical Physical Section consists of:

- Optical Multiplex Section (OMS)
- Optical Transmission Section (OTS)

These sublayers are shown in Figure 2-3.

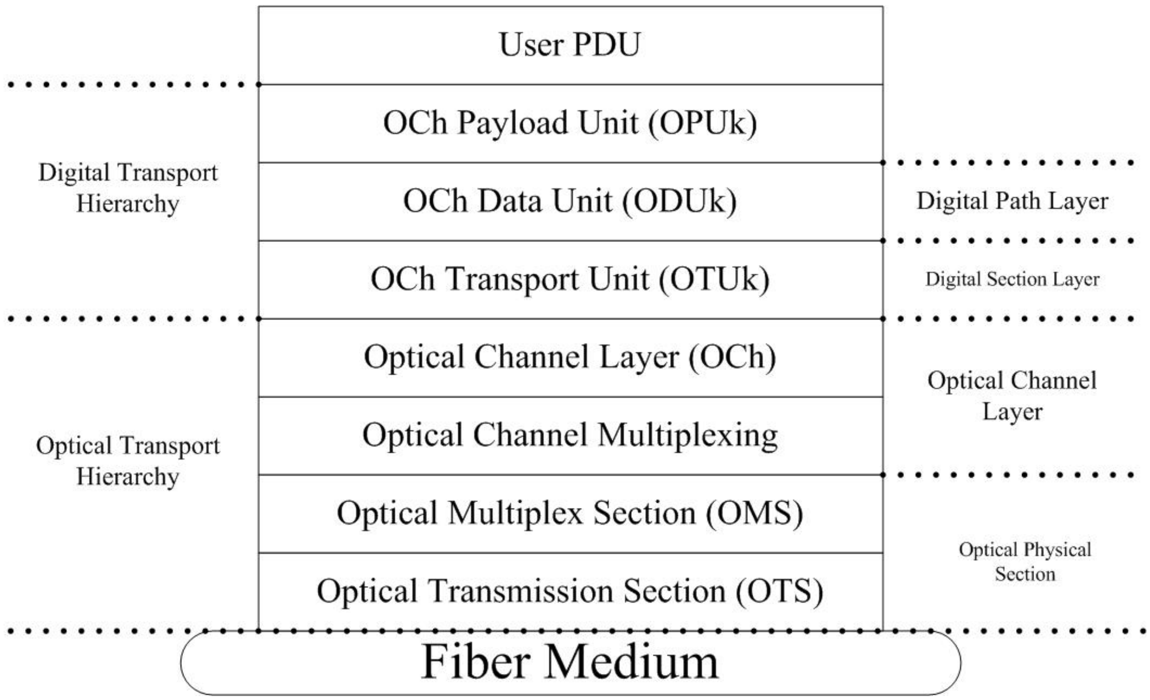


Figure 2-3: The Optical Network Layered Architecture

Optical Channel Layer:

The optical channel (OCh) is needed to support end-to-end network functionality of the optical channel. This layer allows transparent conveying of client information of varied formats. The signals contained in an optical channel can be transmitted using one or more wavelength. This is the point at which the multiplexing of the channels occurs. Optical Channel Multiplexer combines the incoming optical wavelengths to a single optical signal.

Optical Transport Section:

The Optical Multiplex Section (OMS) provides the functionality between multiplexer/demultiplexer and add/drop sites in the network. This function is taken care of by the OMS overhead. This sublayer provides functionality for networking of the multiple wavelength optical signals between add/drop multiplexers and other types of multiplexers/demultiplexers in the optical network.

The Optical Transmission Section (OTS) provides for transmission of signals over individual fiber spans. OTS defines a physical interface detailing optical parameters such as frequency, power lever and signal-to-noise ratio.

2.2.1 Wave Division Multiplexing and Dense Wave Division Multiplexing

Wavelength Division Multiplexing (WDM) technology has been known since the 1980s. It was restricted to two widely separated “wideband” frequencies. The number of distinct wavelengths supported has increased rapidly since WDM became “narrowband” capable in the early 1990s. Initial systems operated at two or four wavelengths, and the term “WDM” is usually used to refer to these low channel – count systems. Beyond WDM is Wide Wave

Division Multiplexing (Wide WDM), operating at four channel applications such as 10 Gbps Ethernet. Beyond that is Dense Wave Division Multiplexing (DWDM), which generally is described as beginning at 10 channels.

Carriers currently have abundant fiber assets in the ground. However, at some point in the future, assets could become overused especially in densely populated, metropolitan areas. WDM is a means of increasing the data-carrying capacity of an optical fiber by simultaneously operating at more than one wavelength. WDM is similar to Frequency Division Multiplexing (FDM) in the analog worlds of electrical and radio transmission systems. In optical fiber communications, WDM is any technique by which two or more optical signals having different wavelengths may be simultaneously transmitted in the same direction on one strand of fiber, and then be separated by wavelength at the distant end. Each wavelength is a "virtual channel," which effectively is a "light pipe" that can support a given signaling rate, such as OC-48 at 2.4 Gbps or OC-192 at 10 Gbps.

Dense Wave-Division Multiplexing (DWDM) creates additional capacity through multiple parallel channels. The basic concept is to multiplex incoming wavelengths from individual fibers onto a single fiber. Wavelengths are sometimes referred to as having different colors; however at this edge of the spectrum (typically in the 1500 nanometer (nm) range) it isn't a difference in color as much as it is a shift in frequency. In many ways WDM functions like a radio network. Each wavelength is used to carry data and is assigned a channel number. However, instead of being broadcast over the airwaves like a radio signal, the digital information is narrowcast[3] down fiber optic cables to a dedicated receiver, where a demultiplexer extracts it. Figure 2-4 shows this relationship in a typical DWDM system.

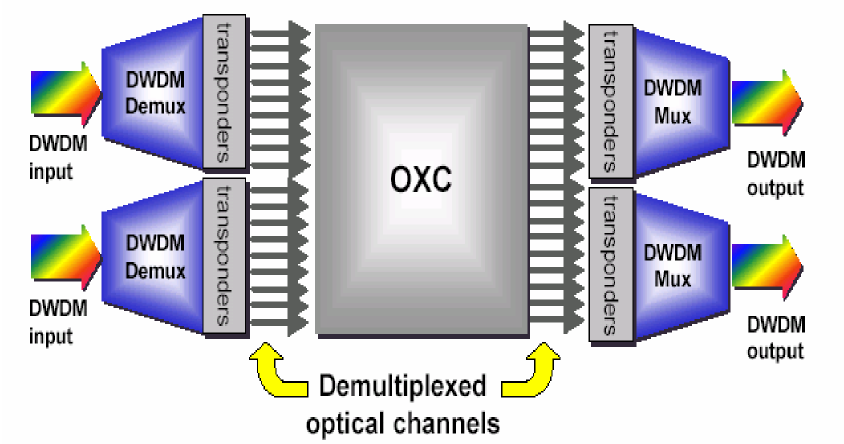


Figure 2-4: DWDM System [10]

Though the multiplexers and demultiplexers are mirror images of one another, there are key operating differences between the two. Multiplexers need to have a minimal effect on signals as they are being combined onto a fiber. Therefore, a low insertion loss is required. They also need to ensure that light isn't reflected or scattered back to any of the transmitters. Demultiplexers, on the other hand, need to be able to extract the optical channels from the multiplexed signal without light leaking from one channel to the next.

[3] Sending of one signal to a select number of devices. [9]

The number of optical channels packed onto a single fiber depends on how the network is designed. The ITU specifies at least 100 Gigahertz (GHz) spacing between optical channels, which is approximately 0.8 nm wavelengths. This would provide for a total of 100 channels. Some advantages and disadvantages of WDM/DWDM are shown below.

ADVANTAGES	DISADVANTAGES
• Uses one fiber to create multiple channels • Allows the provisioning of how much or how little bandwidth is required for a particular application • Ability to add bandwidth temporarily or permanently without disrupting existing circuits	• Expense of equipment • Lack of standards

Table 2-2: Advantages and Disadvantages of WDM/DWDM

Currently, the provisioning of bandwidth using WDM/DWDM systems is done manually. An order for additional capacity is submitted to the carrier where someone has to define the path of the new circuit. Once the order is completed, the customer is notified. The customer and carrier then have to agree on a cutover date. This makes the process of obtaining additional bandwidth take days. OTN seeks to automate this process so that requests for additional bandwidth can be done near real time.

3. Protocols Required for IP over OTN

Previously, discussions were held about how OTN could bridge the gap between the optical control plane and the data plane. IP is heavily favored to make this goal a reality due to its pervasiveness in Government and industry. There are two kinds of protocols that will be required to provide this functionality: signaling and routing. The signaling protocols include Multiprotocol Label Switching (MPLS) and Generalized Multiprotocol Label Switching (GMPLS). The routing protocols for consideration are Open Shortest Path First (OSPF), Intermediate-to-Intermediate System (IS-IS), and Border Gateway Protocol (BGP).

3.1 Signaling Protocols

3.1.1 Multiprotocol Label Switching

MPLS is a new way of routing IP traffic. Unlike typical routing, MPLS works on the idea of flows. Flows are a string of packets between two common end points. Traditional routing works by looking inside routing tables for the appropriate routes for each packet. Every router populates these routing tables by running routing protocols to identify the shortest and/or fastest route through the network between any two points. By contrast, MPLS does the route calculation once on each packet flow through a provider's network. The route is then embedded inside each packet as a string of labels, which are short, fixed-length values typically embedded inside the link layer or referenced by the link layer. Routers along the ways read these labels, and use them to do faster lookups, reduce processing time and improve router scalability.

This, however, is a gross simplification of a very complex process. An example might be when a packet leaves a Personal Computer (PC), it makes its way across the network ultimately reaching a Label Edge Router (LER). The LER is most likely located at the entrance to the carrier's network. As packets travel through the LER, the receiving addresses are examined and the route that they need to take are identified using routing protocols modified for MPLS's unique requirements. These protocols are the OSPF and BGP protocols defined above. With these protocols, network designers can assign various parameters to links, and then use that information to maximize the efficiency of their networks. This is a process referred to as traffic engineering.

Packets are also grouped together into traffic flows called Forward Equivalence Classes (FEC). Each FEC describes traffic flow between two logical points, such as between networks, machines, or even between processes in different machines. The result is that a large number of potential FECs can be defined. The decision as to which FEC is selected comes down to a choice between scalability and functionality. Larger flows will scale better since there are fewer of them. At the same time, smaller flows offer more flexibility in how they get directed through the network. Once the LER determines the route and the FEC, a tag is appended to the packet. Typically, this label gets appended to the layer 2 header. To ensure that transmission capacity is reserved end-to-end, the LER uses a label distribution protocol (LDP). The LDP, which may be Resource Reservation Protocol (RSVP) or Constraint-based Routed-Label Distribution Protocol (CR-LDP), enables the LER to reserve capacity along the route selected by its routing protocols, and to distribute the necessary labels to direct the traffic along the route. Once completed, the label switched path (LSP) is established. Traffic sent onto this LSP traverses the desired route specified by the LER. Each

Label Switched Router (LSR) reads the specific label, looks up in its table where the packets should be forwarded, and acts accordingly.

3.1.2 Generalized Multiprotocol Label Switching

GMPLS extends the MPLS protocol with the necessary constructs to control not just routers but DWDM systems, Add/Drop Multiplexers (ADM), photonic cross-connects, and the like. With GMPLS, providers can dynamically provision resources and provide the necessary redundancy for implementing various protection and restoration techniques.

With MPLS implemented, carriers gain better performance and control over their networks. However, MPLS remains limited in terms of the provisioning of bandwidth within the physical network. With the growth of DWDM and optical switching, providers have the ability to alter the amount of bandwidth on a given link and there is no construct within MPLS to request that additional capacity from an upstream provider.

It's important to keep in mind that GMPLS and MPLS are not network layer protocols. TCP/IP networks like the Internet, for example, still require the Internet Protocol to function. GMPLS is a signaling protocol (Layer 3 of the TCP/IP model, see Figure 1-3), and is used by customer equipment to signal other equipment to establish or tear down a circuit. This is a far cry from today's networks where capacity has to be manually provisioned by a network operator.

GMPLS extends MPLS in the following ways:

- The requisition and communication of labels
- The unidirectional nature of LSPs
- The propagation of errors
- The information provided to synchronize initial and final LSRs of a path

MPLS addressed only Packet Switch Capable (PSC) interfaces. GMPLS adds four other types:

- Layer-2 switch capable (L2SC) interfaces which can forward data based on content within frames and cells
- Time Division Multiplexing (TDM) interfaces which forward data based on the data's time slot
- Lambda Switch Capable (LSC) interfaces, like photonic cross-connects, work on an individual wavelengths or wavebands
- Fiber Switch Capable (FSC) interfaces work on individual or multiple fibers

These interfaces establish LSPs similar to those in MPLS. It should be noted that LSPs must start and end with common devices. For example, an LSP consisting of a SONET circuit must originate and terminate with a SONET device.

GMPLS LSPs take advantage of the nesting that occurs in MPLS. Within an LSP, multiple flows are aggregated into a larger flow. The same basic concept applies. Consider LSPs as virtual representations of physical constructs. LSPs representing lower-order SONET circuits might be nested together within a higher-order SONET circuit. Similarly, LSPs that run between FSCs might contain those that run between LSCs, which could contain those that run between TDMs, followed by L2SC and finally PSC. This hierarchy of LSPs is shown in Figure 3-1.

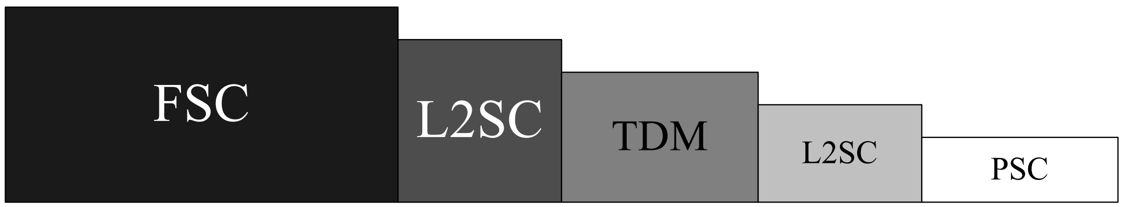


Figure 3-1: Hierarchy of LSPs [4]

LSPs are established by using RSVP-TE or CR-LDP to send what's called a PATH/label request message. This message contains a generalized label request, often an Explicit Route Object (ERO), and specific parameters for the particular technology. The generalized label request is what makes GMPLS different from MPLS. It specifies the LSP encoding type and the LSP payload type. The encoding type indicates the type of technology being considered, whether it is SONET or Gigabit Ethernet, for example. The LSP payload type identifies the kind of information being carried within that LSPs payload. The ERO controls the path that an LSP takes through the network.

The packet traverses a series of nodes to reach its destination. The destination replies with the necessary labels, which are inserted into each LSRs tables along the way. Once the reply reaches the initiating LER, the LSP can be established and traffic sent to the destination.

3.2 Routing Protocols

Routing protocols are used to exchange topology information between the optical control plane and the data plane. There are two types of routing protocols: Interior Gateway Routing Protocols (IGP), and Exterior Gateway Routing Protocols (EGP). The main difference between EGP and IGP is that an IGP shares information existing solely within the same domain. EGPs on the other hand share information between domains. Typically, separate domains are controlled by differing autonomous systems[4] (AS). The two most widely used IGPs in the industry today are OSPF and IS-IS; while the Border Gateway Protocol - Version 4 (BGP4) is the only recognized EGP standard used today.

[4] Autonomous system is atypically an ISP. Within the ISP, routers exchange information freely – all systems are trusted as they are under a single administration in the same domain.

3.2.1 IGPs

3.2.1.1 Open Shortest Path First

OSPF uses a complete topological map of the entire AS. Each router uses Dijkstra's algorithm to compute a shortest path tree to all networks in the system with itself as the root. The shortest path tree is then used to compute the routing table at a given node. Each router sends its routing table to all other routers in the system by using flooding[5]. OSPF has a number of advanced features. It provides secure updating of link state information, allows use of multiple same cost paths for load leveling, allows each link to have different cost metrics for different types of service, provides integrated support for unicast[6] and multicast[7] routing, and supports hierarchical routing within a single autonomous domain.

3.2.1.2 Intermediate-to-Intermediate System

Intermediate System-to-Intermediate System was originally designed as an Open Systems Interconnection (OSI) protocol, which has been modified to work using TCP/IP. IS-IS is a link-state hierarchical routing protocol that floods the network with link-state information to build a complete, consistent picture of network topology. To simplify router design and operation, IS-IS distinguishes between Level 1[8] and Level 2[9] ISs. Level 1 ISs communicate with other Level 1 ISs in the same area. Level 2 ISs route between Level 1 areas and form an intradomain routing backbone. Hierarchical routing simplifies backbone design because Level 1 ISs need to know only how to get to the nearest Level 2 IS. The backbone routing protocol also can change without impacting the intra-area routing protocol. Integrated IS-IS was introduced in the early 1990s to add support for IP based networks.

3.2.2 EGP Border Gateway Protocol Version 4

Border Gateway Protocol is the only EGP currently running that connects different ASs to each other. BGP considers the entire Internet as a network of autonomous systems. An Autonomous System Number (ASN) identifies each entity.

BGP uses TCP as its transport protocol. Two BGP routers form a TCP connection between one another (peer routers) and exchange messages to open and confirm the connection parameters. Any two routers that have formed a TCP connection in order to exchange BGP routing information are called peers, or neighbors. BGP peers initially exchange their full BGP routing tables. After this exchange, incremental updates are sent as the routing table changes. BGP keeps a version number of the BGP table, which should be the same for all of its BGP peers. The version number changes whenever BGP updates the table due to routing information changes. Keep alive packets are sent to ensure that the connection is alive

[5] Flooding is a packet-switched network routing method whereby identical packets are sent in all directions to ensure that they reach their intended destination [9].

[6] Unicast is communication from one device to another device over a network [9].

[7] Multicast is communication between a single device and multiple devices [9].

[8] A Level 1 router knows only the topology of its own area and has Level 1 or Level1/Level2 neighbors in this area. It has a Level 1 link-state database with all the information for intra-area routing. It uses the closest Level 2-capable router in its own area to send packets out of the area,.

[9] A Level 2 router may have neighbors in the same or in different areas, and it has a Level 2 link-state database with all information for inter-area routing. Level 2 routers know about other areas but will not have Level 1 information from its own area.

between the BGP peers and notification packets are sent in response to errors or special conditions. The biggest benefit to using BGP4 is that users have more then one way to reach each other in case one of the circuits to or from a provider goes down.

4. IP Over OTN Models

A nominal IP-over-optical-network model is shown in Figure 4-1. IP routers are attached to an optical core network, and connected to their peers over dynamically established switched light-paths. The optical core itself is incapable of processing individual IP packets. The interaction between the IP routers and the optical core is over a well-defined signaling and routing interface, shown as the User Network Interface (UNI). In addition, the router network can also interface with the optical core through an optical subnet. The router network interfaces with the optical subnet through a UNI and the optical subnet interfaces the optical core through a Network to Network Interface (NNI).

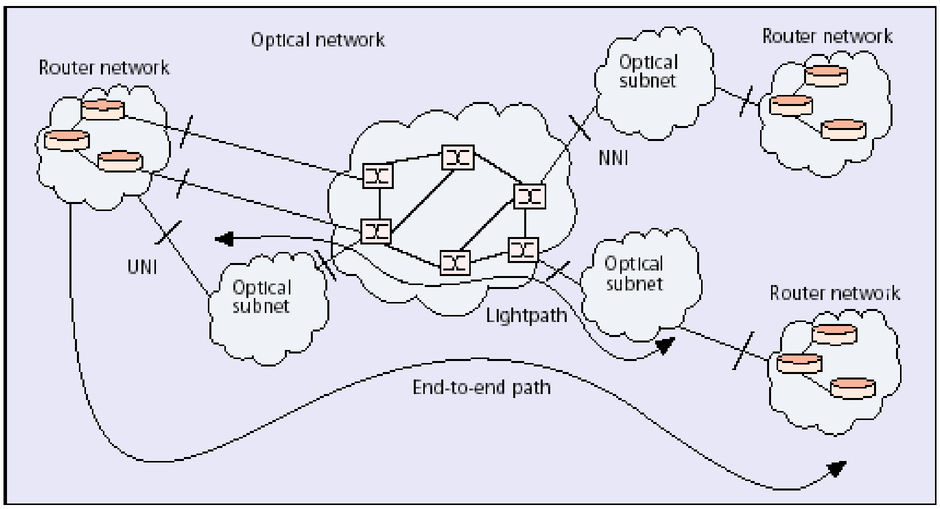


Figure 4-1: An IP Over-Optical-Network Model [11]

To examine the architectural alternatives for IP over optical networks, it is important to distinguish between the data and control planes over the UNI. IP routers at the edge of the optical networks must establish light-paths before communication at the IP layer can begin. Thus, the IP data plane over optical networks is realized over an *overlay* network of light-paths. On the other hand, IP routers and Optical Cross-Connects (OXCs) can have a *peer* relation on the control plane, especially for implementation of a routing protocol that allows dynamic discovery of IP endpoints attached to the optical network. The IP-over optical-network architecture is defined essentially by the organization of the control plane. The assumption is that similar control planes are used in the IP and optical networks. Specifically, it is assumed that a control plane is based on IP routing protocols and MPLS signaling protocols, used in an optical network.

Depending on the service model, however, the control planes in the IP and optical networks can be loosely or tightly coupled. This coupling determines the:

- Details of the topology and routing information communicated by the optical network across the UNI
- Level of control IP routers can exercise in selecting specific paths for connections across the optical network

Currently, there are three interconnection models being considered for IP over optical networks:

- Peer-to-Peer Model
- Overlay Model
- Augmented Hybrid Model

4.1 Peer-to-Peer Model

In the peer-to-peer model, not surprisingly, optical switches and routers act as peers, using a uniform and unified control plane to establish label-switched paths across these devices with complete knowledge of network resources. Figure 4-2 shows this relationship.

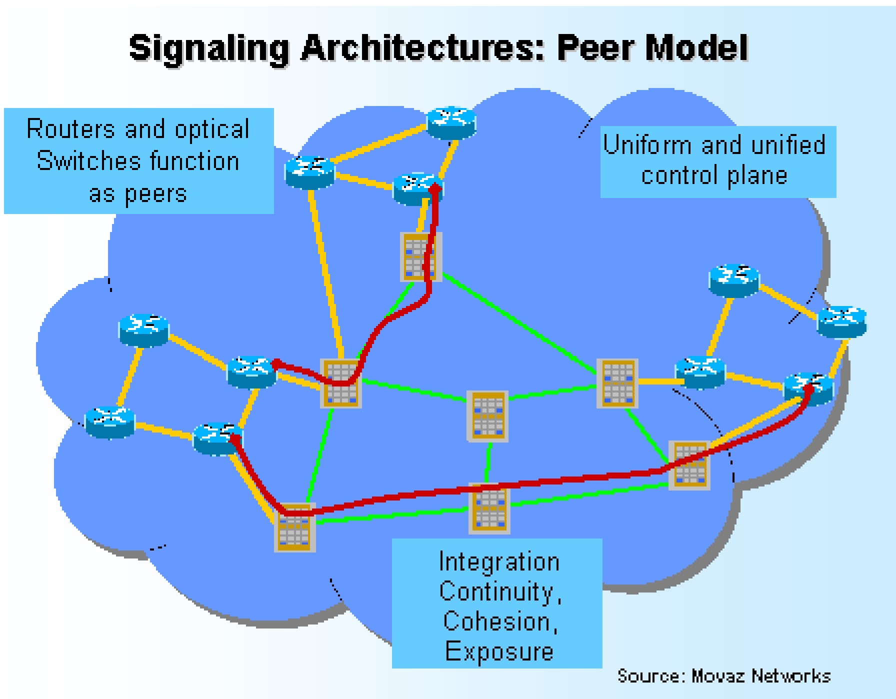


Figure 4-2: Peer-to-Peer Model [14]

In this model there is little or no distinction among UNI, Network to Network Interface (NNI), and router-router (MPLS) control planes; all network elements are direct peers and fully aware of topology and resources. IP-optical interface services are folded into end-to-end MPLS services, meaning label-switched paths could traverse any number of routers and optical switches.

This is a key distinction. In the peer model a single instance of a control plane can span multiple technologies/network elements, provided that the control plane can support each of the technologies. This allows a network operator to create a single network domain composed of different network elements, thereby allowing them greater flexibility than in the overlay model in which an optical cloud is created as a domain unto itself.

GMPLS and the peer model allow complex layered networks scalability by the dynamic assemblage of forwarding hierarchies, from fiber–optic cables to routers. Label-switched paths (LSPs) can be established within each layer and "nested" within other layers. An LSP originating and terminating on an optical switch interface may contain multiple LSPs within the network that begin and end on routers.

The unique IP/MPLS-based control plane in the peer model would simplify control coordination and fault handling among network elements with different technologies, though at the same time require significantly more work to ensure proper integration with the control plane. Additionally, this model offers the benefits of end-to-end protection and failure restoration, traffic engineering based on MPLS concepts, and efficient use of resources in a network composed of multiple technologies.

Important to companies like Cisco and Juniper, routers may control the end-to-end path using traffic engineering-extended routing protocols deployed in IP and optical networks, thus giving them ultimate power over network utilization and resource management. As it favors the intelligence of routers over optical switches, the peer model of the Optical Internet is being pursued most aggressively by router vendors. These have their voices heard most favorably within the Internet Engineering Task Force (IETF).

The peer model does, however, present a scalability problem because of the amount of information to be handled by any network element within an administrative domain. It is easy to see any one network element getting choked by a constant barrage of network state updates. In addition, non-optical devices must know the features of optical devices, which can be an operational nightmare in many traditional networks today, where the boundaries between the transport network and data network are as impassable as the Chinese Wall.

The peer model may well take hold in the future, but it is likely to be a rather distant future. For the time being, carriers are much more likely to reach a comfort level with the overlay model, particularly if the Optical Internetworking Forum (OIF) UNI is adopted by a large number of vendors and the ability to support new optical services and restoration schemes is provided.

The added benefits of the peer model may, indeed, not be sufficient to justify the complexity of implementation. Most carriers today, when posed with the basics of the peer model, respond with a simple question: "Would I want routers (or my customer's routers) making million-dollar decisions on their own?" The answer is always no. And that current perception will make the process of developing standards to suit a peer model very challenging over the next few years.

4.2 Overlay Model

In this model, the optical network "cloud", made up of SONET/SDH, DWDM, and optical switching systems, provides connection services to IP routers and other "client" devices attached to the network. Within this client-server network architecture, different layers of the network remain isolated from each other, but dynamic provisioning of bandwidth is made possible, though entirely on the optical network's terms. Routers or switches "ask" the optical network for a connection, and the optical network either grants it or denies it. These requests can be fairly sophisticated, asking for a certain size circuit with a particular grade of restoration. The key here is that these devices can't see into the network. They're talking to a doorman with firm instructions to keep outsiders where they belong. Figure 4-3 shows a representation of the overlay approach.

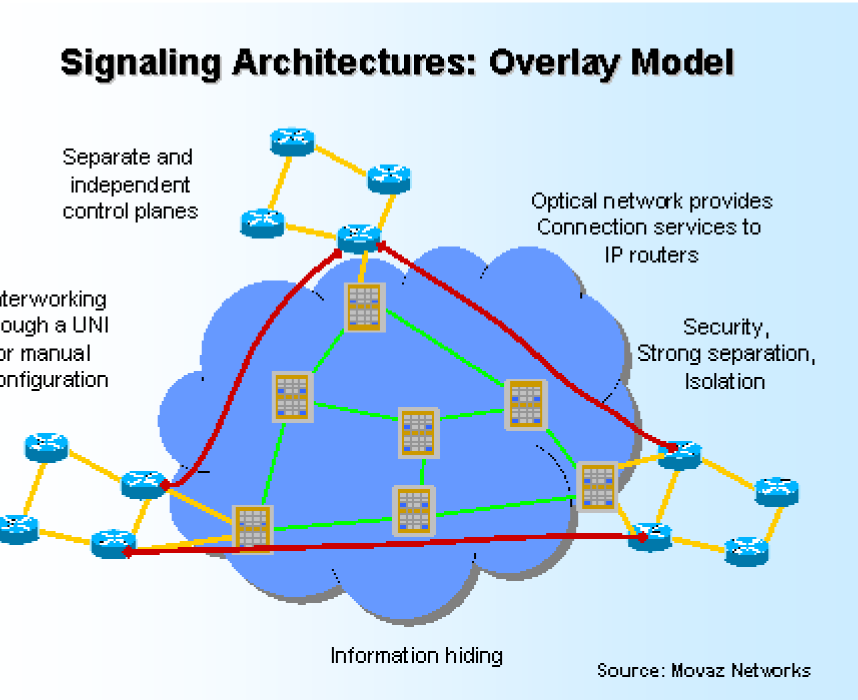


Figure 4-3: Overlay Model [14]

The benefits of this model have led to its early endorsement by the Optical Domain Service Interconnect Coalition (ODSI), the Optical Internetworking Forum, and the International Telecommunication Union (ITU). Chief among the values of the overlay model are, according to its proponents:

- The optical layer comprises subnetworks with well-defined interfaces to client layers
- It allows each subnetwork to evolve independently
- Innovation can evolve in each subnet independently
- It does not strand "older" infrastructure
- It provides IP, ATM, and SONET interoperability using open interfaces
- Optical network topology and resource information is kept secure

To build the overlay, standard network interfaces are required. Network interfaces typically come in two forms, those for within the network and those for its entrance.

The User Network Interface (UNI) provides a signaling mechanism between the user domain and the service provider domain, while the Network-to-Network Interface (NNI) provides a method of communication and signaling among subnetworks within an optical network. It allows attached clients of an optical network to establish optical connections dynamically across the optical cloud, using a neighbor-discovery mechanism and a service-discovery mechanism. Thus, devices attached to an optical network will be able to quickly identify other attached devices, build reliable connection maps, and automatically discover the service resources of any optical network. This speeds the provisioning of services and dramatically reduces operational expenses associated with optical networks.

The NNI is the control plane over which the network's connections are orchestrated, involving lightpath routing, signaling, status reporting, and scheduling. In the context of the optical switched network, the NNI refers to a connection between any of the following:

- Different service provider networks
- Subnetworks of the same provider
- Connection between different vendors' switches within a subnetwork

The definition of the NNI in the optical network remains in the very early stages of development. NNI interface routing options under consideration include static routing, default routing (applicable only to the single homed scenario), and dynamic routing. NNI interface signaling options include Constraint-based Routing Label Distribution Protocol (CR-LDP) and Resource Reservation Protocol with Traffic Engineering extensions (RSVP-TE), both of which are IETF drafts. GMPLS extensions to both CR-LDP and RSVP-TE have been proposed to adapt the respective protocols within the context of the optical domain.

The overlay model, based on the UNI and NNI, makes sense today because it is well suited for an environment that consists of multiple administrative domains, which most carrier networks have. This is particularly useful in large carrier networks, where the group that controls the transmission network does not necessarily like cooperating with the group that controls IP services. The large IXCs all fit into this camp and will likely move first into the overlay model, using it to control their network of optical switches, once they get deployed. With a standardized UNI in place, large IXCs will be able to offer some bandwidth-on-demand services and improve the management of their optical networks.

The overlay model has its limitations, however, and most people in the industry feel it's just a step in the right direction, not the ultimate model. The debate appears to have come down to this: Do we stop at two control planes (one for the transport layer and one for packet layer), or is a unified control plane the ultimate goal of these efforts? The big issue at the heart of this debate is scalability—namely, can a unified control plane scale to support every device in a network?

In the case of the overlay, its simplicity does come with the trade-offs of potentially less efficient use of resources due to information hiding at the domain boundaries, and a susceptibility to a single failure within one domain causing multiple seemingly unrelated failures in other domains. This can be overcome, it seems, with proprietary "tweaking" of signaling within an optical network, so it remains to be seen if this represents a fatal flaw for the overlay model, or just part of its character.

4.3 Augmented Hybrid Model

Even though much of the debate has centered on overlay vs. peer architectures, some people are now beginning to propose hybrid solutions. The hybrid model represents a middle ground between overlay and peer. From the overlay model the hybrid takes the support for multiple administrative domains. From the peer model, hybrids take support for heterogeneous technologies within a single domain.

Ideally, this avoids limitations of the peer and the overlay while combining their benefits and gives a carrier a wide degree of flexibility in how to design its core network. It may be desirable to keep some areas entirely separate for security reasons, and use the UNI to segregate them, while other areas may benefit from having a mix of optical switch and IP routers acting as peers. These domains can be stitched together with a standardized NNI. The most likely scenario for this model is one in which IP and optical networks retain their clear demarcations and exchange only reachability information. For simplicity's sake, separate instances of routing protocols would run in the IP network and in the optical network; any network domain could still accommodate different technologies.

4.4 Comparisons of Models

Operation of an IP over OTN architecture requires a number of functions to be performed by the data and optical layers. These functions include routing, forwarding, signaling, switching, provision of quality of service and variable high bandwidth on demand and protection and restoration. Table 4-1 shows how the models compare to each other with respect to the aforementioned criteria.

The Augmented hybrid model combines the best of the Peer and Overlay models. The optical and data layers are kept separate. This will make the ISPs and carriers happy as they can keep their network topology secret. Control and management overhead are also minimized. This is the model that would be easiest to implement in the near term.

Comparison of Features of the Various OTN Models	Peer Model	Overlay Model	Hybrid Model
Provides Support for Routing	Yes	Yes	Yes
Provides Support for Signaling	Yes	Yes	Yes
Provides Support for Switching	Yes	Yes	Yes
Provides Support for QoS	Yes	Yes	Yes
Provides Support for Variable Bandwidth on Demand	Yes	Yes	Yes
Provides Support for Protection and Restoration	Yes	Yes	Yes
Provides Protection for Proprietary Topological Information	No	Yes	Yes
Control and Management Overhead	Low	High	Moderate
Complexity of Architecture	Low	High	Moderate
Can be Implemented at the Present Time	No	Yes	Yes

Table 4-1: Comparison of Proposed OTN Models

5. Routing Approaches Using IP Over OTN

Thus far, three potential models for OTN - peer, overlay, and hybrid - have been described. Also mentioned were routing protocols required if IP is the protocol to be used to unify the control and data planes. This section will merge these concepts and show how they can be implemented in the future.

5.1 Integrated Routing Approach

This routing approach supports the peer model. Under this approach, the IP and optical networks are assumed to run the same IP routing protocol, OSPF or IS-IS, with suitable "optical" extensions. These extensions capture optical link parameters and any constraints specific to optical networks. IP routers maintain a single topology database for a joint network consisting of IP and optical nodes. Assuming that routers are programmed to apply the correct semantics for the optical network information, IP routers can compute full paths to other IP destinations across the network. For example, in Figure 5-1, router R1 can compute the path R1-R2-R3-O3-O2-R4-R5 where R5 is the receiving router and O3 and O2 are OXCs in the OTN. This path may be signaled hop-by-hop from R1 to R5, using the appropriate MPLS signaling protocols across the UNI and NNI, and within router and optical subnetworks. Once the path is established, however, the segment R3-O3-O2-R4 must be treated as a single virtual link between R3 and R4 of fixed capacity (e.g., OC-48) and perhaps advertised as such in further OSPF or IS-IS updates. The restoration of the light path within the optical network may be visible to all nodes in the network, thereby complicating the process. Figure 5-1 depicts an integrated routing approach.

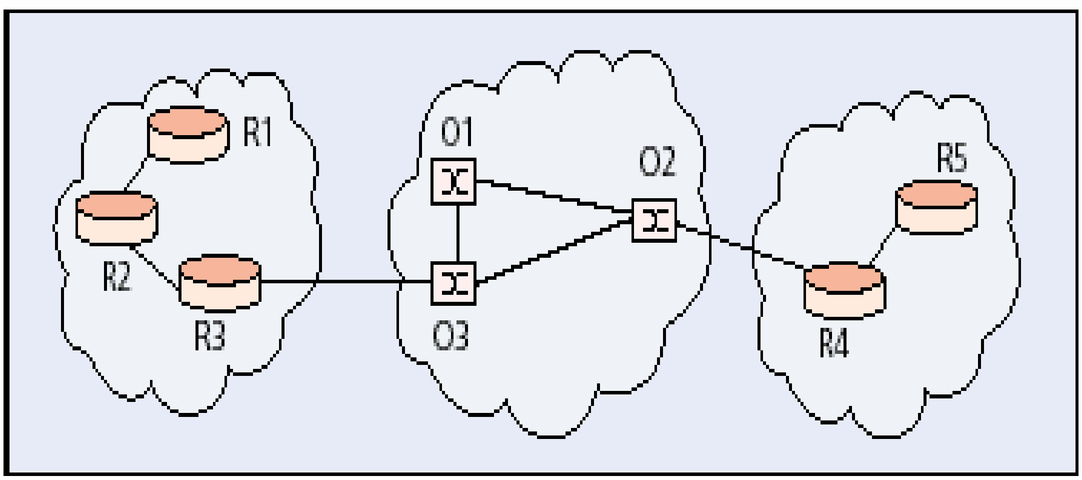


Figure 5-1: An Integrated Routing Example [11]

5.2 Domain Specific Routing Approach

This approach supports the augmented hybrid model. Under this approach, routing within the optical and IP domains are separated, with a standard routing protocol running between domains. The interdomain IP routing protocol, BGP, can be adapted for exchanging routing information between IP and optical domains. This would allow the routers to communicate IP address prefixes within their network to the optical network and to receive external IP address prefixes from the optical network.

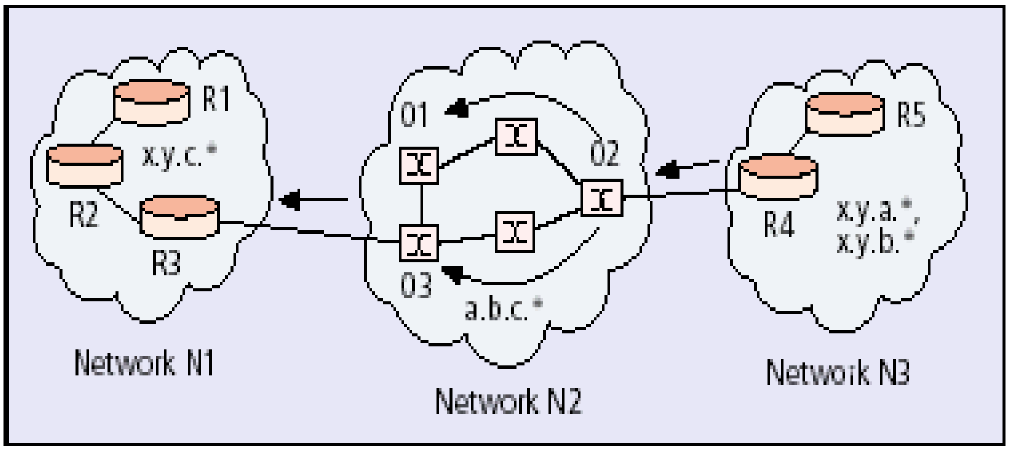


Figure 5-2: Domain-Specific Routing: a BGP Example [11]

In Figure 5-2, networks N1–N3 are assigned the IP address spaces indicated by the network prefixes *x.y.c, a.b.c*, and {*x.y.a*, *x.y.b*}. The propagation of the address prefixes from R4 to R3 through the optical network is shown. Exterior BGP (EBGP) is assumed to run between the IP routers and OXCs over the UNI (between Border routers and Border OXCs), and between neighboring OXCs over the NNI. Within the optical network, it is assumed that interior BGP (IBGP) is used between border OXCs within the same subnet work. The IP address prefixes within the optical network are not advertised to routers using BGP. A border OXC receiving external IP prefixes from a router includes the IP address of the egress port before propagating these prefixes to other border OXCs or border routers. In the example illustrated in Fig. 5-2, the port address of the border OXC router O2 will be advertised along with the prefixes {*x.y.a.**, *x.y.b.**}[10]. A border router receiving this information need not propagate the OXC address further, but must keep the association between external IP addresses and egress OXC addresses. When a specific external IP address is to be reached, the border router can determine if a light-path has already been established to the appropriate egress OXC or a path must be newly established. Specific BGP mechanisms for propagating egress OXC addresses are to be determined **[11].**

5.3 Overlay Routing Approach

The Overlay routing approach supports the overlay interconnection model. Under this approach, an overlay mechanism that allows edge routers to register and query for external addresses is implemented. This is conceptually similar to the address resolution mechanism

[10] x.y.a.* and x.y.b.* are IP addresses internal to the BGP network and not passed to external routers or OXCs.

used for IP over ATM. Under this approach, the optical network could implement a registry that allows edge routers to register IP addresses and VPN identifiers. An edge router may be allowed to query for external addresses belonging to the same set of VPNs it belongs to. A successful query would return the address of the egress optical port through which the external destination can be reached. Because IP optical interface connectivity is limited, the determination of how many light-paths must be established and to what endpoints are traffic-engineering decisions. Furthermore, after an initial set of such light-paths are established, these may be used as adjacencies[11] within VPNs for a VPN-wide routing scheme, for example, OSPF. With this approach, an edge router could first determine other edge routers of interest by querying the registry. After it obtains the appropriate addresses, an initial overlay light-path topology may be formed. Routing adjacencies may then be established across the light-paths and further routing information may be exchanged to establish VPN-wide routing.

[11] Relationships formed between selected neighboring routers and end nodes for the purpose of exchanging routing information.

6. Implementation Issues Related to IP Over OTN Based Networks

This section will take a look at some of the areas that need to be developed in order to make OTN based networks a reality. Areas to be discussed include, but are not limited to, technology evolution, security, attaching legacy systems, and running IP over DWDM directly.

6.1 Technology Evolution

6.1.1 Optical Packet Switching

IP routers and optical cross-connects using MPLS and GMPLS allow rapid dynamic wavelength allocation. This provides flexibility and rapidity in the redistribution of bandwidth along the network. Also, it helps the network cope with massive traffic pattern variations. However, this type of bandwidth allocation is more suitable for circuit switching applications. As IP-based data traffic increases, this mode of operation may not be dynamic enough. Optical packet switching (OPS) offers a potential solution that could provide the most flexible and efficient use of the high bandwidth available at the optical layer. However, implementation of optical packet switching needs more research and development work in the areas of high speed optical switching, large scale optical buffering and regeneration and realization of optical control of optical switches to make OPS a reality.

6.1.2 Optical Burst Switching

In view of the difficulties in the realization of optical packet switching, an alternative technique called optical burst switching (OBS) has been proposed. In this method IP packets are concatenated into optical bursts at edge nodes, and are then routed as a single entity through the network. OBS combines the best of circuit switching and packet switching, and avoids their shortcomings. In conjunction with MPLS, OBS can increase the forwarding capability of routers by using only one header for multiple IP packets. Additional research and development work in high speed optical switching, large scale optical buffering and regeneration, optical control of optical switches and selection of optimum frame size is required before OBS will become a reality.

6.2 Security

Currently, Government and industry are aware of security concerns related to the Internet Protocol. Many of these issues are actively being addressed, and solutions developed. These concerns are beyond the scope of this effort. However, there are several security issues associated with the protocols relating to IP over OTN, which may impact the NS/EP mission of the NCS. These issues include:

- The authentication of entities exchanging information (signaling, routing or link management) across a control interface
- Ensuring the integrity of the information exchanged across the interface
- Protection of the control mechanisms from outside interference

Because optical connections may carry high volumes of data and consume significant network resources, mechanisms are required to safeguard an optical network against unauthorized use of network resources. In addition to the security aspects related to the control plane, the data plane must also be protected from external interference.

6.3 Attaching Legacy Systems to an IP over OTN Based Network

Evolution to a new system often requires that certain legacy equipment may need to remain in the network. There could be a myriad of reasons for the retention of legacy systems which stems from the cost of replacement equipment to a customer that requires a unique solution for their business.

For a large entity that may be using high end equipment, most manufacturers will produce new interfaces which will run on the existing equipment. Smaller customers may have to upgrade their equipment at considerable cost or settle for a lower bandwidth solution until funds can be secured to purchase new equipment.

Each network operator should adopt a rational and phased approach when upgrading equipment to support OTN. Most major operators will likely follow an approach as follows:

- Initialization of MPLS/GMPLS throughout their network. The network will need to be monitored for a period of time to ensure that the new routing approach is working as expected, being tweaked along the way as needed.
- Once MPLS/GMPLS is stable on the network, normally a test bed would be set up using all the various scenarios present in the operator's network. When all the necessary testing is complete and the new equipment and software has been determined to work in unison with what is in the field, then you can move to the next phase.
- Select a site in the network that has minimal traffic and deploy the new equipment. Note any issues that may need to be reviewed with personnel who tested in the lab. Monitor the new equipment under real conditions to see how it performs. Once satisfied that no undue harm will happen from a network wide deployment, move on to the next step.
- Prepare a detailed plan to upgrade the network to the new hardware and software. This approach should be phased over a period of time that will allow for a settling in so that if unexpected complications occur you can put the plan on hold until the issue(s) are resolved.

6.4 Running IP Directly Over DWDM

Currently, standards are not in place to make an OTN viable. No major ISP is running MPLS on 100% on their backbone network. MPLS can be used to provide QoS and other traffic engineering mechanisms, which would replace the current ATM switching technology providing these services. As MPLS/GMPLS becomes widely implemented ATM can be phased out. This has a two-fold benefit. More bandwidth will be available since the ATM management overhead will be gone. Currently large scale networks require switches to provide for traffic engineering. MPLS/GMPLS provides this function at the Network Layer (L3) and thus switches are no longer needed, which will save money in the long run. The biggest disadvantage of ATM is that so far only OC-48 interfaces exist for switches. Most router manufacturers only make an OC-12 ATM interface. This severely limits the ability of an ATM-based network to provide the future high-speed capacity.

6.5 Reconfiguration Time Scale Effects on the Stability of IP Routing Protocols

Intra-domain routing protocols like OSPF and IS-IS base their route computation (is dependent upon the protocol being used) on their knowledge of the topology of the whole domain. If the topology of the domain changes due to some node or link failure, routing tables may not guarantee the shortest paths any more. However, due to the inherent updating process used in these routing protocols, some nodes in the neighborhood of the failure will detect a failure. This knowledge will be reflected in the routing tables of these nodes. During the updating process, the updated routing tables will be disseminated to other nodes. These nodes, in turn, will update their routing tables. It should be noted that the new shortest paths may incur longer delay than before. Moreover, the delays may become even longer if a number of nodes and links fail simultaneously. If the failures occur frequently, the routing tables will need to be updated more frequently, and some packets may be sent on non-optimal routes. Inter-domain routing protocols also use frequent updating of domain lists as a way of improving their performance in the presence of failures. In addition, protection schemes providing quick restoration at the optical layer should help the stability of routing protocols in general.

7. Standardization Activities

The concept of Optical Transport Network has been foremost in the industry for many years. Most ISPs and telecommunications carriers, while they strongly support the concept of high-speed capacity, will not move to this new approach until there are well-defined standards.

7.1 International Telecommunication Union

The standardization efforts within the ITU of interest are carried out in Study Group 15 in the ITU Telecommunication Standardization Sector (ITU-T)[12]. They are:

G.709/Y.1331: "Interfaces for the Optical Transport Network (OTN)", 2/2001

This Recommendation was approved in February 2001. It defines the interfaces of the OTN to be used within and between sub-networks of the optical networks in terms of optical transport hierarchy, functionality of the overhead in support of multi-wavelength optical network, Frame structures, Bit rates, Formats for mapping client signals.

- **G.798: draft 0.7, " Characteristics of OTN Hierarchy Equipment Functional Blocks", 2/2001**

This Recommendation provides a library of basic building blocks for describing OTN equipment and rules by which the building blocks are combined.

See Appendix C for a list of other major ITU-T standards relating to this topic.

7.2 Internet Society

The Internet SOCiety (ISOC)[13] is the international organization for global cooperation and coordination for the Internet and its internetworking technologies and applications. The mission of the Internet Society is "To assure the open development, evolution and use of the Internet for the benefit of all people throughout the world." ISOC is the organizational home of the Internet Engineering Task Force, the Internet Architecture Board (IAB), the Internet Engineering Steering Group (IESG), and the Internet Research Task Force - the standards setting and research arms of the Internet community. The specification documents of the Internet protocol suite, as defined by the IETF, are published as Request for Comments (RFCs). Currently, there are no published RFCs for IP over OTN. However, there are several draft proposals addressing this subject. Internet Drafts addressing OTN are as follows:

- **"Impairments and Other Constraints on Optical Layer Routing", John Strand, Angela Chiu, 27-SEP-02**

  Optical networking poses a number challenges for GMPLS. Optical technology is fundamentally an analog rather than digital technology; and the optical layer is lowest in the transport hierarchy. Hence, it has an intimate relationship with the physical geography

[12] www.itu.int/ITU-T
[13] www.isoc.org

of the network. This RFC surveys some of the aspects of optical networks which impact routing and identifies possible GMPLS responses as they relate to:

- Design of new software controllable network elements
- Single all-optical domain without wavelength conversion
- Complex networks incorporating both all-optical and opaque architectures
- Diversity

- **"IP over Optical Networks: A Framework", Bala Rajagopalan, 10-JUN-02**

  The Internet transport infrastructure is moving towards a model of high-speed routers interconnected by optical core networks. The architectural choices for the interaction between IP and optical network layers, specifically, the routing and signaling aspects, are maturing. At the same time, a consensus has emerged in the industry on utilizing IP-based protocols for the optical control plane. This RFC defines a framework for IP over Optical networks, considering both the IP-based control plane for optical networks as well as IP-optical network interactions (together referred to as "IP over Optical Networks").

- **"Carrier Optical Services Requirements", Yong Xue, 06-NOV-02**

  This Internet Draft describes the major carrier's optical service requirements for the Automatically Switched Optical Networks (ASON) from both an end-user's as well as an operator's perspectives. Its focus is on the description of the service building blocks and service-related control plane functional requirements. The management functions for the optical services and their underlying networks are beyond the scope of this RFC and will be addressed in a separate submission.

Appendix C lists other relevant Internet Drafts and RFCs.

7.3 Committee T1 – Telecommunications

Committee T1[14] is sponsored by the Alliance for Telecommunications Industry Solutions and accredited by the American National Standards Institute to create network interconnections and interoperability standards for the United States. Committee T1 – Telecommunications develops technical standards and reports regarding interconnection and interoperability of telecommunications networks at interfaces with end-user systems, carriers, information and enhanced-service providers, and customer premises equipment. The primary Technical Subcommittee of interest is T1X1 - Digital Hierarchy and Synchronization, whose mission is to develop and recommend standards and prepare technical reports related to telecommunications network technology pertaining to network synchronization interfaces and hierarchical structures for U.S. telecommunications networks. T1X1 focuses on those functions and characteristics necessary to define and establish the interconnection of signals comprising network transport. This includes aspects of both asynchronous and synchronous networks. T1X1 also makes recommendations on related subject matter under consideration in various North American and international standards organizations. Its scope includes the

[14] www.t1.org

concept, definition, analysis and documentation of matters pertaining to the interconnection of network transport signals. All theoretical and analytical work necessary to support the documented results is generated or coordinated by the Technical Subcommittee. This requires close liaison with other Committee T1 Technical Subcommittees as well as standards organizations external to Committee T1. It should be noted that T1 Committee also prepares US contributions, which are submitted through the US Department of State, to the ITU-T sector. Many of these contributions, as well as American National Standards Institute (ANSI) Standards developed by T1X1, relate to ITU-T Recommendation G.709/Y1331. A listing of OTN related standards are shown in Appendix C.

7.4 The Optical Internetworking Forum

While it is not a standards setting body, the mission of the Optical Internetworking Forum (OIF)[15] is to:

- Encourage co-operation among telecom industry participants including equipment manufacturers, telecom service providers and end users
- Promote global development of optical internetworking products
- Promote nationwide and worldwide compatibility and interoperability
- Encourage input to appropriate national and international standards bodies, and
- Identify, select, and augment as appropriate and publish optical internetworking specifications drawn from national and international standards

For example, OIF supports the development of optical switches by different vendors so that they will interoperate with each other. A significant effort involves the User Network Interface for OTN. More specifically, a white paper entitled, "OIF UNI 1.0-Controlling Optical Networks [12]." This white paper indicates that telecommunications service providers have embraced DWDM as the most cost-effective technology for increasing the capacity of optical fiber networks. This new optical network layer now promises intelligent transport services that will allow clients such as IP routers and ATM switches to interconnect, initially using SONET/SDH network interfaces, but followed by other optical interfaces over time." **[12]**

[15] www.oiforum.com

8. Observations

This report has presented an overview of the factors and issues deemed necessary to consider the transition from the current SONET-based network architecture towards the use of the Internet Protocol over Optical Transport Network. It has identified areas that need to be addressed in order to make this goal a reality. The following is a snapshot of where the industry is currently positioned:

- Industry and customers believed that the major ISPs and carrier networks would have a 39.812 Gbps (OC-768) backbone in place by the time this report was published. However, economic slow down has postponed high-speed connections. Most of the major router and switch manufacturers have also delayed the release of their next generation routers that would support speeds up to OC-768.
- OTN lacks standards making it difficult for major players to embrace these technologies
- The augmented hybrid model for OTN appears to be the best model for near-term implementation. This model allows for competition among the major players and keeps management overhead to a minimum.
- Users of high-speed data connections need to be vigilant in their security policies and procedures as more and more data is transmitted across open public networks and thus exposed to an increasing security threat
- Most ISPs and telecommunications carriers, while they strongly support the concept of high-speed capacity, will not move to this new approach until there are well-defined standards. Although industry may implement standards for Optical Transport Network, they are doing so in a proprietary manner.
- Standards for OTNs dos not exist. In order to achieve interoperability, industry needs to develop a comprehensive set of standards that comply with the provisions of ITU-T Recommendation G.709/Y1331, "Interfaces for the Optical Transport Network."

9. Recommendations

There are numerous organizations such as ITU-T, IETF and Committee T1 who are addressing the issue of the development of standards for the use of the Internet Protocol over Optical Transport Network. In support of the NCS' mission relating to NS/EP, it is recommended that:

- NCS and other entities need to be more involved with the Optical Internetworking Forum and other bodies to develop standards for Optical Transport Networks. Without these standards, the manufacturers, backbone carriers, and Tier 1 ISPs will not upgrade their infrastructure to take advantage of OTNs benefits.
- The NCS should further explore the augmented hybrid model for OTN, and develop contributions to the appropriate standards for an Internet Protocol over Optical Transport Network to ensure that NS/EP requirements are addressed. This set of standards should comply with the provisions of ITU-T Recommendation G.709/Y1331, "Interfaces for the Optical Transport Network."
- NCS should initiate a policy review to ensure that all member organization NS/EP circuits are appropriately diverse, i.e., from diverse providers and diverse paths to/from their destinations
- The NCS should coordinate with their member organizations to identify any requirements that would be satisfied by IP over OTN such that the NCS can promote the appropriate standards in national and international fora.
- Major ISPs need to continue implementation of an MPLS based routing structure throughout their backbone networks. Until this protocol is fully implemented by ISPs, backbone carriers, and manufacturers OTN cannot become a reality.

Appendix A: Acronyms

ADM	Add-Drop Multiplexer
ANSI	American National Standards Institute
ARIN	American Registry for Internet Numbers
AS	Autonomous System
ASN	Autonomous System Number
ATM	Asynchronous Transfer Mode
BGP4	Border Gateway Protocol Version 4
BGP	Border Gateway Protocol
COTS	Commercial Off The Shelf
CR-LDP	Constraint Based Routed-Label Distribution Protocol
DCC	Data Communications Channel
DWDM	Dense Wavelength Division Multiplexing
EGP	Exterior Gateway Routing Protocol
EOP	Executive Office of the President
FEC	Forward Equivalence Classes
FOA	Fiber-Optic Amplifier
FOTS	Fiber-optic Transmission System
FSC	Fiber Switch Cable
Gbps	Gigabits per second
GHz	Gigahertz
GMPLS	Generalized Multi Protocol Label Switching
HF	High Frequency
IDN	Integrated Digital network
IEEE	Institute of Electrical and Electronics Engineers
IGP	Interior Gateway Routing Protocol
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPv4	Internet Protocol Version 4
IPv6	Internet Protocol Version 6
IS-IS	Intermediate System to Intermediate System Protocol

ISO	International Organization for standards
ITU	International Telecommunication Union
ITU-T	ITU Telecommunications Standardization Sector
L2SC	Layer 2 Switched Capable
LAN	Local Area Network
LDP	Label Distribution Protocol
LER	Label Edge Router
LSC	Lambda Switch Capable
LSP	Label Switched Path
LSR	Label Switched Router
MAN	Metropolitan Area Network
Mbps	Megabits per second
MEMS	Micro Electromechanical System
MONET	Multiwavelength Optical Networking
MPOA	Multi Protocol over ATM
MPOE	Minimum Point of Entry
MPLS	Multi Protocol Label Switching
NCS	National Communications System
nm	Nanometer
NNI	Network to Network Interface
NS/EP	National Security and Emergency Preparedness
OA	Optical Amplifier
OADM	Optical ADM
OAM	Operations, Administration and Management
OCh	Optical Channel
OMNCS	Office of the Manager, National Communications System
OMS	Optical Multiplex Section
OSC	Optical Supervisory Channel
OSPF	Open Shortest Path First Protocol
OTN	Optical Transport Network
OTS	Optical Transmission Section
OXC	Optical Cross Connect
PCS	Personal Communications Service
PDN	Packet Data Network
PHY	Physical Layer

PM	Physical Medium
PMD	Polarization Mode Dispersion
PN	Public Network
PSN	Public Switched Network
PPP	Point-to-Point Protocol
PVC	Permanent Virtual Circuit
PVP	Permanent Virtual Path
QoS	Quality of Service
R&D	Research and Development
RSVP	Resource Reservation Protocol
SDH	Synchronous Data Hierarchy
SONET	Synchronous Optical Network
STS	Synchronous Transport Signal
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TDM	Time Division Multiplexing
TIB	Technical Information Bulletin
UNI	User Network Interface
VPN	Virtual Private Network
WADM	Wavelength Add-Drop Multiplexer
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing

Appendix B: References

[1] "Convergence Task Force Report," President's National Security Telecommunications Advisory Committee, Washington, D.C., June 2001.

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[3] CTF, " Report of the Convergence Task Force," Washington, D.C., 2000.

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[9] Harry Newton, "Newton's Telecom Dictionary," CMP Books, New York, NY, 2002.

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[12] Bernstein et al, "OIF UNI 1.0 – Controlling of Optical Networks," December 2001

[13] Ramaswami, Rajiv and Sivarajan, Kumar, "Optical Networks 2nd Edition" Morgan Kauffman Publishers, 2001

[14] "Optical Signaling Systems," Light Reading, January 8, 2002, www.lightreading.com

[15] Choi, Joon and Lahay, Danny. "Optical Transport Network Solution to Network Scaability and Manageability." Optix Networks.

Appendix C: SONET & SDH Recommendations & Industry Standards

	ITU-T Published or Draft (Revised) Recommendation	Published or Draft (Revised) ETS or EN	Published or Draft (Revised) ATIS/ANSI T1
Internet Document Source	ITU-T Recommendations	ETSI Standards	ATIS/ANSI T1 Standarts
Physical Interfaces	G.703 (10/98) G.957 (06/99) G.692 (10/98) K.41 (05/98) G.691 (04/00)	ETS 300 166 ETS 300 232, ETS 300 232(A1) ETS 300 166 (09/99)	T1.102-1993 (R1999) T1.105.06-1996 T1.416-1999 T1.416.01-1999 T1.416.02-1999 T1.416.03-1999
Network Architecture	G.805 (11/95), (03/00) G.803 (06/97), (03/00) I.322 (02/99)	ETR 114	T1.105.04-1995
Structures & Mappings	G.704 (10/98) G.707 (10/00) corrigendi 1 & 2, amendment 1 G.7041 (10/01) GFP G.7042 (10/01) LCAS G.708 (10/98) G.832 (10/98)	ETS 300 167 (08/93), (09/99) ETS 300 147 Ed.3 ETS 300 337 Ed.2	T1.105-1995 T1.105-2001 (draft) T1.105.02-1995
Equipment Functional Characteristics	G.664 (06/99) G.781 (06/99) G.783 (10/00) corr. G.958 (01/94) G.705 (04/00) G.806 (04/0)	EN 300 417-x-y (x=1-7,9 y=1-2) ETS 300 635 ETS 300 785 RE/TM-1042-x-1 (x=1-5) MI/TM-4048 (9712)	
Laser Safety	G.664 (06/99)		
Transmission Protection	G.841 (10/98) G.842 (04/97) M.2102 (03/00)	ETS 300 746 ETS 300 417-1-1 ETS 300 417-3-1 ETS 300 417-4-1 TS 101 009 TS 101 010 RE/TM-1042 TR/TM-03070	T1.105.01-1998
Equipment Protection	M.3100 Amendment		
Restoration		DTR/TM-3076	
Equipment Management	G.784 (06/99)	EN 301 167 EN 300 417-7-1 DE/TM-2210-3	
Management			T1.105.04-1995

	ITU-T Published or Draft (Revised) Recommendation	Published or Draft (Revised) ETS or EN	Published or Draft (Revised) ATIS/ANSI T1
Communications Interfaces			
Information Model	G.773 (03/93) G.774 (09/92), Corr.1(11/96), (04/00) G.774.01 (11/94), Corr1(11/96), (04/00) G.774.02 (11/94), Corr1(11/96), (04/00) G.774.03 (11/94), Corr1(11/96), (04/00) G.774.04 (07/95), Corr1(11/96), (04/00) G.774.05 (07/95), Corr1(11/96), (04/00) G.774.06 (04/00) G.774.07 (11/96), (04/00) G.774.08 (04/00) G.774.09 (04/00) G.774.10 (04/00)	ETS 300 304 Ed.2 ETS 300 484 ETS 300 413 ETS 300 411 ETS 300 493 prEN 301 155	T1.119-1994 T1.119.01-1995 T1.119.02-1998 T1.245-1997
Network Management	G.831 (08/96), (03/97) T.50 (09/92) G.85x.y (11/96)	ETS 300 810	T1.204-1997
Error Performance [network level view]	G.826 (02/99) G.827 (02/00) G.827.1 (11/00) G.828 (02/00) G.829 (02/00) M.2101 (02/00) M.2101.1 (04/97) M.2102 (02/00) M.2110 (04/97) M.2120 (04/97), (02/00) M.2130 (02/00) M.2140 (02/00)	EN 301 167	T1.105.05-1994 T1.514-1995
Error Performance [equipment level view]	G.783 (10/00) corr. G.784 (06/99)	EN 300 417-x-1 RE/TM-1042	
Jitter & Wander Performance	G.813 (08/96) G.822 (1988) G.823 (03/93), (03/00) G.824 (03/93), (03/00) G.825 (03/93), (02/99) G.783 (10/00), corr. O.171 (04/97) O.172 (03/99), (06/98)	EN 300 462-5-1 EN 302 084 (01/99) DEN/TM-1079 (05/98)	T1.105.03-1994 T1.105.03a-1995 T1.105.03b-1997

	ITU-T Published or Draft (Revised) Recommendation	Published or Draft (Revised) ETS or EN	Published or Draft (Revised) ATIS/ANSI T1
Components & Subsystems			
Leased Lines	M.13sdh (02/00)	EN 301 164 EN 301 165	
Synchronization [Clocks & Network Architecture]	G.803 (06/97), (02/99) G.810 (08/96) G.811 (09/97) G.812 (06/98) G.813 (08/96)	EN 300 462-1 EN 300 462-2 EN 300 462-3 EN 300 462-4 EN 300 462-5 EN 300 462-6 EN 300 417-6-1 DEG/TM-01080 (03/99)	T1.101-1999 T1.105.09-1996
Test signals	O.150 O.181		
Environment		ETS 300 019-1-0 ETS 300 019-1-1 ETS 300 019-1-2 ETS 300 019-1-3 ETS 300 019-1-3 A1 ETS 300 019-2-0 ETS 300 019-2-1 ETS 300 019-2-2 ETS 300 019-2-3 ETS 300 019-2-3 A1	
Digital Video		ETS 300 814 TR 101 200	
Power & Grounding		ETS 300 132-2 ETS 300 132-2 C1 ETS 300 253	
Physical Design		ETS 300 119-1 ETS 300 119-3 ETS 300 119-4	
EMC		ETS 300 386-1 EN 300 386-2 ETS 300 753	

Appendix D: OTN Related Standards and Industry Agreements

Organization (Subgroup Responsible)	Number	Title	Publication Date
ITU-T (Q.3/4)	M.24otn	Error Performance Objectives and Procedures for Bringing-Into-Service and Maintenance of Optical Transport Networks	2003 target
ITU-T (Q.8/13)	G.optperf	Error and availability performance parameters and objectives for international paths within the Optical Transport Network (OTN)	2003 target
ITU-T (Q.10/13)	G.807/Y.1302	Requirements for Automatic Switched Transport Networks (ASTN)	07/2001
ITU-T (Q.2/15)	G.983.1	Broadband optical access systems based on Passive Optical Networks (PON)	10/1998
ITU-T (Q.2/15)	G.983.1 (Corrig. 1)	Broadband optical access systems based on Passive Optical Networks (PON)	07/1999
ITU-T (Q.2/15)	G.983.1 (Amend.1)	High speed optical access systems based on Passive Optical Network (PON) techniques	11/2001 pre-publ.
ITU-T (Q.2/15)	G.983.2	ONT management and control interface specification for ATM PON	04/2000
ITU-T (Q.2/15)	G.983.2 (Amend.1)	ONT Management and Control Interface Specification for ATM PON (Editorial changes and defect corrections)	11/2001 pre-publ.
ITU-T (Q.2/15)	G.983.2 (Amend.2)	ONT Management and Control Interface Specification for ATM PON (Modifications)	11/2001 pre-publ.
ITU-T (Q.2/15)	G.983.3	A broadband optical access system with increased service capability by wavelength allocation	03/2001
ITU-T (Q.2/15)	G.983.4 (ex G.983.dba)	A Broadband Optical Access System with increased service capability using Dynamic Bandwidth Assignment	11/2001 pre-publ.

Organization (Subgroup Responsible)	Number	Title	Publication Date
ITU-T (Q.2/15)	G.983.5 (ex G.983.sur)	A Broadband Optical Access System with enhanced survivability	01/2002 pre-publ.
ITU-T (Q.2/15)	G.983.6 (G.983.omci.sur)	OMCI for Survivability	
ITU-T (Q.2/15)	G.983.7 (G.983.omci.dba)	ONT management and control interface specification for dynamic bandwidth assignment (DBA) B-PON system	11/2001
ITU-T (Q.2/15)	G.983.omci.ns	ONT Management and Control Interface specification for ATM PON – Enhancements for new services	
ITU-T (Q.9/15)	G.783	Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks	10/2000
ITU-T (Q.9/15)	G.783 (Corrig. 1)	Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks	03/2001 pre-publ.
ITU-T (Q.9/15)	G.783 (Corrig. 2)	Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks	2002 target
ITU-T (Q.9/15)	G.798	Characteristics of Optical Transport Network Hierarchy Equipment Functional Blocks	01/2002 pre-publ.
ITU-T (Q.9/15)	G.798 (Corrigendum)	Characteristics of Optical Transport Network Hierarchy Equipment Functional Blocks	2002 target
ITU-T (Q.9/15)	G.841	Types and characteristics of SDH network protection architectures	10/1998
ITU-T (Q.9/15)	G.841 (Corrigendum)	Types and characteristics of SDH network protection architectures	
ITU-T (Q.9/15)	G.842	Interworking of SDH network protection architectures	4/1997
ITU-T (Q.11/15)	G.707	Network node interface for the synchronous digital hierarchy (SDH)	10/2000
ITU-T (Q.11/15)	G.707 (Corrig. 1)	Network node interface for the synchronous digital hierarchy (SDH)	01/2001 pre-publ.

Organization (Subgroup Responsible)	Number	Title	Publication Date
ITU-T (Q.11/15)	G.707 (Ammend. 1)	Network node interface for the synchronous digital hierarchy (SDH)	11/2001
ITU-T (Q.11/15)	G.707 (Corrig. 2)	Network node interface for the synchronous digital hierarchy (SDH)	11/2001
ITU-T (Q.11/15)	G.707 (Ammend. 2)	Network node interface for the synchronous digital hierarchy (SDH)	2002 target
ITU-T (Q.11/15)	G.709/Y.1331	Interfaces for the optical transport network (OTN)	2/2001
ITU-T (Q.11/15)	G.709/Y.1331 (Addendum 1)	Interfaces for the optical transport network (OTN)	
ITU-T (Q.11/15)	G.7041/Y.1301 (G.gfp)	Generic framing procedure (GFP)	12/2001 pre-publ.
ITU-T (Q.11/15)	G.7041/Y.1301 (Add/Corrig? 1)	Generic framing procedure (GFP)	2002 target
ITU-T (Q.11/15)	G.7042/Y.1305 (G.lcas)	Link capacity adjustment scheme (LCAS) for virtual concatenated signals	11/2001 pre-publ.
ITU-T (Q.11/15)	G.7042/Y.1305 (Add/Corrig? 1)	Link capacity adjustment scheme (LCAS) for virtual concatenated signals	2002 target
ITU-T (Q.12/15)	G.872	Architecture of optical transport networks	11/2001 pre-publ.
ITU-T (Q.12/15)	G.8080/Y.1304 (G.ason)	Architecture for the Automatic Switched Optical Network	11/2001 pre-publ.
ITU-T (Q.13/15)	G.8251 (G.otnjit)	The Control of Jitter and Wander within the Optical Transport Network (OTN)	11/2001 pre-publ.
ITU-T (Q.13/15)	G.8251 (Ammend. 1)	The Control of Jitter and Wander within the Optical Transport Network (OTN)	2002 target
ITU-T (Q.13/15)	G.8251 (Corrig. 1)	The Control of Jitter and Wander within the Optical Transport Network (OTN)	2002 target
ITU-T (Q.14/15)	G.874	Management aspects of the optical transport network element	11/2001 pre-publ.

Organization (Subgroup Responsible)	Number	Title	Publication Date
ITU-T (Q.14/15)	G.874.1	Optical Transport Network (OTN) Protocol-Neutral Management Information Model For The Network Element View	01/2002 pre-publ.
ITU-T (Q.14/15)	G.875	Optical transport network (OTN) management information model for the network element view	
ITU-T (Q.14/15)	G.7710/Y.1701 (G.cemr)	Common equipment management function requirements	11/2001 pre-publ.
ITU-T (Q.14/15)	G.7713/Y.1704 (G.dcm)	Distributed call and connection management (DCM)	12/2001 pre-publ.
ITU-T (Q.14/15)	G.7713.1/Y.1704.1	Distributed Call and Connection Management – PNNI Implementation	
ITU-T (Q.14/15)	G.7713.2/Y.1704.2	Distributed Call and Connection Management – GMPLS RSVP-TE Implementation	
ITU-T (Q.14/15)	G.7713.3/Y.1704.3	Distributed Call and Connection Management – GMPLS CR-LDP Implementation	
ITU-T (Q.14/15)	G.7712/Y.1703 (G.dcn)	Architecture and specification of data communication network	11/2001 pre-publ.
ITU-T (Q.14/15)	G.7714/Y.1705 (G.disc)	Generalized automatic discovery techniques	11/2001
ITU-T (Q.14/15)	G.7715/Y.1706 (G.rtg)	Architecture and requirements for routing in automatically switched optical networks	2002 target
ITU-T (Q.14/15)	G.7716/Y.1707G.lcs	[ASTN link connection status]	
ITU-T (Q.14/15)	G.7717/Y.1708 (G.cac)	[common access control]	
ITU-T (Q.15/15)	G.650	Definition and test methods for the relevant parameters of single-mode fibres	10/2000
ITU-T (Q.15/15)	G.652	Characteristics of a single-mode optical fibre cable	10/2000

Organization (Subgroup Responsible)	Number	Title	Publication Date
ITU-T (Q.15/15)	G.653	Characteristics of a dispersion-shifted single-mode optical fibre cable	10/2000
ITU-T (Q.15/15)	G.654	Characteristics of a cut-off shifted single-mode optical fibre cable	10/2000
ITU-T (Q.15/15)	G.655	Characteristics of a non-zero dispersion shifted single-mode optical fibre cable	10/2000
ITU-T (Q.16/15)	G.691	Optical interfaces for single channel STM-64, STM-256 systems and other SDH systems with optical amplifiers	10/2000
ITU-T (Q.16/15)	G.692	Optical interfaces for multichannel systems with optical amplifiers	10/1998
ITU-T (Q.16/15)	G.692 (Corrigendum)	Optical interfaces for multichannel systems with optical amplifiers – Corrigendum [referencing G.694.1 for frequency grid]	2002 target
ITU-T (Q.16/15)	G.693 (G.vsr)	Optical interfaces for intra-office systems	11/2001 pre-publ.
ITU-T (Q.16/15)	G.694.1 (G.wdm.1)	Spectral grids for WDM applications: DWDM frequency grid	2002 target
ITU-T (Q.16/15)	G.694.2 (G.wdm.2)	Spectral grids for WDM applications: CWDM wavelength grid	2002 target
ITU-T (Q.16/15)	G.959.1	Optical transport network physical layer interfaces	2/2001
ITU-T (Q.16/15)	Sup.dsn	Optical system design and engineering considerations	
ITU-T (Q.16/15)	G.capp	Optical interfaces for Coarse Wavelength Division Multiplexing applications	
ITU-T (Q.17/15)	G.671	Transmission characteristics of optical components and subsystems	02/2001

Organization (Subgroup Responsible)	Number	Title	Publication Date
IETF (ccamp)	draft-ietf-ccamp-gmpls-sonet-sdh-04.txt	GMPLS Extensions for SONET and SDH Control	
IETF (ccamp)	draft-ietf-ccamp-gmpls-architecture-02.txt	Generalized Multi-Protocol Label Switching (GMPLS) Architecture	
IETF (ccamp)	draft-ietf-ccamp-lmp-03.txt	Link Management Protocol (LMP)	
IETF (ccamp)	draft-ietf-ccamp-gmpls-routing-04.txt	Routing Extensions in Support of Generalized MPLS	
IETF (ccamp)	draft-ietf-ccamp-ospf-gmpls-extensions-07.txt	OSPF Extensions in Support of Generalized MPLS	
IETF (ccamp)	draft-ietf-ccamp-gmpls-sonet-sdh-extensions-02.txt	GMPLS Extensions to Control Non-Standard SONET and SDH Features	
IETF (ccamp)	draft-ietf-ccamp-lmp-mib-01.txt	Link Management Protocol Management Information Base	
IETF (ccamp)	draft-ietf-ccamp-oli-reqts-00.txt	TITLE: Optical Link Interface Requirements	
IETF (ccamp)	draft-ietf-ccamp-lmp-wdm-00.txt	Link Management Protocol (LMP) for DWDM Optical Line Systems	
IETF (ccamp)	draft-ietf-ccamp-sdhsonet-control-00.txt	Framework for GMPLS-based Control of SDH/SONET Networks	
IETF (ccamp)	draft-ietf-ccamp-gmpls-signaling-survey-00.txt	Generalized MPLS Signaling - Implementation Survey	
IETF (ccamp)	draft-ietf-ccamp-gmpls-g709-00.txt	GMPLS Signalling Extensions for G.709 Optical Transport Networks Control	
IETF (ipo)	draft-ietf-ipo-impairments-02.txt	Impairments And Other Constraints On Optical Layer Routing	
IETF (ipo)	draft-ietf-ipo-framework-01.txt	IP over Optical Networks: A Framework	
IETF (ipo)	draft-ietf-ipo-carrier-	Carrier Optical Services	

Organization (Subgroup Responsible)	Number	Title	Publication Date
	requirements-02.txt	Requirements	
IETF (ipo)	draft-ietf-ipo-ason-02.txt	Automatic Switched Optical Network (ASON) Architecture and Its Related Protocols	
IETF (ipo)	draft-ietf-ipo-optical-inter-domain-01.txt	Optical Inter Domain Routing Considerations	
IEEE (802.3)		[1Gb LAN PHY]	
IEEE (802.3)		[10Gb LAN PHY]	
IEEE (802.3)		[10Gb WAN PHY]	
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