World Interoperability Demonstration

Introduction

The evolution of high bandwidth data applications and optical technologies has posed challenging deployment issues for today's Carriers embedded with legacy management and operations systems. As data and optical network convergence issues came to light, Carriers began to evaluate and introduce intelligent control-plane mechanisms and enhanced data stream mappings that deliver operational benefits in a multi-vendor environment. However, lack of standardization on previous implementations poses a different set of challenges in addressing multi-vendor interoperability and inter-carrier internetworking.

Traditional optical networks, and the back office systems that support them, and pre-standard intelligent optical networks have limited success with multi-vendor deployment strategies. Vendor specific Network Management Systems (NMS) and provisioning features, among others, typically make multi-vendor interoperability a daunting task. The lack of embedded intelligence on the network elements requires the maintenance of an offline inventory database, which further complicates service planning and design. The inability to support an interoperable control plane for device-to-device communications hinders automated neighbor discovery and dynamic service provisioning. Carriers endure significant manual intervention, associated long lead times and high operational costs to deliver new or modified services.

Optical Internetworking Forum (OIF) members understand these challenges and have long fostered cooperation among a broad and diverse group of Carriers, equipment vendors, and telecom service end users in order to accelerate the deployment of advanced, interoperable, and cost-effective optical network solutions. The OIF's consistent, evolutionary effort has resulted in a broad set of specifications (called Implementation Agreements) that have been tested and publicly demonstrated in progressively more comprehensive environments.

The OIF's World Interoperability Demonstration signifies an industry milestone in Carrier participation and contribution in building intelligent optical networks. The demonstration has been designed on a global stage with seven Carriers across three continents internetworking through intelligent control plane mechanisms created by a multi-vendor environment of fifteen vendor participants. Carriers are able to test new Ethernet over SONET/SDH capabilities utilizing enhanced data encapsulations that make existing optical networks more bandwidth-efficient.

Participants include:

- Seven Carrier Lab Locations:
    - Europe: Deutsche Telekom, Telecom Italia
    - Asia: China Telecom, KDDI , NTT
    - North America: AT&T, Verizon

- Fifteen Vendors:

Alcatel	Marconi
ADVA Optical Networking	NEC
Avici Systems	Nortel Networks
CIENA Corporation	Siemens
Cisco Systems	Sycamore Networks
Fujitsu	Tellabs
Lucent Technologies	Turin Networks
Mahi Networks	

OIF's demonstration successfully includes dynamic end-to-end connection management between client devices and transport network elements in a multi-domain, multi-node environment. The global connectivity includes network elements that incorporate Optical User-to-Network Interface (UNI) and External Network-to-Network Interface (E-NNI) among various vendors. The success of the demonstration validates the work of the OIF in promoting Carrier deployment of integrated data and optical network technologies.

User-to-Network Interface and Network-to-Network Interface

Overview

The optical UNI enables clients of optical networks to dynamically establish connections using signaling, while the E-NNI automates the establishment of these connections between optical networks. Together, UNI and E-NNI permit dynamic A-to-Z provisioning of services across an optical network in real time without manual intervention, resulting in significantly lower operational costs than traditional optical networks.

In addition, UNI and E-NNI provide the following benefits:

- Rapid, dynamic provisioning of end-to-end services enabling a strong foundation for the creation of advanced, customizable service offerings that allow differentiation on service metrics, in addition to bandwidth and price.

- Based on published, well-defined implementation agreements, UNI and E-NNI will underpin multi-vendor interoperability in next generation optical networks, and enable Carriers to deploy 'best of breed' solutions.

- Simplification of vendor selection, network design, implementation, and management, while improving service flexibility.

An example topology consisting of the UNI/E-NNI control plane (CP) and data plane is shown in Figure 1. In this figure the Ethernet network is an out-of-band Data Communications Network (DCN) to carry the UNI and E-NNI protocol messages.

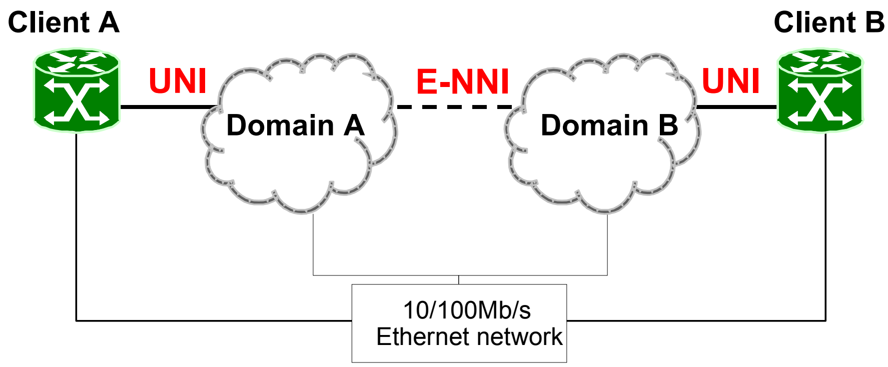

Figure 1: UNI and E-NNI control and data plane

UNI and E-NNI Interoperability Demonstration

The OIF World Interoperability Demonstration highlights the tremendous progress that has been made in optical control plane development. The demonstration represents another OIF milestone that is the result of the combined efforts of Carriers and vendors. Building on previous successful testing and interoperability events, the 2004 UNI/E-NNI demonstration encompasses equipment from 15 vendors that has been tested and validated in 7 Carrier lab facilities. This represents a compelling testament to both the interest that Carriers are showing in these technologies and the confidence that the vendors have in their implementations.

The UNI/E-NNI interoperability demonstration includes a standards based control plane for the set-up and tear-down of an optical path across multi-domain networks.
Figure 2 shows an example of the type of topology used in this demonstration, consisting of several interconnected SONET/SDH core networks providing transport for client services.

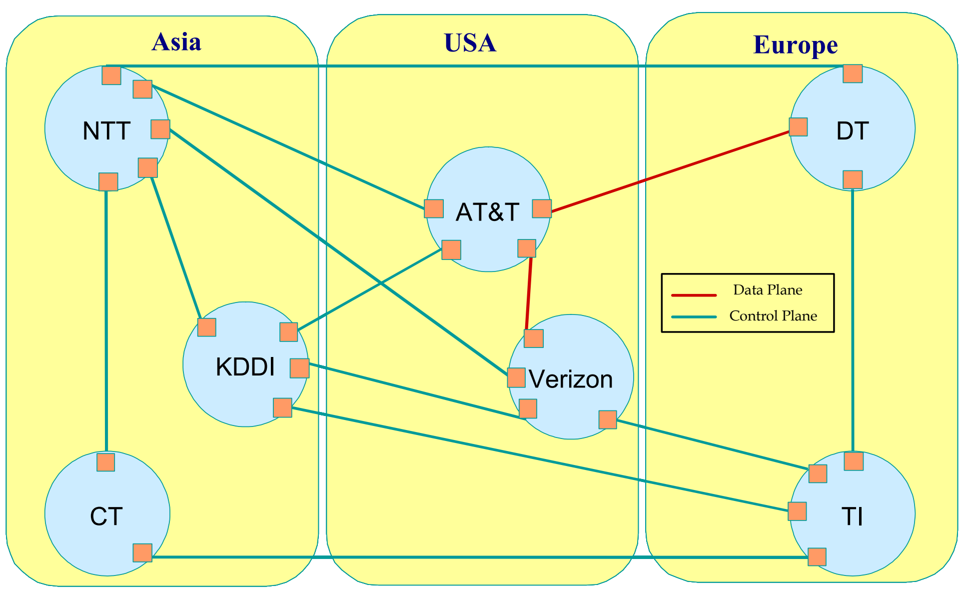

Figure 2: Type of topology used in the OIF World Interoperability Demonstration

Each Carrier domain consists of multiple Network Elements (NE) supplied by different vendors participating in this demonstration. Switched Connection (SC) requests are initiated over a UNI signaling interface (OIF UNI 1.0 R2). Alternatively, Soft Permanent Connection (SPC) requests are initiated via management system request to a NE at the network edge. Multi-domain connections for either SCs or SPCs are completed using E-NNI signaling and routing interfaces. Standardized mechanisms and protocols enable topology discovery and provisioning.

Interoperability testing features UNI 1.0 R2 and E-NNI R1.0 protocol implementation. Technical highlights of the demonstration include:

- Demonstrating the use of a standardized control plane to set-up and tear-down an optical path across a multi-domain network
- UNI client initiated connection (SC)
- Management system initiated connection (SPC)
- Focus on compliance with recent standards and network-wide interworking, including OIF Implementation Agreements:
  - UNI 1.0 R2
  - E-NNI 1.0 Signaling

  and ITU-T Recommendations:
  - G.807, Requirements for Automatically Switched Transport Networks
  - G.8080, Architecture of the Automatically Switched Optical Network
  - G.7712, Architecture and Specification of Data Communication Network
  - G.7713, Distributed Call and Connection Management (DCM)
  - G.7713.2, DCM Signaling Protocol based upon GMPLS RSVP-TE
  - G.7715, Architecture and Requirements for Routing in the ASON
  - G.7715.1, ASON Routing Architecture and Requirements for Link State Protocols

Test Methodology

Testing at Carrier labs focused on the following areas:

- Client initiated switched connection
- Operations Support System (OSS) initiated Soft Permanent Connection
- Multi-area traffic engineering using routing hierarchies
- Multi-vendor interoperability
- Multi-Carrier environment

Testing was performed starting with pair-wise vendor tests within each lab. Pairs were then interconnected leading to networks of larger than two nodes in a lab. Successful interoperability within each lab led to the integration of individual lab networks into a multi-Carrier worldwide network.

UNI and E-NNI Carrier Perspective and Applications

An essential goal of the Next Generation Transport Network (NGTN) is the full integration of Management and Control Planes to reduce the cost, effort and time for provisioning end-to-end services, and to enable new services to attract or retain customers. In short, to reduce OPEX, curtail CAPEX and increase revenues. Carrier support of the OIF World Interoperability Demonstration marks an industry achievement in the successful introduction of control plane interoperability and enhanced data streams mapping that will make the NGTN a reality.

A UNI/E-NNI based control plane is the key to a self-governing Next NGTN that features multiple technologies (WXC, ROADM, OXC, MSPP, and C/DWDM) and heterogeneous platforms from multiple network element providers. A standards-based interoperable CP provides an effective mechanism to interconnect heterogeneous network domains, including the proxy control plane/CP for legacy SONET/SDH networks, to form a logically integrated CP framework capable of offering the following capabilities on an end-to-end basis:

- Auto discovery and self inventory
- Dynamic path provisioning for both coarse- and fine-grain bandwidth applications
- Policy-based traffic engineering
- Seamless interworking with client networks (internal or external)

Dynamic service provisioning places the intelligence for choice of resources and paths through the network within the network itself. Routing protocols are used to collect resource availability information and to build a topology database that is then used to compute the optimal path for a new service. This function can be controlled by a simplified management system that only needs to communicate with the head end of a service in order to set the whole connection. Customer service requests can be streamlined through OSS ordering tools or web-based interfaces that are linked directly to the CP to provision the services on-demand. Alternatively, "On-Demand" features give the customer equipment control of A-to-Z provisioning of services that enables them to meet their specific requirements. Using dynamic provisioning through the CP can lead to rapid turn-up of services, better utilization of bandwidth in the network, and clearer tracking of in-use and freed resources.

Once the network edge has received the service request, it uses the CP features to enable the service across the network. At the remote network edge, the remote customer edge is signaled to let it know about the new service. Note that the customer does not control the path or method of service establishment across the network.- The operational details of this information are managed by the Carrier and not exposed to the client.

Managing services in this way removes another stage of operator intervention and allows the customer to request connectivity and bandwidth as if placing a phone call. One of the major advantages for the customer is the ability to connect to different remote sites at different times with only one point of attachment to the network. Additionally, a Control Plane can dynamically provision end-to-end connections, including segments that are statically provisioned components or legacy networks.

Multi-vendor interoperability showcased in the OIF demonstration provides evidence that Carriers can effectively deploy Control Plane mechanisms to enhance provisioning and new service creation. These capabilities will enable Carriers to streamline OPEX and CAPEX and optimize their existing network to support additional revenue streams.

Ethernet and Generic Framing Procedure (GFP)

Overview

The SONET/SDH transport hierarchy was designed to provide telecom Carriers with a practical means to carry voice and private line services using time-division multiplexing. In its initial design, SONET/SDH maintained a fixed hierarchical structure with a limited set of data rates (e.g. 50Mb/s, 150Mb/s, 600Mb/s, 2.5 Gb/s, 10 Gb/s, 40Gb/s).

With the growth of the Internet and Enterprise data networks, and as the range and type of traffic has expanded, there is a need to make this structure more flexible and powerful.

The introduction of a set of next-generation SONET/SDH technologies, consisting of Generic Framing Procedure (GFP), Virtual Concatenation (VCAT) and Link Capacity Adjustment Scheme (LCAS), transforms the SONET/SDH transport network into a flexible and efficient transport platform of data as well as voice circuits, while retaining the superior operations and management functionality built into SONET/SDH standards for performance monitoring and fault isolation.

Each of the three cornerstone technologies mentioned above has unique contributions to next-generation SONET/SDH:

- GFP, defined in ITU-T Recommendations G.7041 and G.806, is the basic method of encapsulation or mapping an incoming signal such as Ethernet to the SONET/SDH payload. GFP allows multiple different data streams (e.g. Ethernet, HDLC) to be encapsulated and transported over a common path, thereby facilitating applications such as packet aggregation. With framed GFP (GFP-F), the entire client protocol data unit (PDU) is received by the GFP device before encapsulation in a single GFP frame. Compared to previous encapsulation methods such as X.86 (LAPS), GFP encapsulation is more efficient and has a fixed, deterministic overhead. GFP is a robust and efficient encapsulation technique and is better suited to work with newer SONET/SDH procedures such as VCAT and LCAS. For other applications (such as Fiber Channel, FICON, ESCON), a transparent form of GFP (GFP-T) can be supported that maps on a character-by-character basis rather than frame-by-frame, minimizing the latency of the mapping.

- Whereas GFP solves the problem of efficient encapsulation of data signals over SONET/SDH, Virtual Concatenation (defined in ITU-T Recommendations G.707 and G.783, primarily) solves the problem of bandwidth mismatches between SONET/SDH rates and today's data network rates. With VCAT, the end-to-end bandwidth can be broken up into multiple SONET/SDH payloads at VT1.5 /VC-11, VT2 / VC-12, STS-1 / VC-3 or STS-3c /VC-4 granularities allowing far greater efficiency in actual payload usage (close to 100%). VCAT has the added benefit that the supporting channels can be spread out over diverse paths to add reliability against failures, especially when LCAS capability is used in conjunction with VCAT as discussed below.

- LCAS is the latest piece of the next-generation SONET/SDH picture, and is defined in ITU-T Recommendations G.7042, G.806 and G.783. LCAS supports the hitless adjustment of signal bandwidth up or down, when VCAT is used to split the bandwidth across multiple SONET/SDH channels. Using signaling in the path overhead of the SONET/SDH path signal, the status of a component channel is indicated in both directions and the terminating equipment can immediately adjust for channels going out of service or being added to the VCAT group. In this way, the end equipment can compensate for changes in the bandwidth due to path failure and recovery and can also adjust the bandwidth if necessary to account for changes in traffic levels. This is particularly suited for transport of packet traffic, which can be buffered or has end-to-end congestion control functions such as TCP windowing and can adjust to variability of the underlying end-to-end bandwidth.

The OIF World Interoperability Demonstration is the first widespread test of interoperability of the three key technologies for next-generation SONET/SDH, demonstrating the maturity of the technology and the potential for its use in data services over Carrier core transport networks. Data stream services like Ethernet can now be effectively transported over existing SONET/SDH networks as outlined in Figure 3.

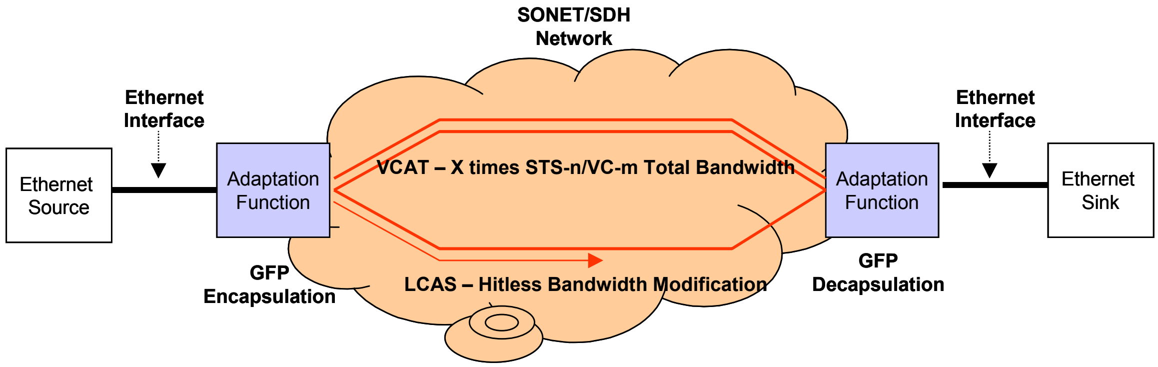

Figure 3: Ethernet mappings using GFP/VCAT/LCAS

Ethernet over SONET/SDH Interoperability Demonstration

The primary objective of the Ethernet over SONET/SDH demonstration is to demonstrate the interoperability of standards-based Ethernet-over-SONET/SDH transport across multi-vendor domain networks.

Figure 4 shows an example of the type of topology used in this demonstration, consisting of several interconnected SONET/SDH core networks providing transport for Ethernet services. The Ethernet signals entered and left the core networks at multi-service nodes that provided the adaptation to the SONET/SDH transport network.

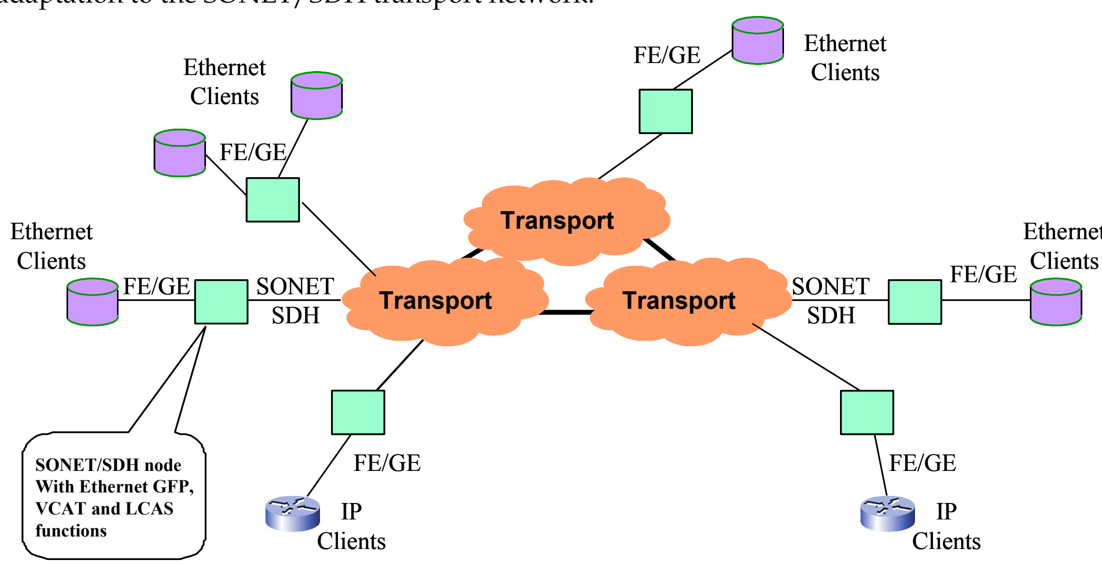

Figure 4: The interoperability testing showcased GFP-F, VCAT and LCAS technologies across a multi-vendor domain environment

Technical highlights of the Ethernet over SONET/SDH interoperability demonstration:

- Demonstration of high-performance transport of Ethernet services over SONET/SDH transport networks

- Showcase of next-generation SONET/SDH technologies:
  - Frame-based Generic Frame Procedure (GFP-F)
  - Virtual Concatenation (VCAT)
  - Link-Capacity Adjustment Scheme (LCAS)
- Focus on compliance to recent standards developments and network-wide interworking

Test Methodology

A comprehensive test plan outlined strict requirements and parameters for device configuration. All equipment and testing requirements were based on the applicable ITU-T Recommendations, in recognition of the Carriers' goal of obtaining standardized, interoperable implementations. Testing focused on four areas:

- Throughput of Ethernet Private Line services over SONET/SDH infrastructure
- Accommodation of partial-rate and full-rate Ethernet transport by means of GFP, VCAT
- Resilience of the adaptation to different network characteristics (differential delays)
- In-service reaction to increased / decreased bandwidth demands and to network failure conditions with LCAS

The test consisted of two phases: an intra-Carrier phase, in which tests were performed with equipment from different vendors within each of the Carrier labs independently, and an inter-Carrier lab phase in which tests were performed across different Carriers' networks. Carriers were responsible for tailoring the test configurations to the particular conditions in their lab.

A generic intra-Carrier configuration is shown in Figure 5. In this type of configuration, MSPPs from different vendors were connected pairwise over the SONET/SDH core network. The MSPPs were configured to map the Ethernet frames coming in at the Ethernet interfaces using GFP-F into a pre-defined number of virtually-concatenated SONET/SDH path-layer signals.

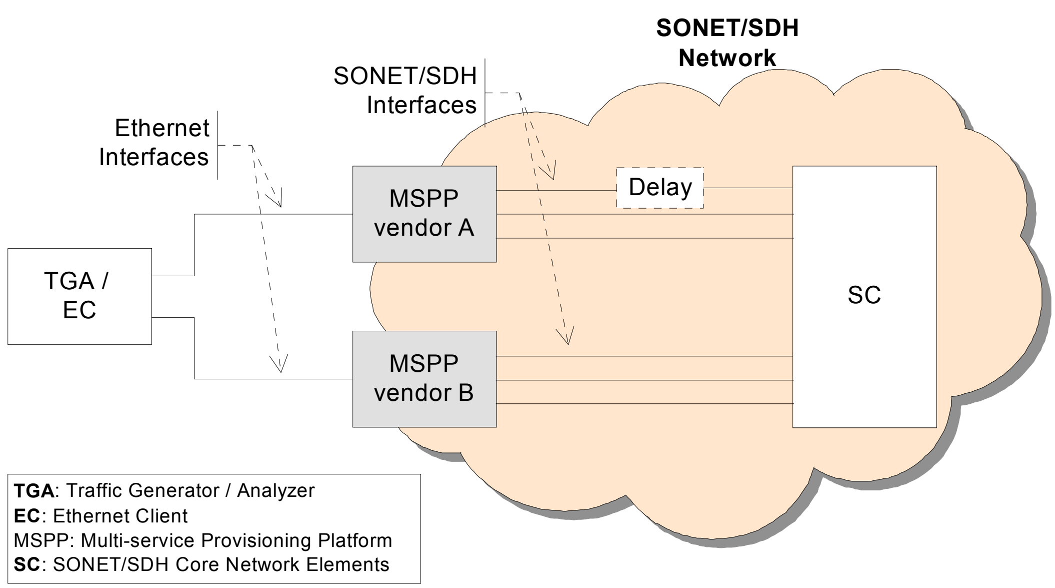

Figure 5: Generic intra-Carrier lab test configuration. The MSPPs are the devices under test

The tests included configurations with Fast Ethernet and Gigabit Ethernet client signals being transported over virtual concatenation groups based on STS-1 / VC-3 and STS-3c / VC-4 signals. Optionally, differential delay was introduced into some of the member signals in order to simulate large networks with diversely-routed paths. The Ethernet throughput was then verified (in both directions) for different SONET/SDH bearer signal capacities. The tests were designed to demonstrate full-rate as well as partial-rate Ethernet services.

Additionally, LCAS bandwidth-management capabilities were tested by demonstrating in-service, operator-controlled member addition and removal. The resilience that LCAS provides to network failures was tested by failing different subsets of the members and verifying the recovery of the Ethernet transport over the remaining bandwidth. The autonomous restoration of the transport to the full bandwidth after the removal of the failure was tested analogously.

Inter-Carrier configurations were as shown in Figure 2. In this type of configuration, the SONET/SDH networks of both Carriers were linked for the purpose of the tests and MSPPs from different vendors were connected pairwise over the inter-Carrier network. The tests performed were analogous to the intra-Carrier tests described above.

Ethernet and GFP Carrier Perspective and Applications

Adding Ethernet over SONET/SDH service adaptation to existing metropolitan and regional optical networks allows Carriers to leverage and reuse their extensive SONET/SDH infrastructure for efficient data transport as opposed to other approaches that require building whole new overlay networks. A range of optical services can be supported using this technology including Ethernet Private Line services that extend the reach of enterprise LANs beyond metropolitan boundaries and Ethernet switched services that can support multi-point configurations and bandwidth sharing.

Ethernet is clearly the leading physical layer supporting enterprise LAN applications. Ethernet is inexpensive, reliable, and familiar to network administrators who have been deploying it for many years. Ethernet application data rates have climbed from less than 10 Megabits per second (Mbps) to 1 Gigabit per second (Gbps) and beyond. Ever increasing demands for Internet access, Intranet connectivity between locations, storage networking, telecommuting, and other applications have combined to challenge Carrier-networking resources.

The OIF demonstration enabled Carriers to evaluate the successful interoperability of Ethernet over SONET/SDH transport in a multi-vendor environment utilizing GFP, VCAT and LCAS technologies to create bandwidth efficient network solutions. These strategies will enable Carriers to efficiently integrate and deploy data and optical technologies that are the foundation of the next generation NGTN.

Summary

The OIF World Interoperability Demonstration successfully brought Carriers together in an interoperable UNI/E-NNI network that supports flexible service creation in a multi-vendor environment. This demonstration confirms that global Carriers of all types can utilize OIF optical UNI/E-NNI specifications to implement dynamic provisioning across global networks. Cooperative efforts such as those showcased at SUPERCOMM 2004 highlight that new data encapsulation and bandwidth mappings enabled by GFP/VCAT/LCAS can be utilized by Carriers to offer new services over their existing networks in a cost-effective manner.

Carrier participation and contributions to the OIF World Interoperability Demonstration validate the work of OIF members to create interoperable network solutions based on optical technologies. Optical signaling and routing mechanisms in a multi-vendor control plane environment have been successfully launched and Carriers will soon be able to create a diverse range of low cost, integrated data, and optical service options. Additionally, the demonstration has enabled existing

SONET/SDH networks to be bandwidth optimized with the use of GFP/VCAT/LCAS technologies to deliver a diverse range of high-speed data services.

About the OIF

Launched in April of 1998, the OIF is a non-profit organization with more than 170 international member companies, including many of the world's leading Carriers and vendors. As the only industry group uniting representatives from data and optical networks, the OIF helps advance the standards and methods of optical networks. OIF's purpose is to accelerate the deployment of interoperable, cost-effective and robust optical internetworks and their associated technologies. Optical internetworks are data networks composed of routers and data switches interconnected by optical networking elements.

With the goal of promoting worldwide compatibility of optical internetworking products, the OIF actively supports and extends the work of national and international standards bodies. Formal liaisons have been established with The ATM Forum, IEEE 802.3 HSSG, IETF, ITU-T Study Group 13, ITU-T Study Group 15, MEF, NPF, T1M1, T1X1, TMF and the XFP MSA Group.

Glossary

C/DWDM:	Coarse/Dense Wavelength Division Multiplexing
CP:	Control Plane
DCN:	Data Communications Network
E-NNI:	External Network-to-Network Interface
GFP:	Generic Framing Procedure
LCAS:	Link Capacity Adjustment Scheme
MSPP:	Multi-Service Provisioning Platform
NGTN:	Next Generation Transport Networks
OSS:	Operations Support System
OTN:	Optical Transport Networks
OXC:	Optical Cross- Connect
ROADM:	Re-configurable Optical Add & Drop Multiplexer
SC:	Switched Connection
SPC:	Soft Permanent Connection
STS:	Synchronous Transport Signal
UNI:	User-to-Network Interface
VC:	Virtual Container
VCAT:	Virtual Concatenation
WXC:	Wavelength Cross-Connect

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