2009 OIF Worldwide Interoperability Demonstration -

Enabling Broadband On-Demand Services

Executive Summary

The 2009 OIF Worldwide Interoperability Demonstration showcases the enabling of broadband on-demand services. It demonstrates end-to-end provisioning of dynamically switched Ethernet Virtual Private Line (EVPL) services over multiple, control-plane enabled intelligent optical core networks through the use of OIF implementation agreements of UNI 2.0 and E-NNI 2.0. Bandwidth on-demand over various transport technologies such as MPLS-TP, PBB-TE and OTN, and multi domain service restoration are some of the new features that are demonstrated.

Interoperability testing of various network equipment includes MSPP, routers, Ethernet Switches, cross-connects, OADM in the data plane as well as various implementation approaches in the control plane. The multi-vendor aspect of the interoperability testing gives carriers confidence that different vendors and technology domains can work together. Additionally, participating vendors demonstrated mature, stable interoperable products based on OIF specifications and leading edge technology in the use of control plane to open new markets for carriers to deliver advanced, carrier-grade Ethernet services through their optical networks more efficiently.

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3 Introduction

Today and most likely in the foreseeable future carriers are facing the challenge to provide services over heterogeneous networks (**Figure 1**). These environments occur because of manifold non-technical reasons, e.g. company mergers, acquisitions, splits, outsourcings and in the migration phase to next generation network technologies or operational support systems. The vision is, that even in these difficult and complex environments, seamless interworking and service provisioning is possible based on ASON/GMPLS intra- and inter-domain functions.

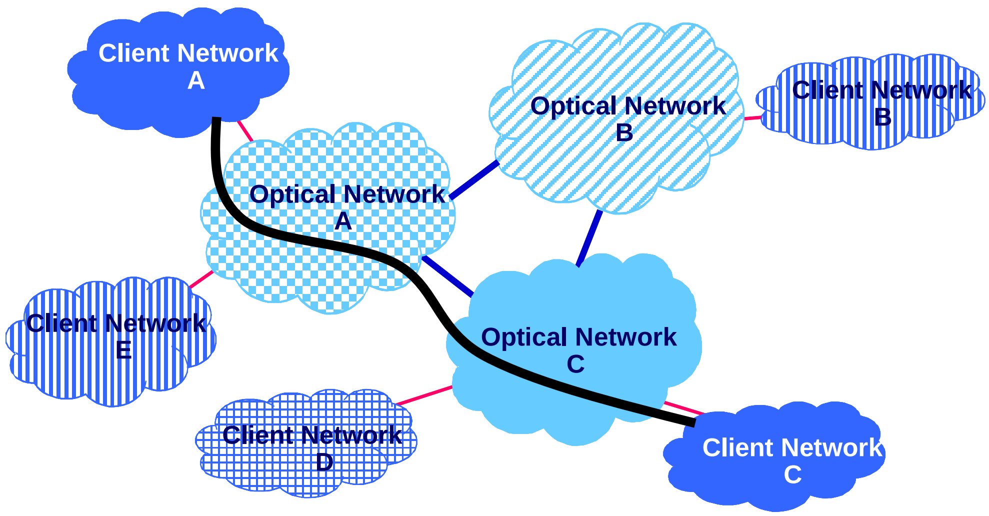

Figure 1: Typical heterogeneous carrier network environment: Multi-domain, multi-layer, multi-technology networks

Optical Internetworking Forum (OIF) members understand these challenges, which require that control plane solutions be developed in the context of such heterogeneous environments, and are able to co-exist with the existing network. The OIF has 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 architecture solutions. The OIF's consistent, evolutionary effort on the path towards this vision has resulted in a broad set of Implementation Agreements (IAs) that have been tested and publicly demonstrated in progressively more comprehensive environments (**Figure 2**).

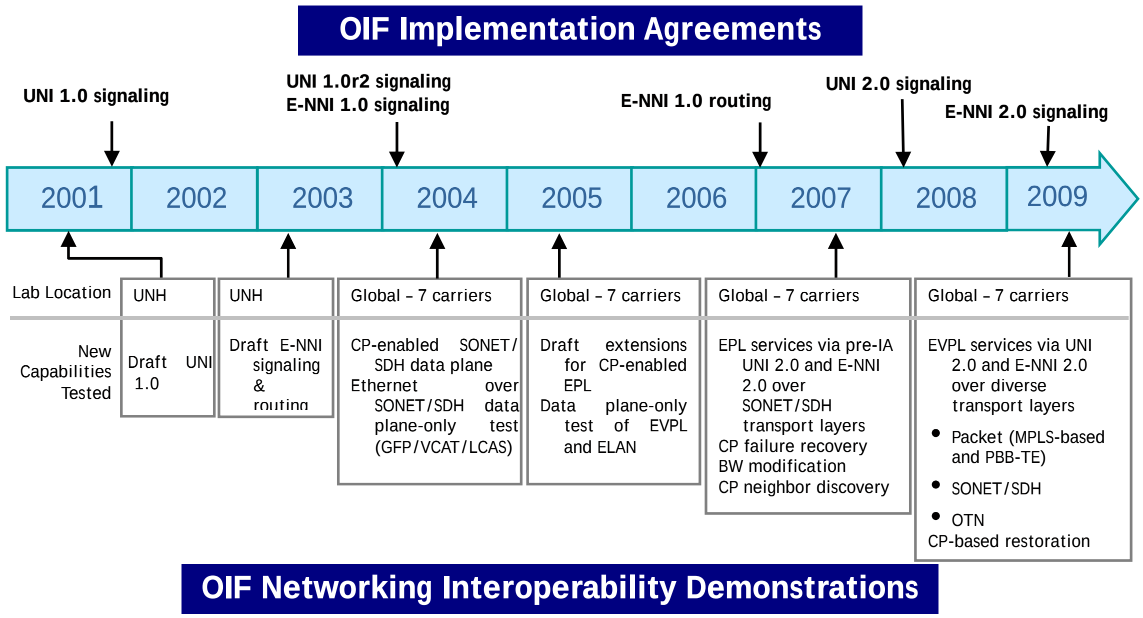

Figure 2: OIF Implementation Agreements and interoperability evaluations – validating and refining the collaborative work of the OIF

The 2009 OIF Worldwide Interoperability Demonstration showcases the enabling of Broadband On-Demand Services in a multi-vendor multi-carrier environment. The OIF's fourth worldwide interoperability test and demonstration is conducted simultaneously in China, Japan, France, Germany, Italy and the United States. The event highlights network-interoperable solutions among the world largest telecommunications companies that are participating in the demo and employing OIF UNI 2.0 and E-NNI 2.0 implementation agreements. The event demonstrates the set up of Ethernet Virtual Private Line (EVPL) Services over multiple, control plane-enabled intelligent optical core networks with technologies ranging from Layer 2 transport to OTN.

4 Demonstration Set-up

The OIF test network has global coverage and is based on the test facilities of seven major carriers from Asia, Europe and North America:

- Asia: China Telecom, KDDI R&D Labs, NTT
- Europe: Deutsche Telekom, Orange Labs - France Telecom Group, Telecom Italia
- North America: Verizon

In the carrier facilities, heterogeneous multi-technology, multi-vendor and multi-domain networks with ASON/GMPLS enabled nodes and domains were built up (**Figure 3**) with equipment from the following vendors:

- Alcatel-Lucent
- Ciena Corporation
- Ericsson AB
- Huawei Technologies
- Marben Products
- NEC Corporation of America
- Nokia Siemens Networks
- Sycamore Networks
- Tellabs
- ZTE Corporation

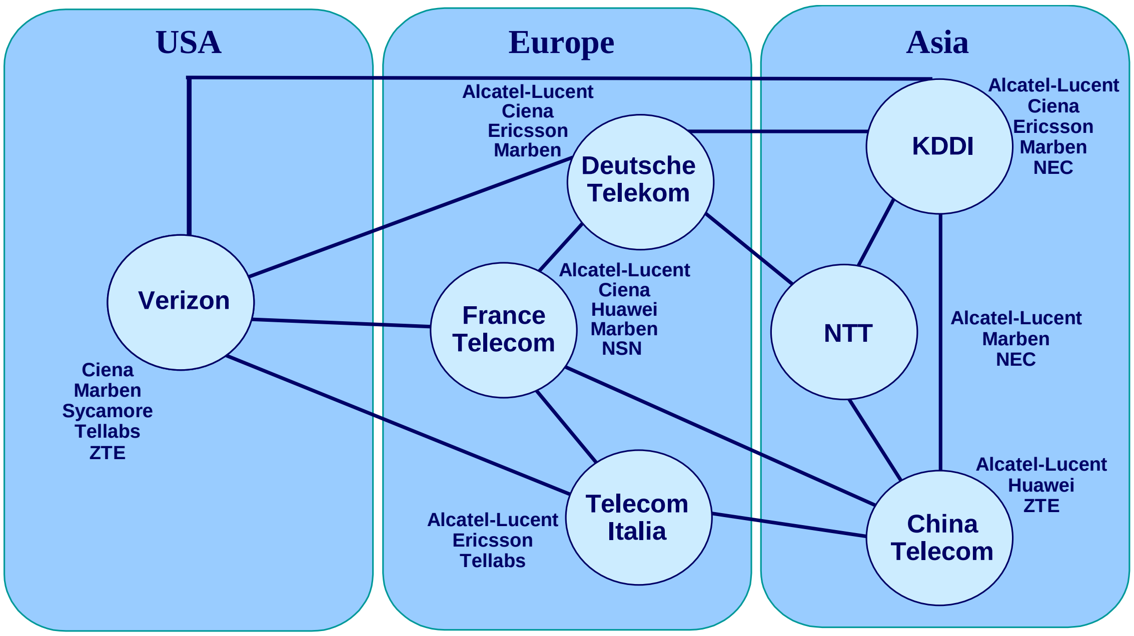

Figure 3: OIF test network topology – carrier sites and vendor equipment distribution

The demonstration set-up in 2009 comprises two main areas:

- Data plane interoperability testing of Ethernet Virtual Private Line (EVPL) services over Next Generation (NG) transport network switching equipment of different technology types, including PBB-TE, MPLS-TP, OTN and SONET/SDH
- Data and control plane interoperability testing of on-demand EVPL and SONET/SDH services as well as multi-domain service restoration, especially the following:
  - Applying OIF UNI 2.0 function to NG packet transport networks
  - Using UNI 2.0/E-NNI 2.0 for EVPL over SONET/SDH services
  - Using E-NNI 2.0 with extensions for SONET/SDH multi-domain service recovery

The carriers' labs and the local control plane enabled network domains were interconnected using OIF E-NNI and UNI interfaces resulting in a worldwide test network. This worldwide test network builds the basis for global interoperability evaluations of control plane features, crossing heterogeneous multi-domain networks composed of various vendors' equipment.

To support the testing, a global Signaling Communications Network (SCN) was set up over the public Internet secured by IPSec at the endpoints. **Figure 3** gives an overview of the involved carrier sites and the vendor equipment distribution in the carrier labs.

In addition to the transport of signaling and routing protocols, the SCN is used for monitoring, checking and collecting information about the status of established connections and for the display of the connections crossing multiple network domains. The interactive topology display will be shown during multiple regional events in the June 2009 time frame:

- iPOP, June 11, 2009, Tokyo, Japan
- OIF Carrier Lab Day at Verizon Laboratory, June 19, 2009, Waltham, MA, USA (for invited press, analysts and demo participants)
- IIR WDM & Next Generation Optical Networking, June 25, 2009, Nice, France

Furthermore, the OIF interoperability achievements will be presented to the public at:

- Broadband World Forum Europe, September 8, 2009, Paris, France
- ECOC, September 20, 2009, Vienna, Austria

5 Ethernet Service Types

The MEF classifies Ethernet services as E-Line (point to point) and E-LAN (multipoint to multipoint). E-Line is further divided into:

- Ethernet Private Line (EPL), defined by ITU-T Recommendation G.8011.1, where a whole Ethernet port is switched across a provider network, and
- Ethernet Virtual Private Line (EVPL), defined by ITU-T Recommendation G.8011.2, where VLAN sets can be switched to multiple destinations.

OIF UNI 2.0 Implementation Agreements (IAs) support both EPL and EVPL. A client (UNI-C) device can dynamically request the establishment of EPL or EVPL service across an operator's network. UNI signaling functions, along with the OIF E-NNI and each domain's I-NNI signaling protocol (the latter not specified by OIF), are used to establish an end-to-end connection.

The 2009 OIF Worldwide Interoperability Demonstration focuses on a reliable end-to-end Ethernet connectivity and interoperability of on-demand Ethernet Services that are defined in the EVPL model in ITU-T Recommendation G.8011.2.

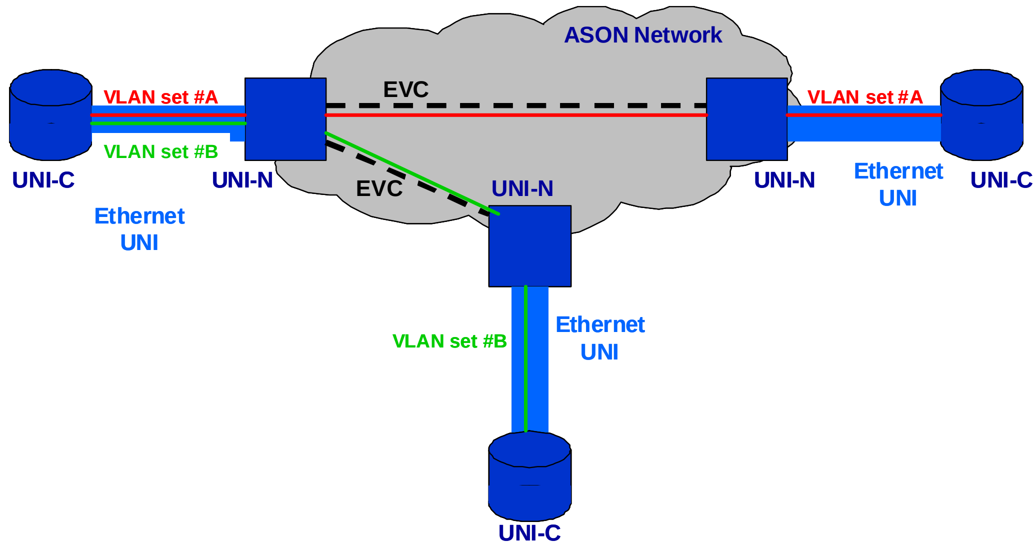

Figure 4: Ethernet Private Line network configuration

6 Transport Technologies employed for the transport of EVPL Services

6.1 Packet Transport Technology

Connection-Oriented Packet Transport or simply "packet transport" has evolved in response to many factors:

- Explosion of traffic demand with a diversity of service delivery requirements, pushing carriers toward a converged service-independent infrastructure
- Widespread adoption of IP/MPLS and Ethernet: connectionless packet-switched (CL-PS) technologies
- Requirements for carrier-class operation, commonly delivered today by SONET/SDH and OTH: connection-oriented circuit-switched (CO-CS) technologies

Packet transport describes the combination of the best features of CO-CS (predictability, a rich OAM feature set, high reliability) and CL-PS (service-awareness, traffic engineering, ubiquity), resulting in a connection-oriented packet switched (CO-PS) approach. This combination is embodied in both Provider Backbone Bridge - Traffic Engineering (PBB-TE) and MPLS Transport Profile (MPLS-TP) technologies and lead to the following features:

- End-to-end bidirectional, point-to-point connections or tunnels, supporting many packet based services
- Protection of these tunnels on an end-to-end basis with the ability to switchover in 50 milliseconds
- Assurance of end-to-end OAM integrity to support protection switching, fault detection and performance monitoring of tunnels

- Scalability and support for network growth
- Use of network management systems and/or intelligent control planes for provisioning of tunnels

6.1.1 MPLS Transport Profile - MPLS-TP

MPLS-TP is a joint effort by IETF and ITU-T now in progress, to define a profile of MPLS that supports the capabilities and functionalities of a packet transport network as defined by ITU-T requirements. MPLS-TP uses a subset of MPLS features to achieve CO-PS capability and interworking with IP/MPLS networks. Like traditional MPLS, MPLS-TP appends a label to incoming traffic to control forwarding/switching functions and provide robust OAM capability. As shown in the following figure, MPLS-TP provides a layered hierarchy for logical connections at tunnel (path) and pseudo-wire (channel) levels.

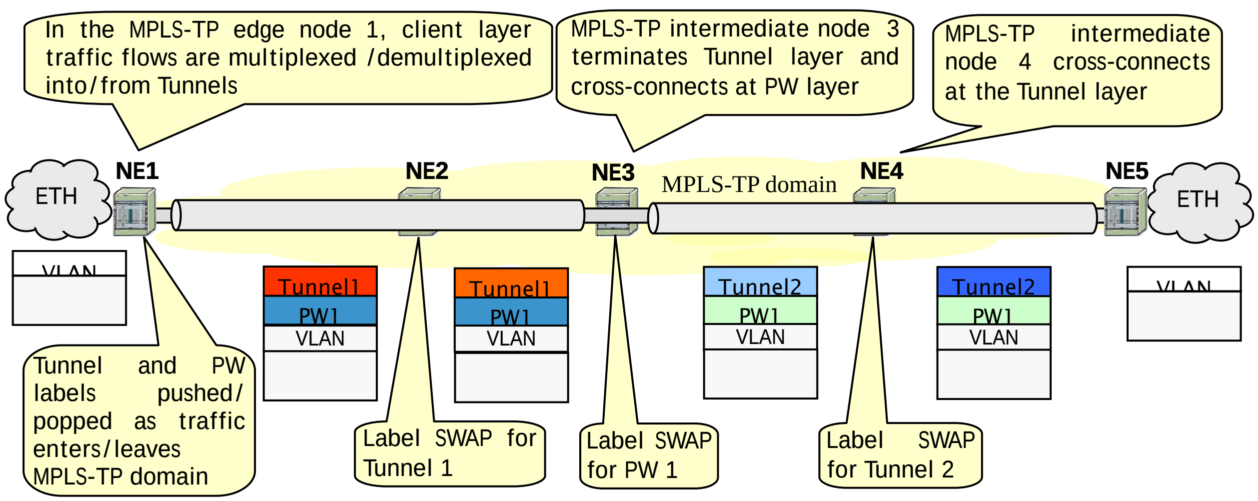

Figure 5: MPLS-TP set-up

The 2009 OIF Worldwide Interoperability Demonstration includes prototyping of packet transport based on preliminary MPLS-TP architecture and functionality, in order to help further the development of MPLS-TP standards. Implementations tested used the ITU-T G.81xx series of Recommendations as guidelines for some future MPLS-TP functionality. Aspects of MPLS-TP functionality tested include:

- Adaptation and transport of EVPL over various physical layers: Ethernet, SDH, OTN
- Dynamic setup and teardown of EVPL using OIF UNI 2.0 (Switched Connection)
- Point-to-point and point-to-multipoint topologies, with and without service multiplexing
- Quality of Service testing at tunnel and pseudo-wire levels
- Protection switching at tunnel and pseudo-wire levels, based on either failure or operator action
- OAM functions – continuity/connectivity verification, reverse defect indication, APS protocol

6.1.2 Provider Backbone Bridging – Traffic Engineering (PBB-TE)

Ethernet is a ubiquitous technology for data interfaces and switching in the Enterprise, and has been extended over the past few years to better fit carrier requirements as well. PBB-TE (IEEE 802.1Qay) has emerged as a further extension of Ethernet technology to address limitations related to scalability and reliability and incorporate packet transport concepts. Under PBB-TE, traditional Ethernet address learning and flooding procedures are replaced by traffic engineered tunnels created by the management system or control plane that carry client frames across the network with deterministic performance and QoS.

PBB-TE tunnels are set up to transport Ethernet Virtual Circuits (IEEE 802.1ad), with the subscriber frames encapsulated using 802.1ah encapsulation. Tunnels are identified by the Backbone Destination Address (B-DA) and the Backbone VLAN ID (B-VID). The B-VID can be used to provision redundant tunnels to the same destination. Carrier Ethernet OAM (IEEE 802.1ag) Connectivity Fault Management (CFM) as well as ITU-T Y.1731 performance monitoring is used to provide management and recovery for the PBB-TE tunnels.

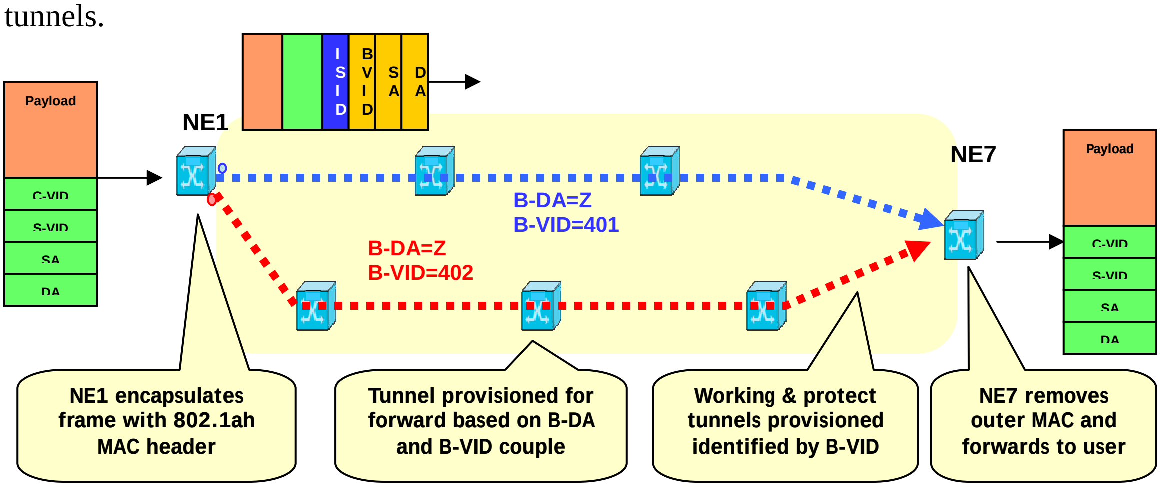

Figure 6: PBB-TE Encapsulation and Forwarding

Features of PBB-TE tested for the 2009 Demo included:

- Adaptation and transport of EPL and EVPL services over PBB-TE, using shared and dedicated tunnels
- Support of multiple classes of service and fairness of behavior for multiple flows in the same QoS class
- OAM procedures for fault detection, loopback and performance monitoring
- Protection switching between working and protect tunnels aimed at 50 ms restoration of service

6.2 EVPL and SONET/SDH over Optical Transport Network (OTN)

With the emergence of Ethernet as the predominant client signal there has been great activity within the telecommunications industry to define suitable transport technologies for reliable transport and management of Ethernet services. ITU-T SG15 had previously developed specifications for the next generation optical transport network (OTN), and these have proved to be an ideal Layer-1 technology for handling Ethernet transport with circuit-switched, guaranteed bandwidth. OTN's "digital wrapper" structure is flexibly designed to support a variety of additional service types, including wavelength services, storage networks, video and traditional TDM, at data rates up to 100 Gbps. ITU-T Recommendation G.709 specifies a well-defined frame structure and OAM capabilities for OTN that closely follow those of already mature and widely deployed SONET/SDH technology, making it easy to grow existing carrier networks with newer OTN equipment.

OTN specifications cover a hierarchy of transport layers from the Optical Data Unit (ODU) to the Optical Channel (OCh). For the 2009 Demo, the OIF has pioneered interoperability testing of OTN switching in the electrical domain, supporting EPL and EVPL services and transport of embedded SONET/SDH over OTN connections. For the 2009 Demo, the OTN features tested include:

- Mapping of EVPL services into OTN connections
- Switching of OTN connections for EVPL across an OTN transport infrastructure
- Mapping of embedded SONET/SDH OC48/STM16 links over OTN OTU2 links
- Switching of OTN connections carrying embedded SONET/SDH
- Support of SONET/SDH control plane E-NNI 2.0 for embedded SONET/SDH over OTN
- Optional support of vendor-specific OTN I-NNI control plane for dynamic OTN connection provisioning and restoration

7 Multi-domain Service Restoration

Until now, OIF's specification work has left restoration and recovery up to the specific I-NNI protocol within a domain. This year, OIF has begun investigation of restoration across E-NNI boundaries, thanks to a carriers' initiative within the OIF that led to the development of a "Carriers' Requirements" document for multi-domain service recovery. Consequently, the 2009 demonstration incorporates testing of prototype implementations for multi-domain service restoration. The demonstration results should provide input to the ongoing OIF work towards an implementation agreement on this technology.

Carriers' internal studies show that the introduction of dynamic restoration leads to a gain of 20 to 25 % of the overall CapEx. Restoration supports recovery of service even after multiple failures, potentially as a result supporting availability rates of up 99.9999 % (6 nines). Furthermore, restoration of multiple failures could relax the critical impact on field intervention for repairing the first outage, as a second failure would not render the service unusable.

End-to-end restoration across the E-NNI allows carriers to replace an end-to-end connection in a call by re-routing the connection away from failures affecting the E-NNI link or border node, or affecting an entire domain. While different flavors exist for restoration, this year's demo focuses on dynamic restoration, where a new path is computed to recover a failed path, after a failure was detected or reported.

Since restoration and administrative re-routing rely on the same principle, enabling the first capability would also provide operators with the ability for end-to-end planned maintenance activity. By using user-constrained re-routing, operators can ask to re-route connections out of a particular E-NNI link/node where maintenance activity is planned. The ability for the head node to re-compute a new path for the connection and smoothly switch traffic to this new path helps greatly in maintenance process simplification.

8 Applications of Optical Control Plane

A control plane is implemented to overcome the limitations of centralized network management systems to effectively manage network resources in today's environment of ever-growing data traffic. The growth of data traffic challenges carrier networks in terms of traffic volume but also the variable and asymmetrical nature of the traffic. This is driven by the rise in bandwidth-intensive enterprise data networking (locally, regionally and globally) and triple play end user applications. All of this causes fluctuating demand for bandwidth. Control plane technology can reduce the amount or need to reserve extra network capacity needed to guarantee contracted service levels thereby improving bandwidth utilization and ultimately realizing CapEx and OpEx savings for carriers. These benefits can be attained through the following applications of optical control plane technology.

- Control plane for bandwidth de-fragmentation
- Provisioning via EMS/NMS and control plane
- Bandwidth on Demand (BoD) in transport networks
- Scheduled BoD including GbE services
- OSS simplification
- Control plane for auto-discovery, network restoration and self-inventory

9 Benefits to the Carriers and Users

9.1 Carriers' view

Within the last few years, carriers have seen increasing demand for high-speed, flexible, highly resilient transport services. In order to provide these services on an end-to-end basis across multiple network domains, while maintaining resilience and meeting customer expectation, carriers must provide interoperable technologies and networks that can support cost-effective dynamic bandwidth services in a heterogeneous network environment.

Ethernet service, which can offer broadband data services in an efficient and cost-effective manner, has become an indispensable service for carriers today. Since the importance of the Ethernet has increased and has become so widely used, carriers are now faced with the need to provide Ethernet services with even more flexibility. EVPL is a service that opens a path to meeting this requirement by introducing more efficient bandwidth granularity with suitable quality of service levels.

At the same time, the emerging new transport technologies such as PBB-TE, MPLS-TP, OTN as well as SONET/SDH provide the possibility to build carrier networks of a diverse architecture to meet the service requirements in terms of operation, management, performance and reliability. Furthermore, the growth in diversity of services and the emerging of various transport technologies highlight the need to adopt control plane technologies that incorporate added flexibility, reliability, and speed to service delivery in heterogeneous carrier network environments.

9.2 Ethernet Services Transport over MPLS-TP and PBB-TE

MPLS-TP

The key to enabling efficient use of carrier network facilities is the aggregation of the user traffic for transport over the transport network. MPLS-TP is a promising transport technology that enables such efficient traffic aggregation as well as reliable transport for services. MPLS-TP can accommodate various types of user traffic including not only Ethernet, but also legacy technologies with a wide range of bandwidth granularity and various types of quality of services.

PBB-TE

PBB-TE provides carriers with a method for transport of Ethernet services over packet networks with similar features as that offered by SONET/SDH. PBB-TE is a carrier grade transport technology that enhances the transport of Carrier Ethernet services with Traffic Engineering capabilities and deterministic performance. Backhauling of next generation mobile network or business Ethernet service delivery are applications where PBB-TE technology can have a bright future. PBB-TE relies on various standardized components from the IEEE and ITU-T and is designed so that it can be deployed in networks alongside standard Ethernet bridging.

9.3 Carriers' Use of Optical Control Plane

An optical control plane is the key to realizing the full potential of transport networks to support dynamic bandwidth services. For example, the control plane supports rapid turn-up of services, efficient allocation of bandwidth in the network and reliable tracking of available resources. Standardized UNI/E-NNI interfaces provide an effective mechanism to interconnect both different vendors' equipment and different carriers' domains.

The introduction of network intelligence at the optical layer improves the provisioning process, enabling carriers to define new services and bring them to the market in a timely manner as have been shown by many carrier field trials and service implementations. Furthermore, intelligent networks keep updated network information (inventory, topology) within the network itself, thus alleviating the problem of synchronizing external databases. This network concept allows devices within the network to actually manage itself and facilitate network provisioning in a matter of seconds. Initial economic analysis (qualitative and quantitative) of the impact of control plane on high-speed circuit provisioning and revenue realization indicates OSS simplification resulting in cost savings and significant opportunities for new bandwidth services with early revenue realization.

Availability of control plane-enabled recovery (protection and restoration) in multi-domain intelligent optical networks should address many intra domain, inter domain and end-to-end failure scenarios.

10 Related Standards Activities

The 2009 OIF Worldwide Interoperability Demonstration relies on the work of a number of standards organizations developing specifications for support of Ethernet service across different transport technologies, especially work of IEEE Committee 802.1 on PBB-TE, ITU-T SG 15 on OTN, and both IETF and ITU-T on optical control plane. There is a strong synergy between OIF's efforts and other standard groups' activities. One of the main goals of the OIF interoperability testing is to communicate results into standards organizations where open areas or differing interpretations are found.

The OIF has worked with the MEF to understand and implement its Ethernet service definitions, including Ethernet Private Line and Ethernet Virtual Private Line services. Detailed MEF reference documents are available at http://metroethernetforum.org/PDF_Documents/metro-ethernet-services.pdf.

OIF strongly supports the joint cooperative effort now in progress in both ITU-T SG15 and IETF to define MPLS-TP standards. The 2009 OIF Worldwide Interoperability Demonstration includes prototyping of packet transport based on preliminary MPLS-TP architecture and functionality, and is intended to provide practical input into the development and standardization of MPLS-TP in IETF and ITU-T.

11 Conclusion

The 2009 OIF Worldwide Interoperability Demonstration shows end-to-end provisioning of dynamic switched Ethernet (EVPL) services over multiple, control plane-enabled intelligent optical core networks through the use of OIF implementation agreements for UNI 2.0 and E-NNI 2.0. Bandwidth on demand over various transport technologies and multi-domain service restoration are some of the new features that are demonstrated for 2009.

The types of equipment used in testing range from multi-service packet switching platforms to intelligent optical switches and ROADMs. OIF interoperability testing allows the participating vendors to test their equipment's ability to support carrier requirements and desired functionality, while giving carriers confidence that different vendors and technology domains can work together using OIF Implementation Agreements, opening new markets for carriers to deliver carrier-grade Ethernet services through their optical transport networks.

12 Appendix A: List of Contributors

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13 Appendix B: About the OIF

Launched in April of 1998, the OIF unites representatives from data and optical networking disciplines, including many of the world's leading carriers, component manufacturers and system vendors. The OIF promotes the development and deployment of interoperable networking solutions and services through the creation of Implementation Agreements (IAs) for optical, interconnect, network processing and component technologies, and optical networking systems. The OIF actively supports and extends the work of standards bodies with the goal of promoting worldwide compatibility of optical internetworking products. Working relationships or formal liaisons have been established with the Ethernet Alliance, IEEE 802.3, IETF, ITU-T Study Group 13, ITU-T Study Group 15, IPv6 Forum, MEF, ATIS OPTXS, ATIS TMOC, Rapid I/O, TMF, UXPi and the XFP MSA Group. Information on the OIF can be found at http://www.oiforum.com.

14 Appendix C: Glossary

ASON: Automatically Switched Optical Network	NG-SONET/SDH : Next Generation-SONET/SDH
BoD : Bandwidth on Demand	NMS: Network Management System
CL-PS : Connectionless Packet Switched	OADM: Optical Add/Drop Multiplexer
CO-CS : Connection Oriented Circuit Switched	OAM: Operations, Administration, Maintenance
CO-PS : Connection Oriented Packet Switched	OCh : Optical Channel Unit
EMS: Element Management System	ODU : Optical Channel Data Unit
E-NNI: External Network-to-Network Interface	OIF: Optical Internetworking Forum
EPL: Ethernet Private Line	OSS: Operations Support System
EVC: Ethernet Virtual Connection	OTN: Optical Transport Network
EVPL: Ethernet Virtual Private Line	OTU : Optical Channel Transport Unit
GMPLS: Generalized Multi-Protocol Label Switching	PBB-TE: Provider Backbone Bridging - Traffic Engineering
IA: Implementation Agreement	ROADM: Re-configurable Optical Add & Drop Multiplexer
I-NNI: Internal Network-Network Interface	SCN: Signaling Communications Network
IPSec: IP security	SONET/SDH: Synchronous Optical Network/Synchronous Digital Hierarchy
LAN: Local Area Network	TDM: Time Division Multiplexing
MEF: Metro Ethernet Forum	UNI: User-to-Network Interface
MPLS-TP: Multi Protocol Label Switch - Transport Profile	UNI-C: User-Network Interface-Client
MSPP: Multi-Service Provisioning Platform	UNI-N: User-Network Interface-Network
NE: Network Element	VLAN: Virtual LAN