Multi-Protocol Lambda Switching for Packet, Lambda, and Fiber Network

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Backgrounds for Optical Network - 1

- Transform functionality of SONET/SDH to optical layer
- Dynamic allocation for DWDM network capacity
- Just-in-time provisioning for Dynamic Re-configurable Optical Network
- Innovation and advances in optical components and transport technologies
  - Optical technology changing rapidly
  - Optical device latency and synchronization
  - Increased focus between electrical and optical devices
- Optical Multiplexing Schemes
  - WDM, OTDM, Optical CDMA
  - Underline frame structure (PDH, SDH, Digital Wrapper, MPLS, GbE etc.)
Backgrounds for Optical Network - 2

- Re-evaluation of traditional network platforms and cost structures
  - Service delivery requirements changing
    - (e.g., 50 ms restoration time, reliability, etc.)
  - Growing demand on OC-48c/OC-192c routers

- Limitations of existing architecture
  - Existing SONET/SDH ring-based architecture failing
  - Optimized for voice, Can’t scale enough for data

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Motivation for Optical Networking

- **Cost and Efficiencies**
  - Waves cheaper than switching packets
  - Eliminates costly O/E/O conversions and equipments

- **Flexibility and Management**
  - Just-in-time service provisioning?
  - Traffic engineering at the wave level?

- **Revenue Opportunities**
  - Fast provisioned wave services
  - Bursty IP services through backbone network
Reviews of SONET/SDH Technologies

- Mature Technology $\rightarrow$ Too expensive, Over estimated, not proper more than 2.5 Gbps, scalability problem
- Multiplexing, Switching and Grooming $\rightarrow$ useful for existing digital hierarchy
- Self-Healing Capability $\rightarrow$ less effective
- High Availability and Extensive Management Capability $\rightarrow$ No effective compared with others

- Limitations of SONET/SDH Ring
  - Rings inefficient for large pipes
    - End-to-end provisioning, management, and protection
  - Meshes are more efficient
Motivations for IP over WDM

- **Tremendous growth in data traffic**
  - Router interfaces for OC-48c and OC-192c

- **Elimination of SONET/SDH equipments**

- **Pros and Cons of IP over WDM**
  
  - **Pros**
    - Protocol Independent, Efficiency-Overhead
    - Suitable for Applications with Large Volumes
  
  - **Cons**
    - Not Suitable for High Error Environments
    - Unable to Guaranteed Performance
    - No Gain of Bandwidth Efficiency for Bursty Traffic
    - Not Suitable for Low Speed Links
On-going Issues for IP over WDM

- Restoration and protection
- Performance monitoring
- Fault isolation
- Network engineering and bandwidth distribution
- Wavelength management
- Network scalability
- Adopting new transmission technologies
Physical Limitation for Optical Internet - 1

- **Limitations of Optical Devices**
  - No optical buffering (not a delay line)
  - No optical processing

- **Limitations of Optical WDM**
  - Large bandwidth on single wavelength
  - Long latency time for Wavelength tuning and conversion

- **Limitations of Optical Switch**
  - Large bandwidth on single fiber
  - Relative small size of optical switch (e.g. 256 x 256)
  - Long latency time for Switching-over
Optical Switching Technologies - 1

- Possible Architectures
  - Lambda Switching with dynamic Re-configuration
  - Optical Burst Switching
  - Optical Tag or Packet Switching

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Optical Switching Technologies - 2

- **Pros/Cons**
  - Large BW with loose control capabilities
  - Suitable for large volume traffic with traffic aggregation
  - No traffic engineering in Lambda level → Single QoS for a lambda, No flow control and No contention resolution

- **Supports migration to mesh networks**
  - Virtual level protection
  - Scaled services: protected, unprotected, ...
Optical Switching Technologies - 3

 Vision for Optical XC
Protocol Reference Model for Optical Internet

Telecommunication Management Network
Routing and Signalling Network

- **C-plane**
  - IP Layer
  - WDM Layer
  - Optical Layer
  - IP Signalling (SIP, etc)
  - MPLS Signalling
  - RWA Signalling

- **M-plane**
  - IP Layer
  - WDM Layer
  - Optical Layer
  - IP Signalling (SIP, etc)
  - MPLS Signalling
  - RWA Signalling

- **U-plane**
  - Core Router
  - Edge Router
  - Optical Link Management
  - WDM Management
  - Traffic, Flow QoS Management
  - IP Routing

**Annotations**

- **Core Router**
- **Edge Router**

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Architectural Model for Optical Network

- **Overlay Model**
  - Separate the control plane between Optical Transport Network (OTN) domains and IP domains

- **Integrated (or Peer) Model**
  - Same control plane in the OTN and IP domains
Evolution Model for Optical Internet - 1
Evolution Model for Optical Internet - 2
Evolution Stage - 1

- **1st Stage (IP over static WDM)**
  - Utilize Large Bandwidth of Optical Device by Traffic Aggregation
  - Utilize Controllability and Manageability of Electronic IP Domain
  - Examples
    - User interface: IP over static WDM
    - Access and Core: WDM-XC and Optical Fiber Switch by configuration at set-up time

- **2nd Stage (IP over Dynamic WDM, Dynamic WDM-XC)**
  - Reduce latency of wavelength tuning and conversion time
  - Reduce latency of Switching Over time
  - Examples
    - User interface: IP over static or dynamic WDM
    - Access and Core: WDM-XC and Optical Fiber Switch by dynamic reconfiguration
Evolution Stage - 2

- **3rd Stage (Optical Tag Switch or Optical Burst Switch)**
  - Limited Optical Header Processing for framing and switching
  - Optical Switch tightly coupled with electric control logic
  - Examples
    - User interface: IP over dynamic WDM with variable-size message flow
    - Access and Core: WDM-XC and Optical Fiber Switch by on-line and on-demand control
    
    (note) on-line control is classified into in-band and out-of-band signalling
    (note) Optical Burst Switching is out-of-band signalling without header processing.
    Instead, it utilizes electric control signals to synchronize optical signals for switching

- **4th Stage (Optical Packet Switch)**
  - Optical Header Processing with small latency time
  - Examples
    - User interface: IP over dynamic WDM with fixed-size packet
    - Access and Core: Optical Packet Switch by on-line and on-demand control
Control Plane for Optical Networking - 1

- **Control Requirements**
  - Cost-effective OAM
    - Fault isolation and performance monitoring
      - Protection and restoration
  - Rapid service provisioning for negotiated bandwidth and QoS
  - Scalability on bandwidth provisioning
  - Grooming of sub-rate circuits
  - Dynamic Optical VPN according to SLA
  - Automatic configuration and topology auto-discovery

- **Intelligence of Optical Networking**
  - Done by controllability
    - Traffic control, Resource Control (Bandwidth, Lambda, Buffer), QoS, Signalling, VPN, etc.
    - Node, Link and Path protection mechanism
Control Plane for Optical Networking - 2

- **Dynamic Reconfiguration of Optical Network**
  - Link Protection, Capacity Planning, Load distribution, etc.

- **Integrated L1, L2 and L3 forwarding Engine**
  - Switching/Routing, class (e.g., FEC), priority, etc.

- **Traffic control and Traffic aggregation**
  - Based on application, flow, class, lambda

- **Optical VPN for multicast and security**

- **Multiple Access scheme for shared media (PON, etc)**

- **Naming and addressing both for Optical switching and IP routing**
Control Plane for Optical Networking - 3

- **Generic Requirements for OXC Control Plane**
  - Establish optical channel trails expeditiously
  - Support traffic engineering functions
  - Support various protection and restoration schemes

- **MPLS Traffic Engineering Control Plane**
  - Resource discovery
  - State information dissemination
  - Path selection and Path management
IP-based Optical Control Plane Issues - 1

- **Addressing**
  - Identifiable entity
    - OXC, optical link, optical channel, sub-channel
    - SRLG (Shared Risk Link Group)
      - An identifier assigned to a group of optical links that share a physical resource
IP-based Optical Control Plane Issues - 2

- Neighbor Discovery
  - Discovery of local link status
  - NDP (Neighbor Discovery Protocol)
    - Determine the parameters between adjacent OXCs
      - Up/down status of each optical link
      - Bandwidth and other parameters of the link
      - Identity of the remote link (e.g., remote port number)
    - Link management and fault isolation
    - Require in-band communication on the bearer channels
    - Determine local connectivity and link status
IP-based Optical Control Plane Issues - 3

- Topology Discovery
  - Procedure of determination the topology and resource state of all the links in a sub network
  - Using a link state routing protocol or management protocol
  - In optical links,
    - Link state information
      - May consist of link bundles, Each link bundle is an abstract link in the network topology
      - Capture restoration-related parameters for optical links
    - Maintenance a single routing adjacency between neighbors
    - Flexibly updates link state owing to dynamic change of link availability information
IP-based Optical Control Plane Issues - 4

- **Restoration Models**
  - Local mechanism
    - Select an alternate link between two adjacent OXCs when a failure affects the primary link
  - End-to-end mechanism
    - Pre-computed alternate paths
    - “1+1” protection
      - Establish a back-up path for the protected primary path along a physically diverse route. Both paths are active.
      - The failure along the primary path \( \rightarrow \) immediate switch-over to the back-up path
  - Shared protection
    - Back-up paths share the same network resources
    - When a failure affects a primary path, the same failure don’t affect the other paths whose back-ups share resources.
IP-based Optical Control Plane Issues - 5

- **Signaling Issues**
  - Bi-directional Light path Establishment
    - Output port for the forward direction at an OXC = input port for the reverse direction of the path
  - Collision detection
    - The involved paths may be torn down and re-established.
    - Or, collisions may be avoided altogether.
  - Failure Recovery
    - When failures occur, a backup processor or a backup control channel will be activated.
    - During failure recovery, desirable to recover local state at the concerned OXC with least disruption to existing optical paths.
IP-based Optical Control Plane Issues - 6

- Optical Internetworking
  - Should dynamically provision and restore light paths across optical sub-networks
  - Requirements
    - Uniquely identify light path end-points in different sub-network
    - Protocol for determining reachability of end-points across sub-nets
    - Signaling protocol for provisioning light paths across sub-nets
    - Procedure for the restoration of light paths across sub-nets.
Generalized MPLS & Optical User Network Interface Signaling

Generalized MPLS - Signaling Functional Description
<draft-ietf-mpls-generalized-signaling-00.txt>

Signaling Requirements at the Optical UNI
<draft-bala-mpls-optical-uni-signaling-01.txt>
Network Service Model

- **Domain Service Model**
  - Services defined by layered domain
  - Client/Server domain relationship
    - IP is a client of the optical domain
    - Optical layer provides point-to-point channels for clients

- **Unified Service Model**
  - A single integrated control plane structure
    - single signaling and routing protocol
  - MPLS-based optical network
  - IP signaling and routing protocols need to be modified to support optical characteristics
MPLS-Based Approach for Optical Internet – 1

- **IP-based approaches for rapid provisioning**
  - Re-use existing signaling framework
  - Less standardization, faster vendor interoperability
  - No addressing concerns arise (use IP addresses)

- **Key MPLS features exploited**
  - Hierarchical LSP tunneling (label stacking/swapping)
  - Explicit routing capabilities
  - LSP survivability capabilities
  - Constraint-based routing
MPLS-Based Approach for Optical Internet – 2

- Traffic Engineering in Optical Network
  - Optical network load balancing
  - Performance optimization
  - Resource utilization optimization

- Requires Dynamic Control Mechanism
  - Network state monitoring
  - Feedback control
    - Routing parameters, Resource parameters, Traffic management parameters, etc.
Extensions to MPLS signaling

- Encompass time-division (e.g. SONET ADMs), wavelength (optical lambdas) and spatial switching (e.g. incoming port or fiber to outgoing port or fiber)
- Label is encoded as a time slot, wavelength, or a position in the physical space
- Bandwidth allocation performed in discrete units.
Integrated Control Plane for Optical Internet - 2

- **Supports Multiple Types of Switching**
  - Support for TDM, lambda, and fiber (port) switching
  - OXC (Optical Cross-Connect) can switch an optical data stream on an input port to a output port
  - A control-plane processor that implements signaling and routing protocol

- **Optical Mesh Sub-Network**
  - A net. of OXCs that supports end-to-end networking
  - Provide functionality like routing, monitoring, grooming and protection and restoration of optical channels
Forwarding Interface of GMPLS

- **Packet-Switch Capable (PSC)**
  - Recognize packet/cell boundaries and forward data based on header.

- **Time-Division Multiplex Capable (TDM)**
  - Forward data based on the data’s time slot in a repeating cycle.

- **Lambda Switch Capable (LSC)**
  - Forward data based on the wavelength

- **Fiber-Switch Capable (FSC)**
  - Forward data based on a position of the data in the real physical spaces.

Allow the system to scale by building a forwarding Hierarchy
Client – Optical Interface Model - 1

- **Direct Interface**
  - IPCC (IP control channel)
    - exchanging signaling and routing messages between the router and the OXC
  - Edge router and the OXC are peers in the control plane
  - Example routing protocol - OSPF/ISIS or BGP
  - Example signaling protocol - RSVP-TE or CR-LDP
Client – Optical Interface Model - 2

- **Indirect Interface**
  - Out-of-band IP control channel
    - Between the client and optical network elements, in case that the OXCs and/or clients don’t support a direct interface

- **Provisioned Interface**
  - Manually provisioned by Network Operator
  - No control interfaces between edge router and the optical network
Generalized Label Request

- Generalized label contains information to program cross connect
- Supports communication of characteristic to support the LSP
- Include link protection, LSP encoding, and LSP payload
  - LSP Encoding Type indicates the encoding of the LSP
  - Link Protection Flags indicates the desired protection level
  - Generalized PID is the identifier of the payload carried by an LSP.

- LSR must verify that the request parameters can be satisfied
- If node cannot support, the node must generate a Notification message
  - “Routing problem/Unsupported Encoding”
  - “Routing problem/Unsupported Link Protection”
  - “Routing problem/Unsupported G-PID”
Generalized Label

- **Carry a label that represents**
  - A single fiber in a bundle
  - A single waveband within fiber
  - A single wavelength within a waveband
  - A set of time-slots within a wavelength

- Label : Variable (depends on the type of the link)
Suggested Label

- Used to provide a downstream node with the upstream node’s preference
- Upstream node configures its hardware with the proposed label before the label is received by the downstream node
- Reduce setup latency

- CR-LDP
  - Label Request
  - Label
  - Suggested Label
  - Label Request
  - Label
  - Suggested Label
  - Label Request
  - Label
  - Suggested Label

- With extensions
  - Label Request
  - Label
  - Suggested Label
  - Label Request
  - Label
  - Suggested Label
  - Label Request
  - Label
  - Suggested Label

- Downstream LSR can ignore label suggestion

Source: Chromisys

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Bi-directional LSP establishment

- Reduces trail establishment latency
- Increases success probability

- **LDP**

  - Label Request → Label → Label Request
  - Label Request → Label → Label Request
  - Label Request → Label → Label Request

- **With extensions**

  - Upstream Label, Suggested Label → Label → Label → Label → Upstream Label, Suggested Label
  - Upstream Label, Suggested Label → Label → Label → Label → Upstream Label, Suggested Label
  - Upstream Label, Suggested Label → Label → Label → Label → Upstream Label, Suggested Label

Source: Chromisys

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Physical Control Structure of O-UNI

- **Direct Interface**

- **Indirect Interface**: Client to Optical Network Management Agent

- **Indirect Interface**: Client Agent to ONE

- **Indirect Interface**: Client Agent to Optical Network Management

ONE: Optical Network Element
ISI: Internal Signaling Interface
ND: UNI neighbor discovery
UNI Signaling Message

- Lightpath Create Request
- Lightpath Create Response
- Lightpath Delete Request
- Lightpath Delete Response
- Lightpath Modification Request
- Lightpath Modification Response
- Lightpath Status Enquiry
- Lightpath Status Response
- Notification
- Address Query
UNI Message Parameter (1/2)

- **Identification**
  - Lightpath ID: A network unique identifier for a lightpath
  - Contact ID: A carrier-assigned identification to identify the service contract
  - Source/destination client point of attachment: Optical network administered IP address and logical port information
  - User group ID: VPN identifier
  - UNI-C ID: IP address of the UNI-C entity

- **Service-Related**
  - Directionality: Uni-directional or bi-directional
  - Framing type: Format of the signal to be transported across the UNI
  - Overhead termination type: Specifies to what degree the framing overhead bytes are terminated for SONET and SDH framing.
  - Bandwidth: The bandwidth of the service.
  - Propagation delay: Maximum acceptable propagation delay.
  - Service level: An integer specifying the service level requested for the lightpath
UNI Message Parameter (2/2)

- **Routing-related**
  - Diversity: A list of \( n \) lightpaths from which the present lightpath must be physically diverse in the network.

- **Miscellaneous**
  - Result Code: Indicates success or failure of certain operation
  - Status: Indicates the status of a lightpath

- **Security-related**

- **Policy, accounting and authorization related**
LDP Extensions for O-UNI signaling

- Applying LDP at the O-UNI allows for:
  - The reuse of already defined LDP message and message formats
  - The reuse of LDP session management and control procedures
  - Additions to the already specified procedures for notification of errors
  - The reuse of the LDP security mechanism

- The addition of new TLVs to support the attributes required for lightpath establishment at the O-UNI

- Two new LDP messages to allow for the exchange of lightpath status information across the UNI
O-UNI Session Management and Control

- **Hello Message**
  - Use the format and the procedures of the LDP Hello Message

- **KeepAlive Message**
  - Use the format and the procedures of the LDP KeepAlive Message

- **Initialization Message**
  - The Label Advertisement Discipline is always set at 1 to indicate Downstream on Demand label distribution mode.
  - Loop Detection is always disable, D = 0.
Use of LDP Messages for O-UNI (1/2)

- **Lightpath Create Action**
  - **Lightpath Create Request**: achieved by the LDP Label Request Message and Generalized Label Request TLV
  - **Lightpath Create Response**: achieved by the LDP Label Mapping Message and Generalized label

- **Lightpath Delete Action**
  - **Lightpath Delete Request**: achieved by the LDP Label Release Request Message.
  - **Lightpath Delete Response**: achieved by the LDP Label Withdraw Message
Use of LDP Messages for O-UNI (2/2)

- **Lightpath Modify Action**
  - After a lightpath is setup, some of its attributes may need to be changed by the network operator
  - Does not require the definition of new LDP message
  - Use the Action Flag (ActFlg) field in the Lightpath Id TLV in the Lightpath Create Request Message.

- **Lightpath Status Action**
  - **Lightpath Status Enquiry Message**: solicit a Status Response Message from its peer.
  - **Lightpath Status Response Message**: The Status TLV carries information that describes the current status of lightpath.

- **Notification Action**
  - The LDP Notification message is used across the O-UNI
Conclusions

- **Architectural Evolution for Optical Network**
  - Single Control Plane Both for IP domain and Optical Domain
  - IP-centric control mechanisms are being used for optical layer control

- **MPλS Technologies**
  - Extends MPLS to encompass time-division, wavelength and spatial switching
  - Adapt IP Traffics to Physical limitations of Optical Technologies
  - Generalized MPLS is used both for Unified Service Model and Domain Service Model
References

- Osama S. Aboul-Magd et. al. “Signaling Requirement at the Optical UNI”, <draft-bala-mpls-optical-uni-sigaling-01.txt>, October, 2000