



The Migration Toward the Optical Internet

Lesson 6

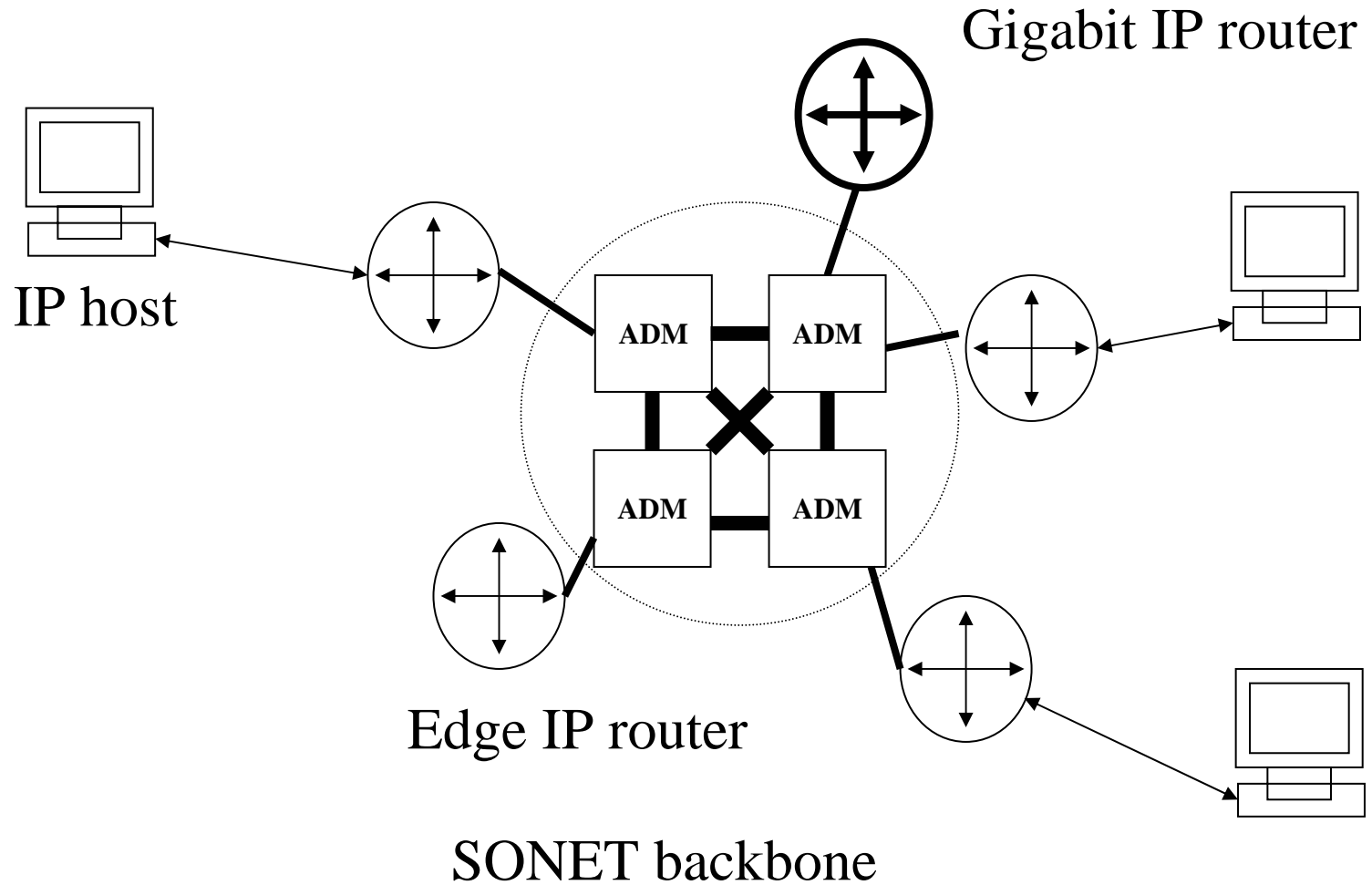
Luca Valcarenghi

(part of these notes are taken from

A. Fumagalli and J.Arakil, "Optical Internet: Available Technologies and Challenges", ICC 2002 Tutorial)



The Second Generation Optical Internet - Step I





SGOI - Step I

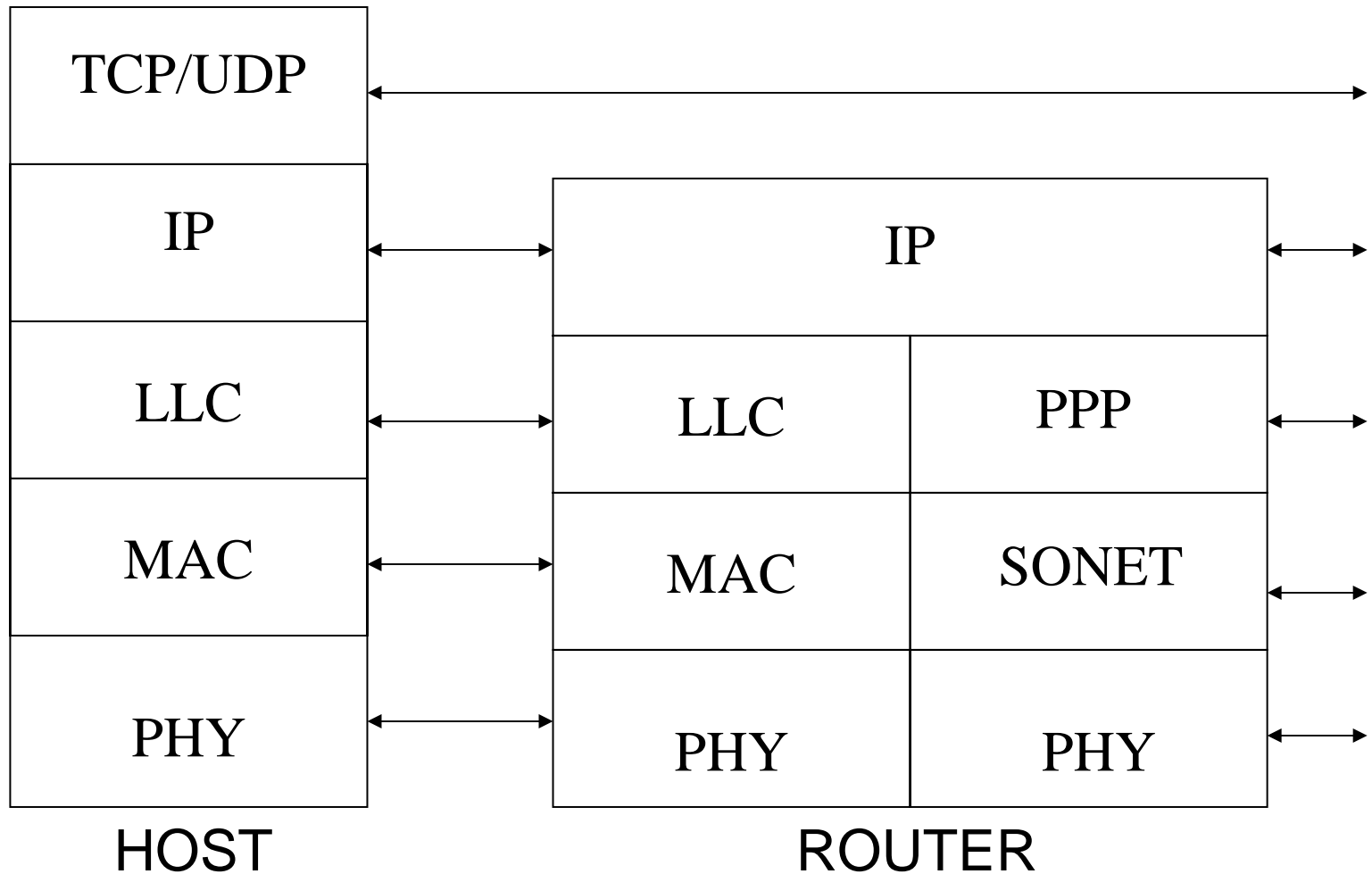
IP

SONET reconfigurable
network

Static lightpath network



Protocol Architecture (Step I)





IP over (Reconfigurable) SONET - Advantages

- No “cell tax” (ATM overhead for IP packet size roughly 25%)
- Supports OAM operations
- Support of OC-48 (ATM SAR not feasible).
Internet demand is forcing move to OC-48



IP over (Reconfigurable) SONET - Disadvantages

- SONET can only provide bandwidth in tributary quanta
- SONET is intended for voice channels not datagrams
- SONET payload transparency compromised: need of additional scrambler



IP over (Reconfigurable) SONET versus IP over Optical Layer (WDM)

- IP over SONET adds physical layer overhead and synchronous operation not needed for asynchronous transport
- SONET allows for more granularity in bandwidth assignment
- In some cases (links between gigabit routers) a native IP over WDM is desirable but still the framing is an open issue



Generic Framing Procedure (GFP)

- Need of using SONET/SDH to carry signals for which SONET/SDH was not initially designed (i.e., data signals)
- Efforts by ANSI and ITU-T to provide a generic mechanism to adapt traffic from higher layer client signals over SDH/SONET or Optical Transport Networks (OTNs)
- GFP consists of both common and client-specific aspects
- Common aspects of GFP apply to all GFP-adapted traffic
 - Two modes of client signal adaptation are defined for GFP
 - PDU-oriented adaptation mode: frame-mapped GFP
 - block-code-oriented adaptation mode: transparent GFP
- Client-specific mapping definitions are underway for many protocols (e.g, Ethernet, HDLC)



GFP (2)

- In short, GFP defines a standard framing procedure for octet-aligned, variable length payloads for subsequent mapping into SONET/SDH SPE or OCh payload

Ethernet	IP/PPP	Other bearer services
GFP – client-specific aspects (payload-dependent)		
GFP – common aspects (payload independent)		
SONET/SDH path		OTN OCh path



GFP for SONET/SDH

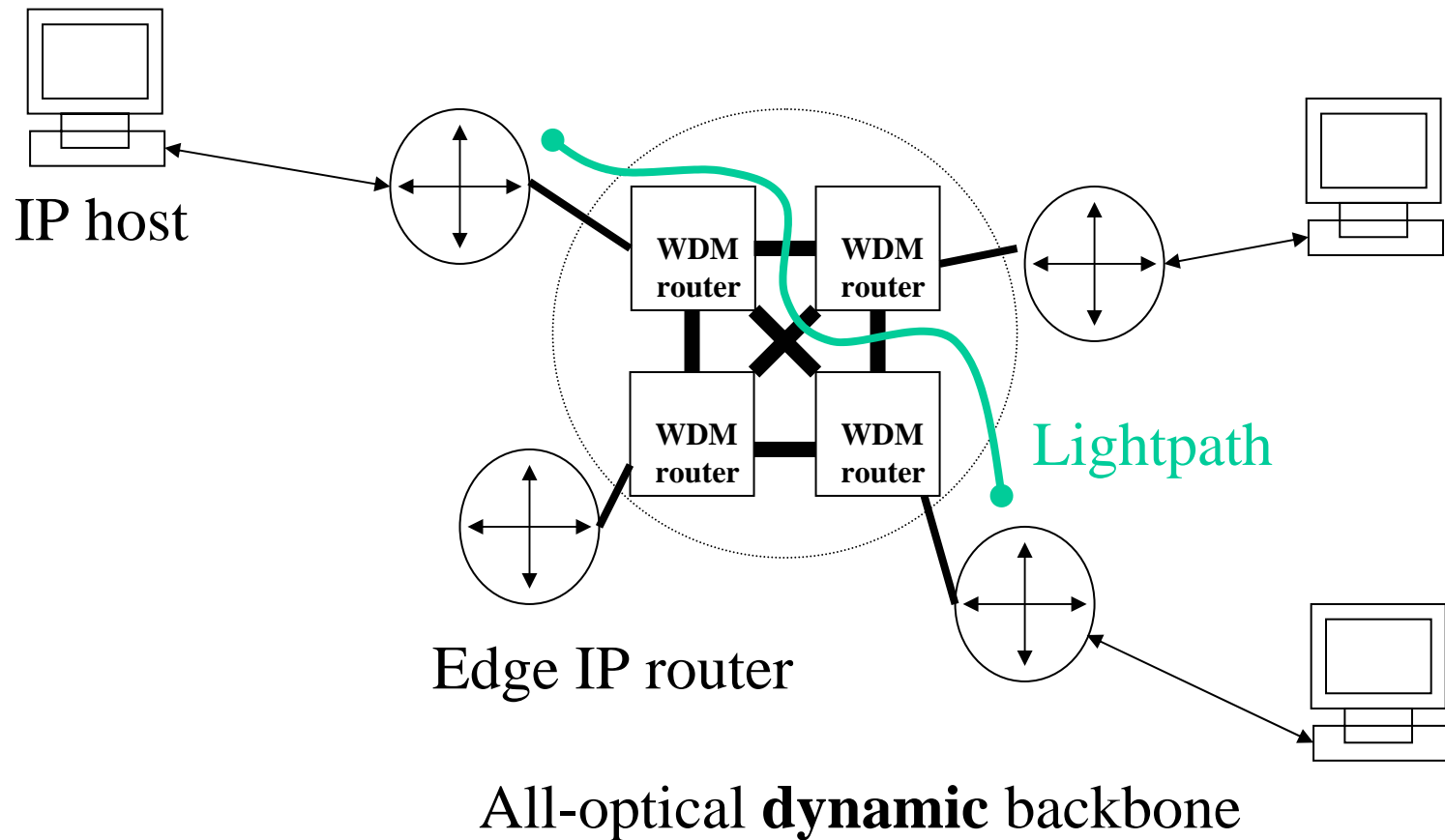
- Attempts to standardize the Virtual Concatenation (VC) of SONET/SDH paths
 - VC allows for relaxation of the “rigidity” of SONET/SDH bit rates
- Mapping of wide variety of data signals allowed
- Leveraging emerging capability of dynamically sizing virtually concatenated SONET/SDH paths using a link capacity adjustment scheme (LCAS)
 - LCAS provides a control mechanism to “hitless” increase or decrease the capacity of a link to meet the bandwidth needs of the application
- Combined VC, GFP, and LCAS offer an attractive option for carrying data networking protocols over transport networks, and present an alternative to the use of ATM and MPLS for transport oriented statistical multiplexing gain



Resilient Packet Ring (RPR)

- IEEE initiative for setting up a standard with code 802.17 for Resilient Packet Rings (RPRs)
 - Goal of 802.17 is to define and standardize a protocol suite optimized for high-speed ($> 1\text{Gb/s}$) packet transmission in resilient ring topologies
- The philosophy behind the RPR initiative consists of combining the resilient nature of ring topologies with the statistical multiplexing and QoS capabilities of a packet-optimized MAC protocol

The Next Generation Optical Internet - Step II?





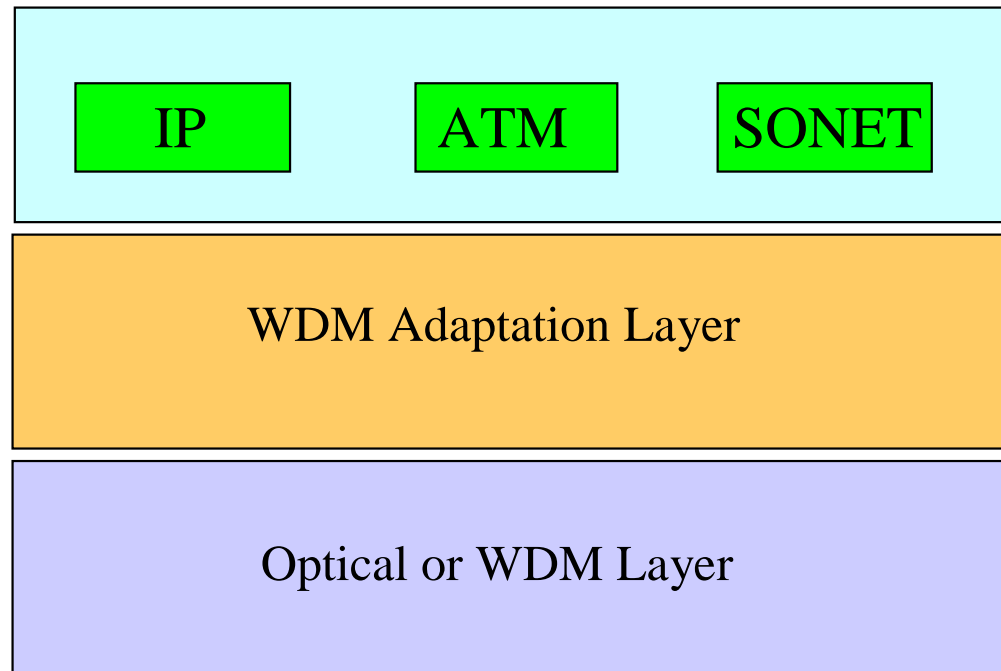
NGI - Step II

IP

Dynamic lightpath network

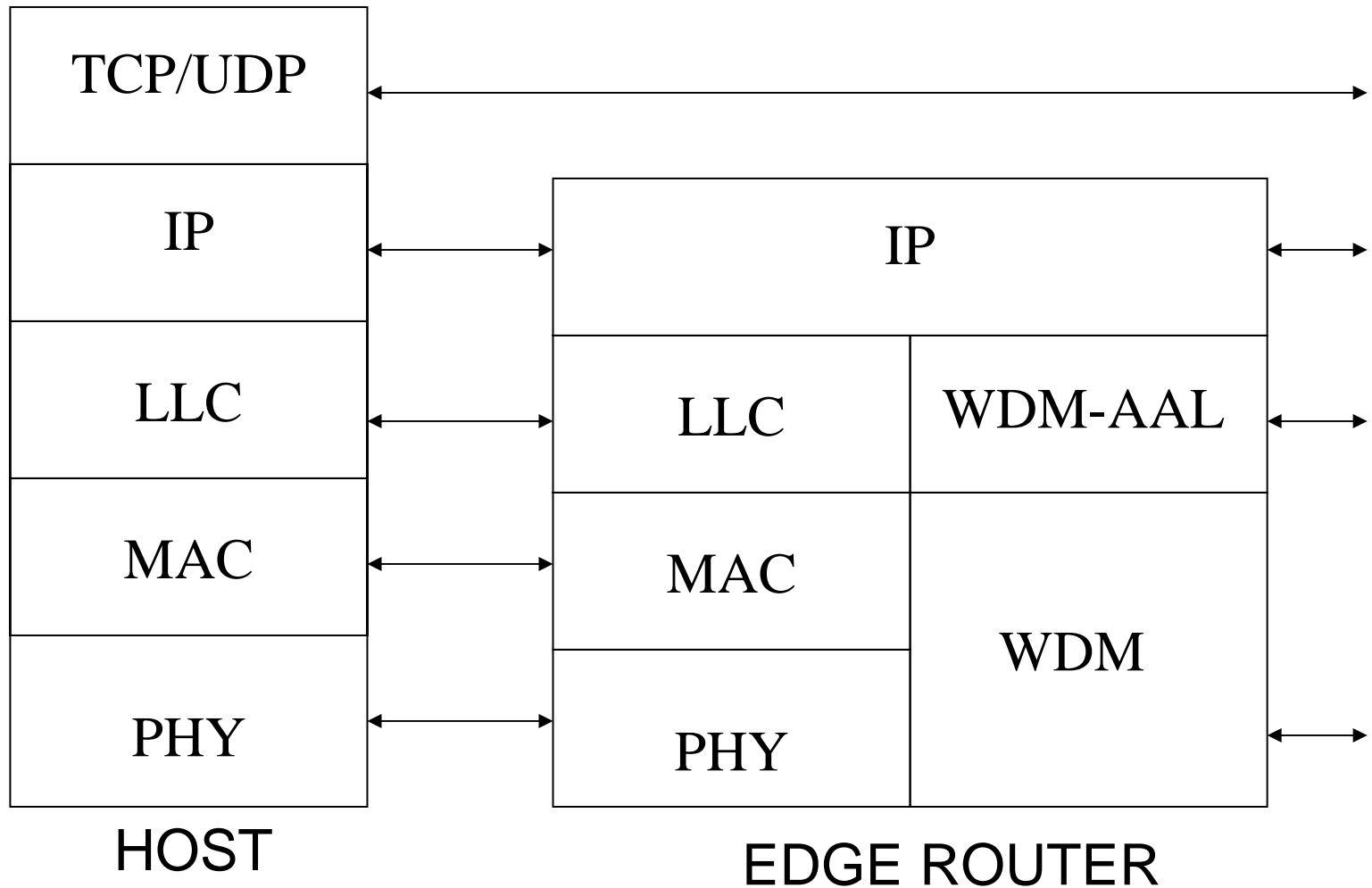


Optical Networking Trends





Protocol Architecture





WDM AAL Features

- Frame delimitation and synchronization
- Multiprotocol encapsulation (LLC)
- Signaling for dynamic resources allocation (dynamic lightpath/optical burst)
- FEC



WDM AAL Example: Digital Wrappers (Lucent)

- Optical layer performance monitoring, FEC and ring protection *independent of input signal*



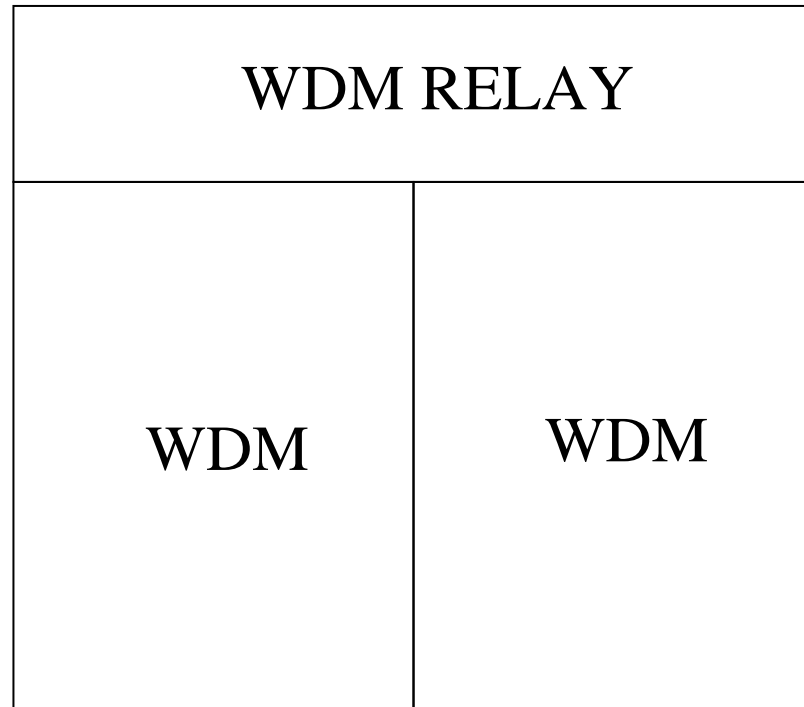


Digital Wrapper Features

- Substitutes SONET-like framing
- This scheme takes advantage of the need for opto-electronic regeneration to add additional capacity to the Optical Channel (OCh) client
- Permits to support all of the OCh-level Operation, Administration, and maintenance (OAM) requirements
- The use of digital wrapper technology provides functionality and reliability similar to SONET/SDH on a per wavelength basis (independently on the input signal)
 - Optical layer performance monitoring
 - FEC
 - ring protection and network restoration



WDM Routers



BACKBONE WDM ROUTER



The Optical Layer

- Optical fiber
- Optical Amplifiers (OA)
- Wavelength Routing Nodes (WRN)
- ITU Optical Layer



Optical Fiber

- Three transmission windows
 - first: 800-900 nm (Multimode)
 - second: 1240-1340 nm (Singlemode)
 - third: 1500-1650 nm (Singlemode)
- Potentially available bandwidth in each window ~ 20 THz
- Attenuation peak between second and third window dramatically reduced \Rightarrow second+third window
- Effective bandwidth limited by the device characteristics



Semiconductor Optical Amplifiers (SOA)

- Broadband gain characteristics
(work both at 1300 nm and 1550 nm)
- Maximum bandwidth up to 100 nm
- Short switching time
- Gain fluctuation, polarization dependent, high coupling loss
- Suitable for single channel amplification
- Highly non-linear



Doped Fiber Amplifiers

- Erbium-Doped Fiber Amplifiers (EDFA)
 - Short (S) λ band ~1450-1530 nm
 - Conventional (C) λ band ~1530-1570 nm
 - Long (L) λ band ~1570-1620 nm
 - Total available bandwidth ~ 170 nm (i.e., 200 channels with 0.8nm (“100GHz”) spacing)
 - ☺ High gain with no crosstalk, low noise figure, low loss
 - ☹ Gain function of λ , bigger dimensions, slow gain dynamic
- Other rare earth doped amplifiers x-DFA with peculiar characteristics (Praseodymium Doped Fluoride Amplifiers, Telluride Based ErbiumDoped Optical Amplifiers)



Linear Optical Amplifiers (LOA)

- Amplify multiple wavelengths
- Low gain transient
- Smaller size and lower power consumption than EDFA
- Suitable for metropolitan applications (switched environments)



Raman Amplifiers (RA)

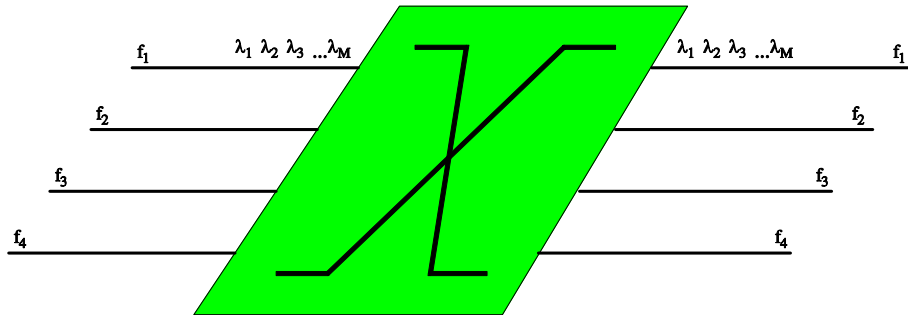
- Distributed Amplifier
- Strong laser light (pump 100s mW)
- 20 nm amplification bandwidth per pump
- Multiple pumps are possible
- Any fiber can be used to couple pump and signal
- Advantages:
 - Low noise figure
 - Low power signal
 - Reduced non-linear effects of fiber



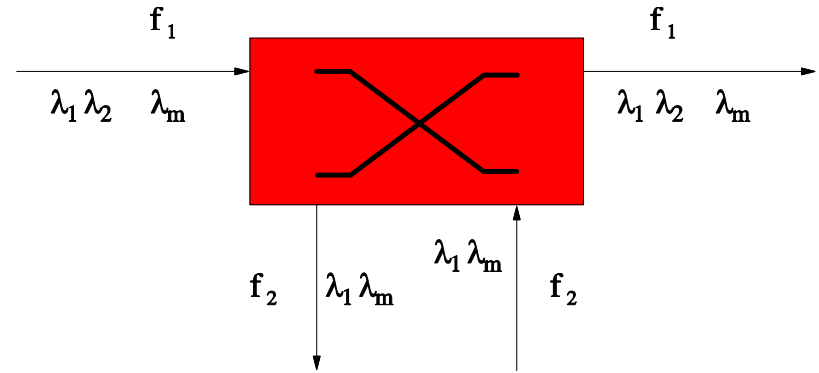
Wavelength Routing Nodes (WRN)

- OADM (Optical Add Drop Multiplexer)
- F-OXC (Fiber Optical Crossconnect)
- WR-OXC (Wavelength Routing Optical Crossconnect)
- WT-OXC (Wavelength Translating Optical Crossconnect)

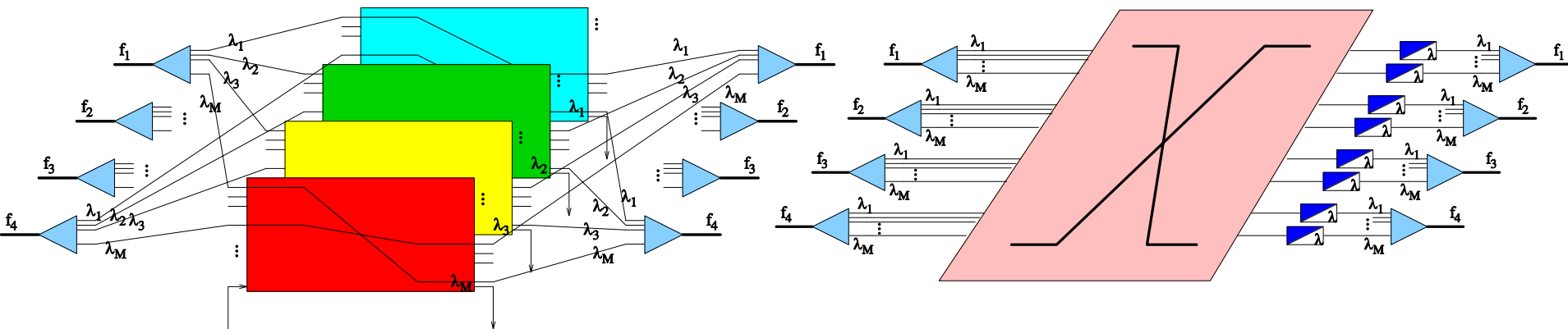
WRN Schematic Representation



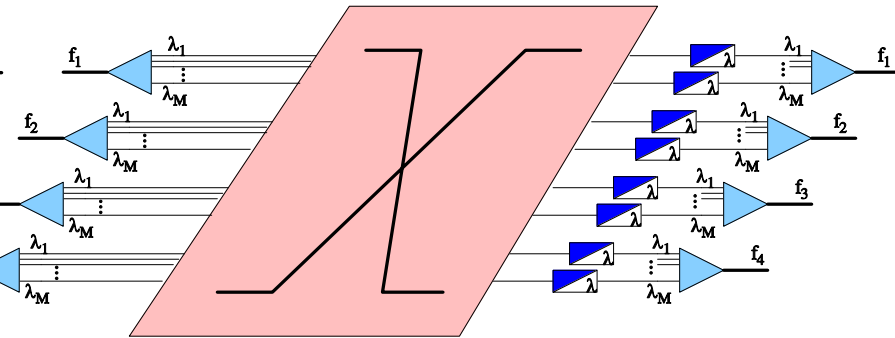
F-OXC



OADM



WR-OXC



WT-OXC



WRN Functions

- **OADM** typically 2x2 **F-OXC** with λ adding and dropping
- **F-OXC** fiber switching with λ adding and dropping
- **WR-OXC** wavelength and fiber switching without λ conversion
- **WT-OXC** wavelength and fiber switching with λ conversion



ITU and Optical Layer

- International Telecommunications Union agency of United Nations devoted to standardize international communications
- Optical Layer defined by ITU inside the ISO-OSI Data Link layer (Rec. G.805, G.872)
- OL provides *lightpaths* to higher layers
- *Lightpath*: point-to-point all-optical connection between physically non-adjacent nodes

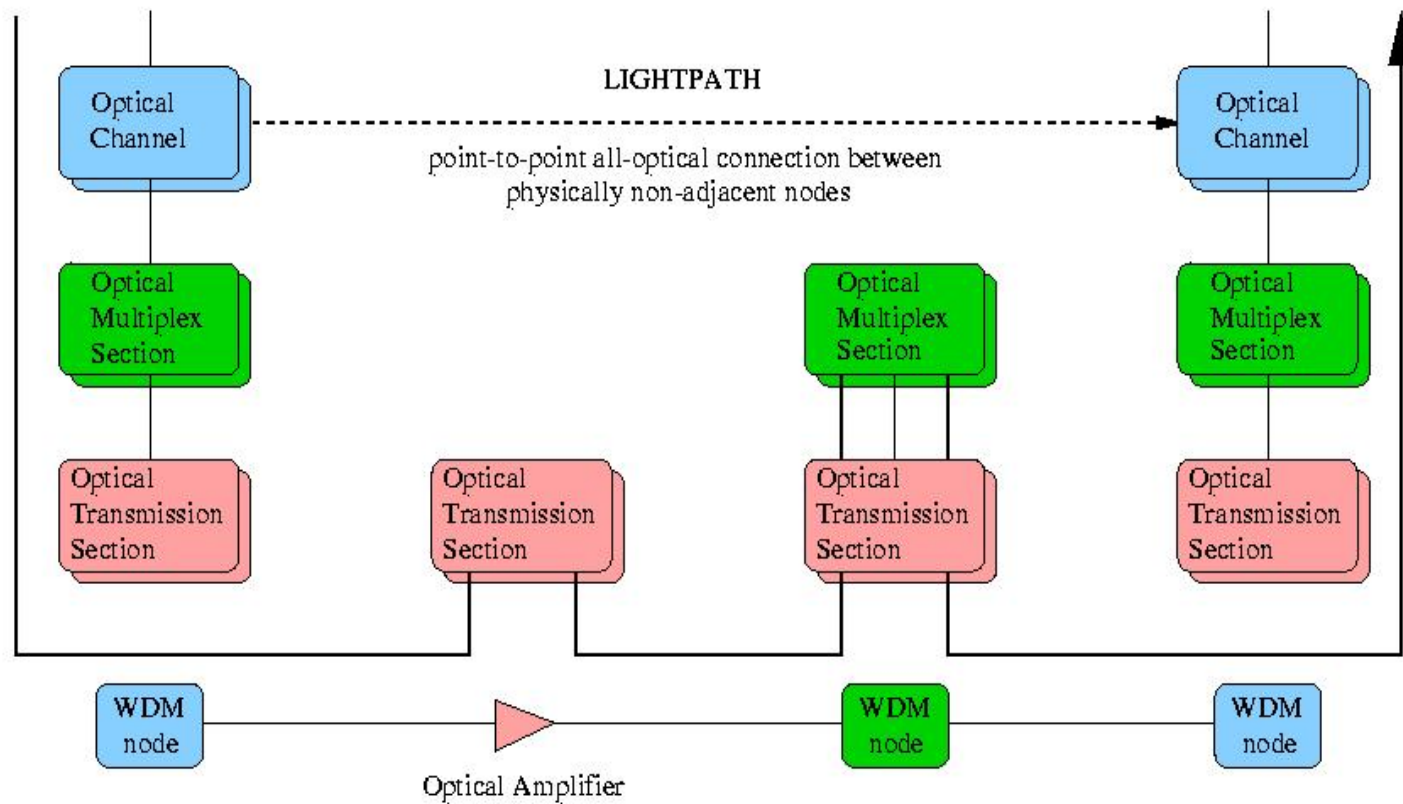


Optical Layer (OL)

Consists of:

- *Optical Channel (OCh)* sub-layer or *lightpath layer* \Rightarrow end-to-end route of the lightpaths
- *Optical Multiplex Section (OMS)* sub-layer \Rightarrow point-to-point link along the route of a lightpath
- *Optical Transmission Section (OTS)* sub-layer \Rightarrow link segment between two optical amplifier stages

Optical Sub-Layers





Inter-layer Design Issues

Issues in establishing, e.g., a lightpath :

- **OCh** layer \Rightarrow routing, protection, and management
- **OMS** layer \Rightarrow monitoring, multiplexing
- **OTS** layer \Rightarrow regeneration, amplification



Optical Network Techniques

- Static/Semi-static Lightpath
- Dynamic Lightpath
- Optical Packet and Burst Switching



Static/Semi-Static Lightpath

- Lightpath established when network is built
 - No active switches
 - No dynamic λ converters
 - Fixed routing pattern at the nodes
 - Logical topology on top of physical topology
- Periodic network reconfigurations
 - Active devices controlled manually or via signaling
 - Logical topology may be changed to best suit traffic characteristics



Static/Semi-Static Lighthpath Networks

- Design issues and the RWA problem
- Survey of network architectures
- Effect of transmission constraints
- Multicast in WDM networks
- OL protection and restoration mechanisms
- Testbeds



Optical Layer Dimensioning

- Each fiber can carry up to 128 λ 's each operating at 10 Gb/s [Chabt *et al.* '98]
- A lightpath demand matrix is given
- Demands are obtained by traffic models (e.g., traffic models for IP layer)



Static RWA Problem

- The **R**outing and **W**avelength **A**ssignment (**RWA**) problem:
given a physical topology and a set of end-to-end lightpath demands determine a route and a λ assignment for each request
- RWA (with no λ conversion) is a NP-complete problem [Chlamtac '92]
- Approximate and heuristic solutions available

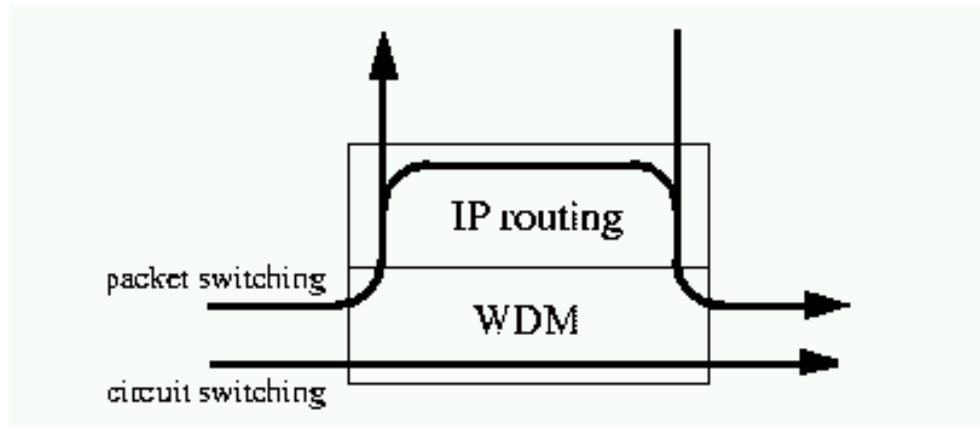


Dynamic Lightpath Networks

- Dynamic routing and channel assignment
- Network scenario and layering
- Intra-ring dynamic lightpath set up

Static Lightpath

- IP directly over WDM to reduce
 - complexity
 - end-to-end delay
 - transmission overhead





Dynamic Lightpath

- *Reconfigurable* networks
- **WT-OXC, WR-OXC**, and active components used
- More expensive than fixed networks
- Adaptive to varying traffic demands
- Restoration as opposed to protection



Dynamic Routing and Wavelength Assignment

- Logical connection (lightpaths) requests arrive randomly
- Network state:
 - all active connections with their optical path (route and wavelength assignment)
- Real-time algorithms needed to accommodate requests
- Delay set-up, blocking and fairness issues



Intra-Ring Dynamic RWA

- Problem: on-line **R**outing and **W**avelength **A**ssignment (**RWA**) of lightpaths
- Solutions:
 - Centralized control [ONRAMP]
 - Distributed control [LightRing]



Centralized Control

- Source node sends lightpath request to controller
- Controller checks on available resources and grants or rejects access
- If access is granted, controller must select wavelength for lightpath
- Controller keeps track of available resources



Wavelength Selection at Controller

- Random algorithm (RD)
- First-Fit algorithm (FF)
- Max-Sum algorithm (MS)
- Greedy algorithm with Wavelength Converter (WC)



Distributed LightRing (LR) Multi-token Control

- Controller is not required
- Nodes are updated on network status by means of a multi-token control
- One token per data channel
- Token transmitted on control channel
- Token control for on-demand lightpath establishment



Optical Packet Switching

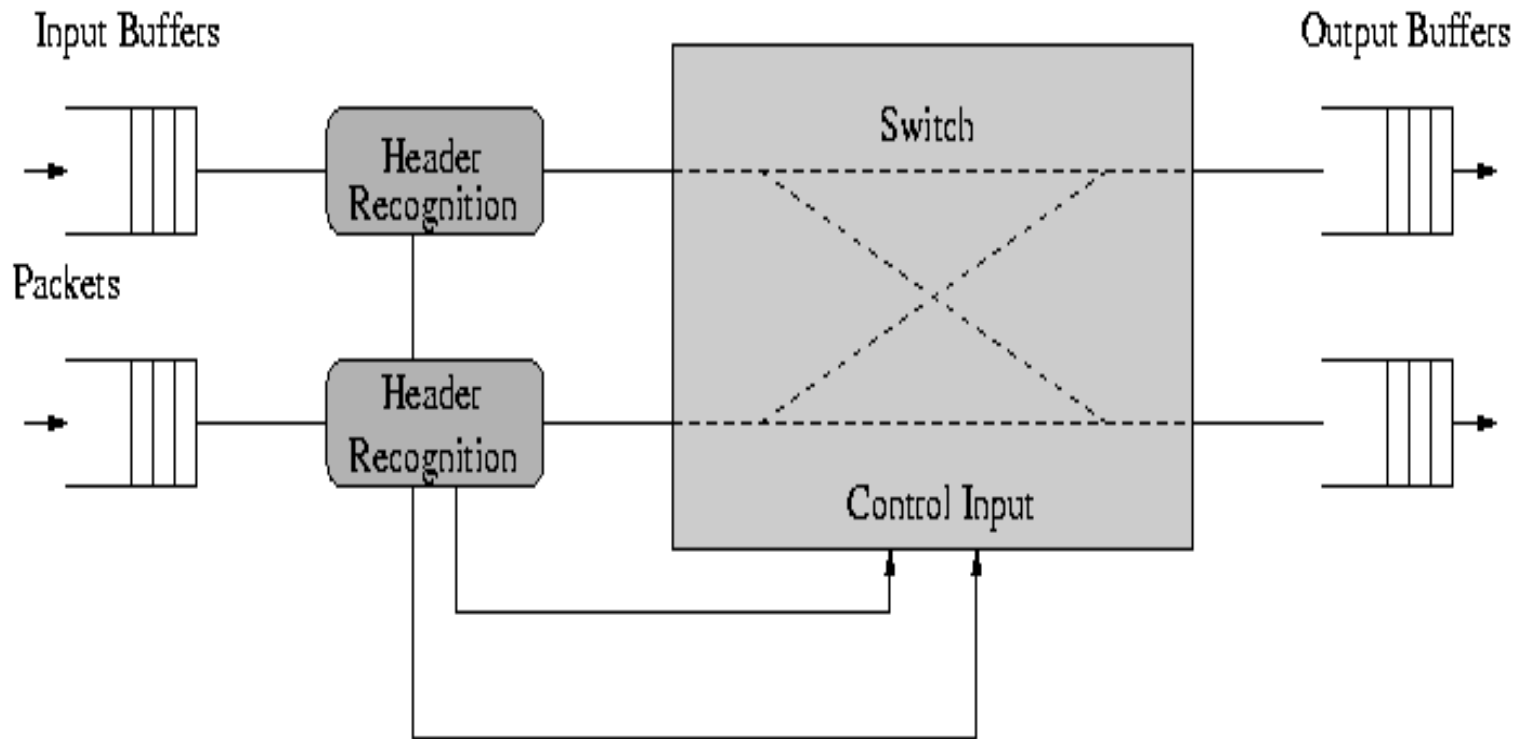
- Experimental phase
- Switch optically routes packets based on their header
- Enabling technologies
- Routing node structure
- Proposed solutions



Enabling Optical Technologies

- Multiplexing (bit and packet interleaving)
- Demultiplexing
- Synchronization
- Packet header detection
- Buffering
- Logical gates
- High speed switches

Routing Node Structure





Routing Node Functions

- Synchronization
 - utilization of variable delay lines
- Header Recognition
 - performed either optically or electronically while the remainder of the packet is optically buffered
- Buffering
 - *feed-forward* and *feed-back* delay lines structures
- Routing
 - *deflection* or *hot-potato* either with or without small input and output buffer



Optical Burst Switching (OBS)

- Packets are aggregated to form a single burst of data
- Burst is transmitted optically, in a bufferless network
- Reservation for network resources is performed by sending a control message that propagates ahead of the burst
- Reservation lasts only the burst duration



OBS vs. Optical Packet Switching

- OBS advantages
 - OBS more commercially viable technique because of switching speed and buffering
 - OBS can be designed to not require optical buffering
- OBS drawbacks
 - Burst switching schemes and burst size need to be studied



OBS vs. Optical Circuit Switching (Static/Semi-Static Lightpath)

- OBS advantages
 - More bandwidth flexible
 - Burst statistical multiplexing
- OBS drawbacks
 - Reservation policies required
 - Reservation contention



OBS Reservation Policies

- Centralized
 - Central controller handle all requests and grant access to network resources
- Distributed
 - The nodes coordinate themselves to handle resource contention

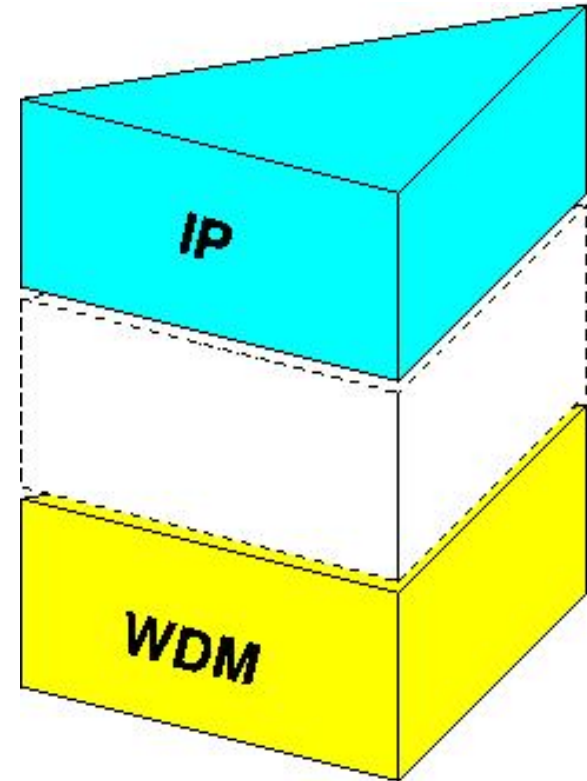


OBS Distributed Reservation Policies

- Tell-and-wait (TAW)
 - Request packet sent to destination and burst held at the source
 - If all switches along source-destination path can accommodate burst
⇒ burst transmitted
- Tell-and-go (TAG)
 - Request packet sent to destination
 - Burst sent immediately after request packet without waiting for confirmation
- Just-enough-time (JET)
 - Delay between request packet and the burst transmission
 - Delay set to be larger than request packet processing time at the nodes ⇒ no need for buffering at the intermediate nodes

IP over Optical Layer (WDM)

- Advantages
 - WDM \Rightarrow high bandwidth availability ($> 10\text{THz}$)
 - IP/WDM \Rightarrow elimination intermediate layers redundancies (IP/ATM/SONET/WDM)
- Drawbacks
 - IP and WDM layer coordination
 - Missing resilient transport layer (e.g., SONET/SDH)



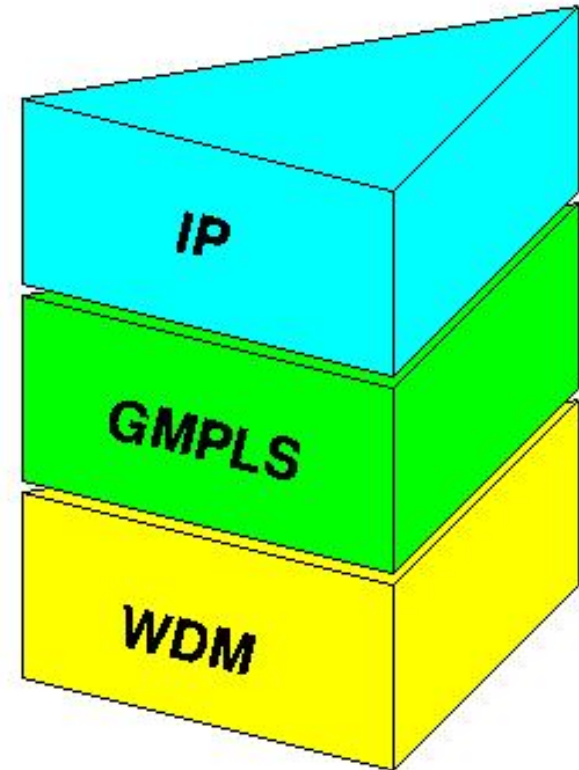


IP over WDM Coordination

- Overlay model
 - IP client
 - WDM server
 - Separated IP and WDM control planes
 - User to Network Interface (UNI) between IP and WDM
- Peer model
 - Integrated control plane (Generalized MultiProtocol Label Switching - GMPLS)

GMPLS Enabled Intelligent Optical Network Architecture

- IP over WDM
- IP/GMPLS control plane
 - Routing \Rightarrow IGP
(e.g., OSPF, OSPF-TE)
 - Signaling \Rightarrow GMPLS
(e.g., CR-LDP, RSVP-TE)
- WDM data plane
- Highly dynamic IP traffic characteristics \Rightarrow high flexibility in WDM





Generalized Multiprotocol Label Switching (GMPLS)

- Extends MPLS to provide the control plane (routing and signaling) for devices that switch in any of these domains
 - packet
 - time
 - wavelength
 - fiber
- The common control plane promises to simplify network operation and management by
 - automating end-to-end provisioning of connections
 - managing network resources
 - providing the level of QoS that applications expect



GMPLS Impact

- GMPLS provides the ability to automate network resource management and service provisioning of end-to-end traffic engineered paths
- Deployment of GMPLS-based nodes allow carriers to
 - avoid manual, lengthy, and costly manual provisioning of traditional SONET/SDH-based networks
 - automate the provisioning and management of the network
 - This could lower the cost of operation by several orders of magnitude (days or even minutes instead of week or months)



Evolution of GMPLS from MPLS

- Current IP-based MPLS networks are capable of providing advanced services such as
 - bandwidth-based guaranteed service
 - priority-based bandwidth allocation
 - preemption services
- MPLS place IP traffic on a defined engineered path, i.e., Label Switched Path (LSP)



MPLS Signaling

- Signaling to establish a traffic-engineered LSP is done using a label distribution protocol that runs on every MPLS node
- Different label distribution protocols
 - Resource reSerVation Protocol-traffic engineering (RSVP-TE)
 - Extended version of the original RSVP used in IP
 - Constraint-Based Label Distribution Protocol (CR-LDP)
 - Designed specifically for the purpose of piggyback and distribute label on its messages and to provide traffic-engineering capabilities



MPLS Routing

- Extension to existing IP link-state routing protocols
- Routing protocols provide real-time coordination of the current network topology, including attributes of each link
- MPLS extensions to OSPF and Intermediate System-Intermediate System (IS-IS) allow node to exchange extended information
 - (not only) network topology configuration
 - resource information and policy information
 - IP addresses
 - available bandwidth
 - load-balancing policies
- Constraint-based routing algorithms use this information to compute the optimal paths for the LSPs through the network



MPLS Evolution to GMPLS

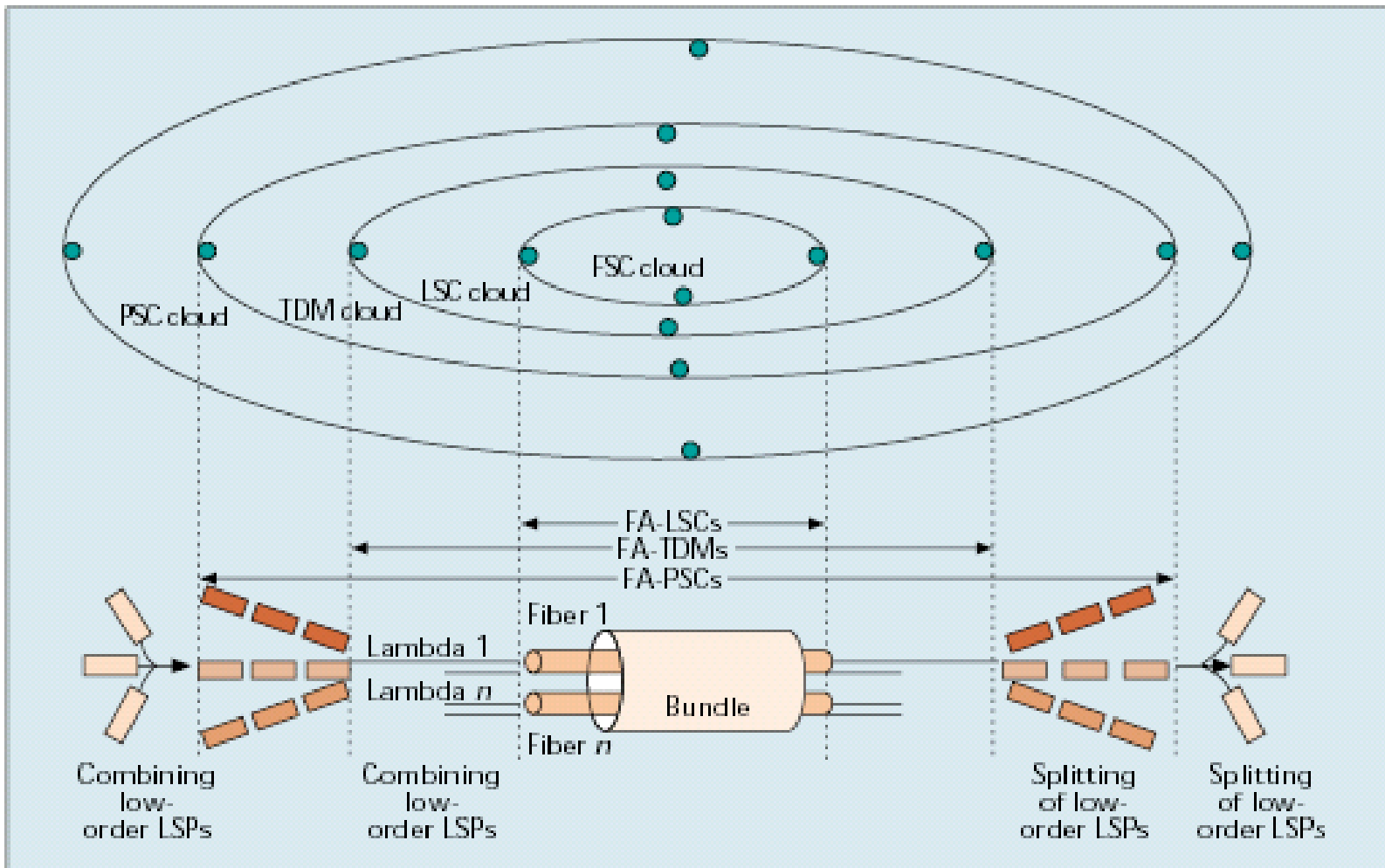
- MPLS suite of protocols has been extended to include devices that switch in
 - time
 - wavelength (e.g., DWDM)
 - space (e.g., Optical Crossconnect OXC)
- The extended MPLS is named Generalized MPLS (GMPLS)
- GMPLS-based networks are able to find and provision an optimal path based on user traffic requirements for a flow that potentially starts on an IP network, is then transported by SONET, and then is switched through a specific wavelength on a specific physical fiber



Switching Domains

Switching Domain	Traffic Type	Forwarding Scheme	Example of Device	Name
Packet, cell	IP, ATM	Label as shim header, virtual channel connection (VCC)	IP router, ATM switch	Packet Switch Capable (PSC)
Time	TDM/SONET	Time slot in repeating cycle	Digital cross-connect system (DCS), ADM	TDM capable
Wavelength	Transparent	Wavelength	DWDM	Lambda switch capable (LSC)
Physical space	Transparent	Fiber, line	OXC	Fiber switch capable (FSC)

GMPLS Domain





Required Modifications to MPLS

- New Link Management Protocol (LMP) to address issues related to link management in optical networks using photonic switches
- Enhancements to OSPF/IS-IS routing protocols to advertise availability of optical resources in the network (e.g., generalized representation of various link types, bandwidth on wavelengths, link protection type, fiber identifiers)
- Enhancements to the RSVP/CR-LDP signaling protocols for traffic engineering purposes that allow a label-switched path (LSP) to be explicitly specified across the optical core
- Scalability enhancements such as hierarchical LSP formation, link bundling, and unnumbered links



Enhancements to Routing

- MPLS label space is comparatively large (one million per port)
 - there are a relatively limited number of lambdas and TDM channels (tens to hundreds per port today, scaling to thousands over the next few years)
- MPLS LSPs can be allocated bandwidth from a continuous spectrum
 - Optical/TDM bandwidth allocation is from a small discrete set of values
- To handle the growth of traffic providers need to deploy hundreds of parallel fibers, each carrying hundreds of lambdas between a pair of network elements \Rightarrow sub-issues
 - The overall number of links in an optical/TDM network can be several orders of magnitude larger than that of an MPLS network
 - Assigning IP addresses to each fiber, lambda, and TDM channel is a serious concern, because of both the scarcity of IP addresses and the management burden
 - Identifying which port on a network element is connected to which port on a neighboring network element is a major management burden and highly error prone



Enhancement to Routing (2)

- Fast fault detection and isolation, and fast failover to an alternate channel are needed
- The user data carried in the optical domain is transparently switched to increase the efficiency of the network. This necessitates transmitting control plane information decoupled from user data



Enhancements to Signaling

- Enhancements to signaling (RSVP-TE and CR-LDP) allow the signaling and instantiation of optical channel trails in optical transport networks and other connection-oriented networking environment
- In order to set up LSPs between transparent devices, signaling requests need to be terminated \Rightarrow separate control plane transport network to convey signaling messages
- GMPLS allows the control plane to be physically diverse from the associated data plane



Enhancements to Signaling (2)

- Hierarchical LSP Setup
 - GMPLS supports the concept of Hierarchical LSP
 - Hierarchical LSP is when a new LSP is tunneled inside an existing higher-order LSP so that the preexisting LSP services as a link along the path of the new LSP



Enhancements to Signaling (3)

- Suggested Label
 - GMPLS signaling allows a label to be suggested by an upstream node
 - The suggested label is particularly valuable
 - when it is desired to set up a bidirectional LSP during paired transmit (Tx) and receive (Rx) interfaces to the same physical port (e.g., WDM transponders Tx/Rx pair)
 - to set up an LSP transiting certain kinds of optical switching equipment where there is some latency associated with configuring the switching fabric
 - in optical subnetworks with limited wavelength conversion capability where wavelength assignment can be performed by the originating node of an optical LSP to minimize blocking probability



Enhancements to Signaling (4)

- Bidirectional optical LSPs (lightpaths)
 - it is assumed that both directions of such LSPs have the same traffic engineering requirements, including fate sharing, protection, and restoration, and resource requirements
 - initiator = node that starts the establishment of and LSP
 - terminator = LSP destination node
 - In the basic MPLS architecture LSPs are unidirectional so in order to establish a bidirectional LSP two unidirectional LSPs in opposite directions must be established independently
 - Additional methods have been defined to allow bidirectional LSP's downstream and upstream data paths to be established using a single set of Path/Request and Resv/Mapping messages



Enhancements to Signaling (5)

- Key requirements for providing network reliability
 - quick reaction to failures
 - decisions made intelligently
- Notify message has been added to RSVP-TE for GMPLS to provide a mechanism for informing nonadjacent nodes of LSP-related failures
 - similar mechanism has not been defined for CR-LDP
- The Notify message does not replace existing RSVP error messages
- it differs from them in that it can be targeted to any node other than the immediate upstream or down stream neighbor