Generalized MPLS – An Overview

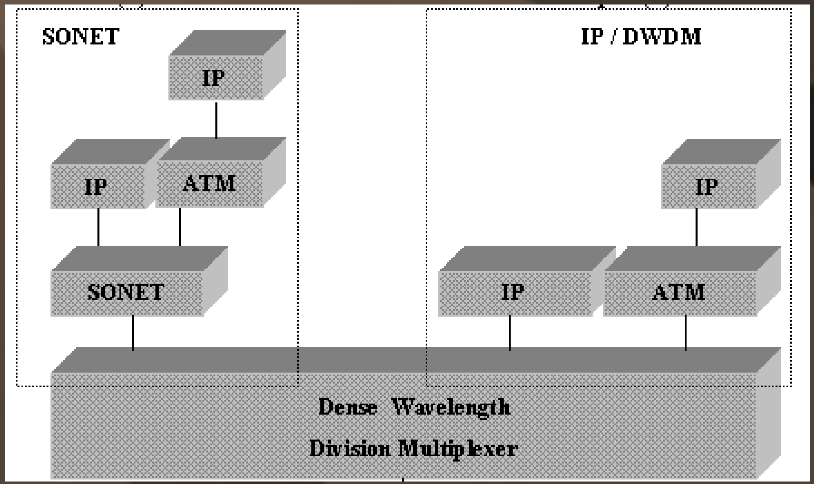
Overview

- An optical extension of MPLS
- Provides a control plane for devices that switch in time, packet, wavelength and fiber domains
- Aims to simplify the network operation and management

Overview

- Need to reconstruct network architecture
- SP needs to carry large volume of data in a cost-efficient way(optical)
- Trend is to converge IP with optical layer
- IP need to improve flexibility, intelligence and scalability

Network Structure



- Current data network layer
- Each layer limits the scalability (bottleneck)
- (ATM) QoS - overhead

MPLS

- Multiprotocol label switching
- Uses labels instead of routing tables
- Ip packets are assigned labels at the ingress by a LER (Label Edge Routers)
- Then forwarded along an LSP (Label Switched Path)
- LSR (Label Swithcing Router) makes a routing descision based on label

Pros

- Don't need to examine IP header
- Quicker than route lookups
- Can define a path trough network

Signaling

- LDP (Label Distribution Protocol)

1. RSVP-TE (Resource Reservation Protcol)
2. CR-LDP (Constrained based Routing LDP)

- Provide real-time coordination of current network topolgoy

MPLambaS

- Label can be mapped to color spectrum
- Packets can be linked directly to optical net.
- IETF extended MPLS protocol to handle:

    -FSC (Fiber Switch Capable)

    -LSC (Lambda Switch Capable)

    -TSC (TDM – Time Division Multi. -Switch capa.

    -PSC (Packet Switch Capable)

Differences

- GMPLS
- Focus on control plane
- PSC, FSC, LSC, TSC
- Label – arbitrary length

- MPLS
- Focus on data plane
- PSC
- Label – 32 bit

G-Label (Generalized Label)

- To deal with widening scope of MPLS new labels are required
- Labels for FSC, LSC, TSC, PSC
- Specification

-Values only have significace between two neighbours

- Does not identify which class it belongs(implicit)
- Non hierarchical, single level
- Carries a varible length label parameter

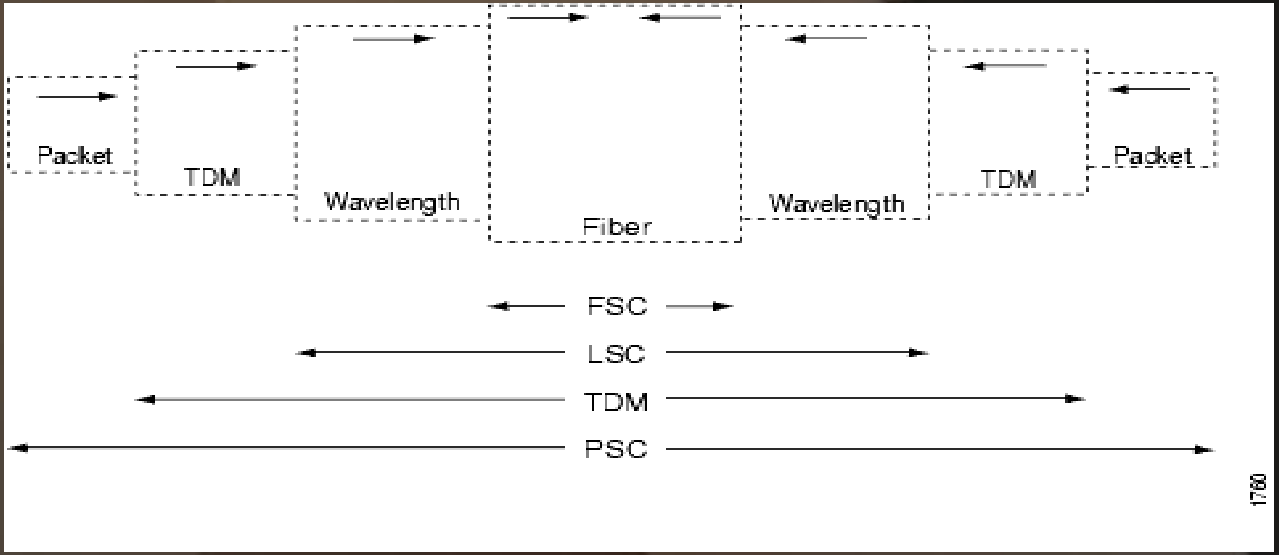
- Label value implies bandwith

Characteristics

- Data must be associated with a label type
- Five different types:

- MPLS Labels (MPLS, FR, ATM)
- Fiber Labels (nr spesify which fiber to use)
- Wavelength Labels (to allocate a wavelength to requested flow)
- Waveband Labels (id, upper lower wavelengths of bundle of wavelength)
- Time-slot Labels (to allocate time slots to a flow)

GMPLS Hierarchy



- Nesting one G-LSP inside another
- Better scalability and flexibility

Interface

- PSC (Packet Switch Capable)

- Recognizes paket/cell boundaries
- Forward data based on header

- TSC (TDM Switch Capable)

- Forwards data based on time slot in a repeating cycle

- LSC (Lambda Switch Capable)

- Forwards data based on wavelength

- FSC (Fiber Switched Capable)

- Forwards based on position in real world physical space

GMPLS protocols

- **Control plane** – a set of protocols that is responsible for setting up the data plane. These include: routing protocols, routing databases, and signaling protocols.
- **Data plane** – is a forwarding path in the Label Switching Router
- **Signaling protocols** are responsible for setting up, modifying, and removing LSP information from the data plane.
- Unlike in IP networks, **routing in MPLS/GMPLS** networks means distribution of networking information among LSRs, so that they have a complete converged view of the network. This information is used to compute LSPs in a GMPLS network.

GMPLS protocols

Separation of data and control planes:

- In IP-MPLS networks the control packet of the routing or signaling protocols goes through the same channel as data packets = inband signaling.
- This is not suitable for GMPLS (ex. In optical networks this would mean that LSRs need to continuously examine data stream to fetch controlling frames – would slow processing speed)
- Decision = to use **out-of-band signaling** (specific time slot, wavelength, or just another cable)

GMPLS protocols

Addressing in control plane:

- Communication and addressing in control plane is IP based. It means that LSRs have IP addresses, and control frames are destined to this addresses.
- Out-of-band signaling → links should be identified (at least LSR scope uniqueness).
- Signaling message carries two addressing sets: “to which LSR”, “concerning what links”.

GMPLS protocols

LINK MANAGEMENT PROTOCOL (RFC 4204)

- point-to-point protocol
- Runs on top of UDP (port 701)
- Between adjacent nodes
- LMP enables communication between nodes for routing, signaling, and link management by setting up control channels

LMP functions:

- Control-channel management
- Link connectivity verification
- Link property correlation
- Fault management

GMPLS protocols

LINK MANAGEMENT PROTOCOL

Control channel management:

- The IP address on the far end of the control channel must be known (manual configuration or automatic discovery) to setup a channel.
- Config/ConfigAck exchange discovers peer's IP address and establishes LMP adjacency relationship automatically. The control channel parameters negotiation is done during this exchange.
- Adjacency relationship requires at least one bidirectional control channel (multiple can be used simultaneously) between peers
- Control channel maintenance is done by periodic Hello messages

GMPLS protocols

LINK MANAGEMENT PROTOCOL

Link connectivity verification = automatic TE link establishment

- An LSR knows its local IDs for data links that are connected to a peer. Does not know how a peer identifies these data links. Does not know about the state of the data links.

- Link IDs mapping between peers should be made in order to have a common unambiguous association between a link and a link ID in order to understand signaling messages (concerning which links ?)received from a peer

- verified by exchanging Test messages over each of the data links associated with the TE link. Test message contains sender’s local data_link_ID and Verify_ID, received previously from a peer. The peer looks at Verify_ID to understand from which adjacent LSR the message comes. The peer answers with TestStatusSuccess that contains peer’s local data link ID and the data link ID from the Test message.

GMPLS protocols

LINK MANAGEMENT PROTOCOL

Link property correlation – a process of synchronizing properties of data channels (ex. supported switching and encoding types, maximum bandwidth that can be reserved, etc.) between peers and aggregation of data channels to form one TE link.

Done by exchange of LinkSummary and LinkSummaryAck. LinkSummaryNack – if the peer does not agree on some parameters, + contains proposal for other values. A new LinkSummary message is sent after LinkSummaryNack.

GMPLS protocols

LINK MANAGEMENT PROTOCOL

Fault management – procedure to rapidly localize a failure and to issue notification messages → results in fast recovery

- A single data channel, multiple data channels, or an entire TE link can fail.
- To locate a fault, up to a particular link between adjacent nodes, a downstream node (in terms of data flow) that detects data link failures will send a ChannelStatus message to notify its upstream peer.
- Once the failure has been located, the signaling protocols may be used to initiate path protection

GMPLS protocols

Routing protocols in GMPLS (RFC 4202)

- Unlike in IP networks, **routing in MPLS/GMPLS** networks means distribution of networking information among LSRs, so that they have a complete converged view of the network. This information is used to compute LSPs in a GMPLS network.
- OSPF-TE and IS-IS-TE with extensions for GMPLS are used
- Link state information + information in MPLS extensions is not enough → routing extensions for GMPLS to carry additional data

Why link-state protocols?= The router that creates the TE path must know all topology information to see all the possible paths and characteristics of these paths [*]. Links –state protocol is suitable since all routers have a common complete view of the network. A distance vector router forwards only the best route (from its point of view) to its adjacent neighbors = no information on alternative paths.

[*] Luc De Ghein, “MPLS Fundamentals”, Cisco Press, 2006

GMPLS protocols

GMPLS routing enhancements:

- *Unnumbered links support*: carrying information about identifiers of the link (local ID + remote ID). Numbered link has network-scope unique 32-bit IDs on both peers (ex. IPv4 addresses), unnumbered link has LSR-scope unique IDs.
- *Link protection type*: represents protection capability that exist for a link.

Extra traffic	**Unprotected**	**Shared**	**Dedicated 1:1**	**Dedicated 1+1**	**Enhanced**
This link is used for protection	No link is protecting this link	There are extra traffic links that protect this link	Protection link is not active	Same traffic on a protection link. Protection link is not advertised	Protection more reliable than Dedicated 1+1

GMPLS protocols

GMPLS routing enhancements:

- *Shared Risk Link Group information*: SRLG = a group of links that share resource whose failure affects all links. A link may belong to multiple SRLGs.

- *Interface Switching Capability Descriptor*: describes switching capability of an interface. Interface can have more than one switching capability.

    Example = "fiber link carrying a set of lambdas that terminates on an LSR interface that could either cross-connect one of these lambdas to some other outgoing optical channel, or could terminate the lambda, and extract (demultiplex) data from that lambda using TDM, and then cross-connect these TDM channels to some outgoing TDM channels" [RFC 4202]

GMPLS protocols

GMPLS TE path computation:

- Routing information distributed by OSPF-TE or IS-IS-TE is stored in Traffic Engineering Database.
- Traffic Engineering Database (TED) – contains all TE links and their respective attributes
- Protocols to calculate the most optimal path based on information in TED*: (ex.* Constrained Shortest Path First (CSPF) is used in OSPF and IS-IS)
- *Calculation output =* Explicit Route Object, used by RSVP-TE to signal the LSP

GMPLS protocols

Signaling:

- To have two protocols RSVP-TE and CR-LDP with the same functionality is unreasonable (RFC 3468) → all work on CR-LDP was stopped
- Resource Reservation Protocol Traffic Engineering (RSVP -TE) is de facto the standard protocol for setting-up and managing LSPs.

In an MPLS network:

- *RSVP-TE is responsible for managing only PSC-LSP*
- *assigning a label doesn't mean assigning network resources, it is just to setup LSP*
- *Unidirectional LSP*

In a GMPLS network:

- *except packet layer, assigning labels means assigning network resources (time slot, wavelength)*
- *RSVP-TE is responsible for managing TDM-, LSC-, and FSC-LSP besides packet switched capable LSP*
- *Bidirectional LSP*

GMPLS protocols

GMPLS RSVP-TE (RFC 3473) Signaling:

- LSP setup ≈ exchange of labels.
- PATH and RESV messages to signal a path.
- Downstream on demand label allocation
- The head router computes the best path through the network based on bandwidth, specific LSRs, links, and other constraints (provided by OSPF-TE or IS-IS-TE)
- PATH message contains Label-request (request for generalized label)
- RSVP Notify messages - a mechanism to inform non-adjacent nodes of LSP related events. (ex. failures)

GMPLS protocols

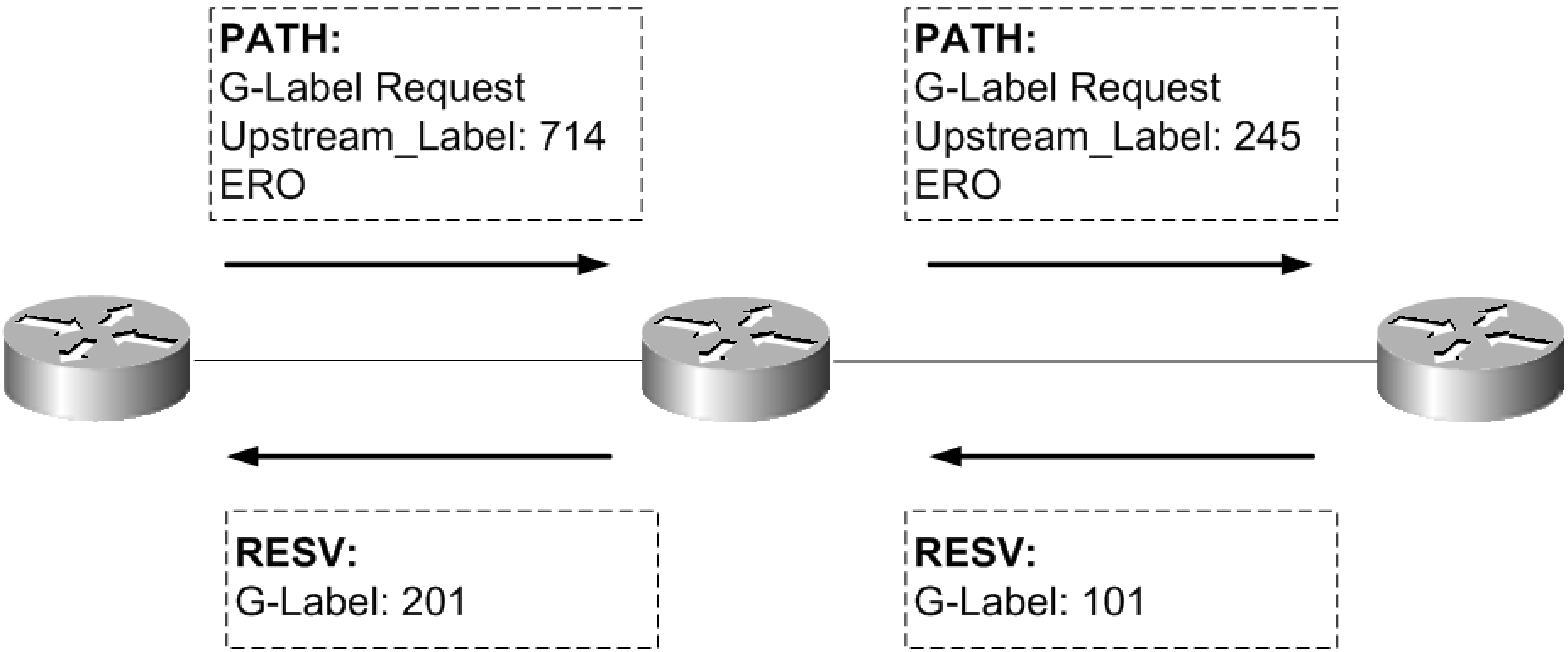
RSVP-TE Signaling: Generalized Label request

LSP Encoding Type (8 bits)	Switching Type(8 bits)	G-PID (16 bits)

- LSP Enc. Type – defines encoding for data in LSP (ex. Packet, Ethernet, lambda, fiber). Represents the nature of LSP and not individual links. An egress node and transit nodes along the path must check if they support requested encoding. If not – generate a PathErr message
- Switching Type – indicates which switching type is used (ex. PSC, TDM, LSC, FSC). LSRs along LSP must check if they support requested switching type.
- G-PID – identifies payload carried in LSP

GMPLS protocols

RSVP-TE Signaling: bidirectional LSP setup



Signaling is extended (+ Upstream_Label)to enable bidirectional LSP setup.

GMPLS protocols

References:

1. *A. Farrel, I. Bryskin, "GMPLS* Architecture and Applications*",* Morgan Kaufmann Publishers, 2006
2. *N. Yamanaka, K. Shiomoto, E. Oki, "*GMPLS Technologies: Broadband Backbone Networks and Systems*",* CRC Press, 2006
3. Luc De Ghein, "MPLS Fundamentals", Cisco Press, 2006
4. D. V. Cunha , G. Bressan, "Generalized MPLS - an overview", ConTEL International Conference on Telecommunications, June 2003, pp.435 – 442
5. L. Andersson, G. Swallow, "The Multiprotocol Label Switching (MPLS) Working Group decision on MPLS signaling protocols", RFC 3468, February 2003
6. L. Berger, "GMPLS Signaling RSVP-TE Extensions", RFC 3473, January 2003
7. K. Kompella, Y. Rekhter, "Routing Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)", RFC 4202, October 2005
8. J. Lang, "Link Management Protocol (LMP)", RFC 4204, October 2005

Lightpath routing in optical networks (Wavelength-routed optical networks)

- A lightpath – end-to-end optical WDM channel that spans multiple fiber links
- First generation WDM networks provided only point-to-pint physical links which were statically configured *[1]*
- Introduction of reconfigurable Optical Add-Drop Multiplexers and Optical Crossconnects made possible management of lightpaths and dynamic topology change → result = new network level technology – wavelength-routing networks
- Characterized by end-to-end circuit-switched connection-oriented lightpaths

[1] B. Mukherjee, "Optical WDM Networks", Springer Science+ Business Media, 2006

Wavelength-routed optical networks

- Unscalable approach: in a network that has *n* nodes to provide each node with *n – 1* transceivers, and for each pair of nodes provision unique wavelength. Thus we have no networking problem to solve (just choose the best path in terms of hops or something else). However, we require $n \cdot (n-1)/2$ wavelengths!
- Problem = wavelengths is a limited resource
- Routing and wavelength assignment problem (RWA) = for a set of lightpaths that need to be established, to compute the most optimal routes from all available and to determine the wavelengths that should be assigned to each lightpath in such a way that in total the minimum number of wavelengths is used *[2]*.

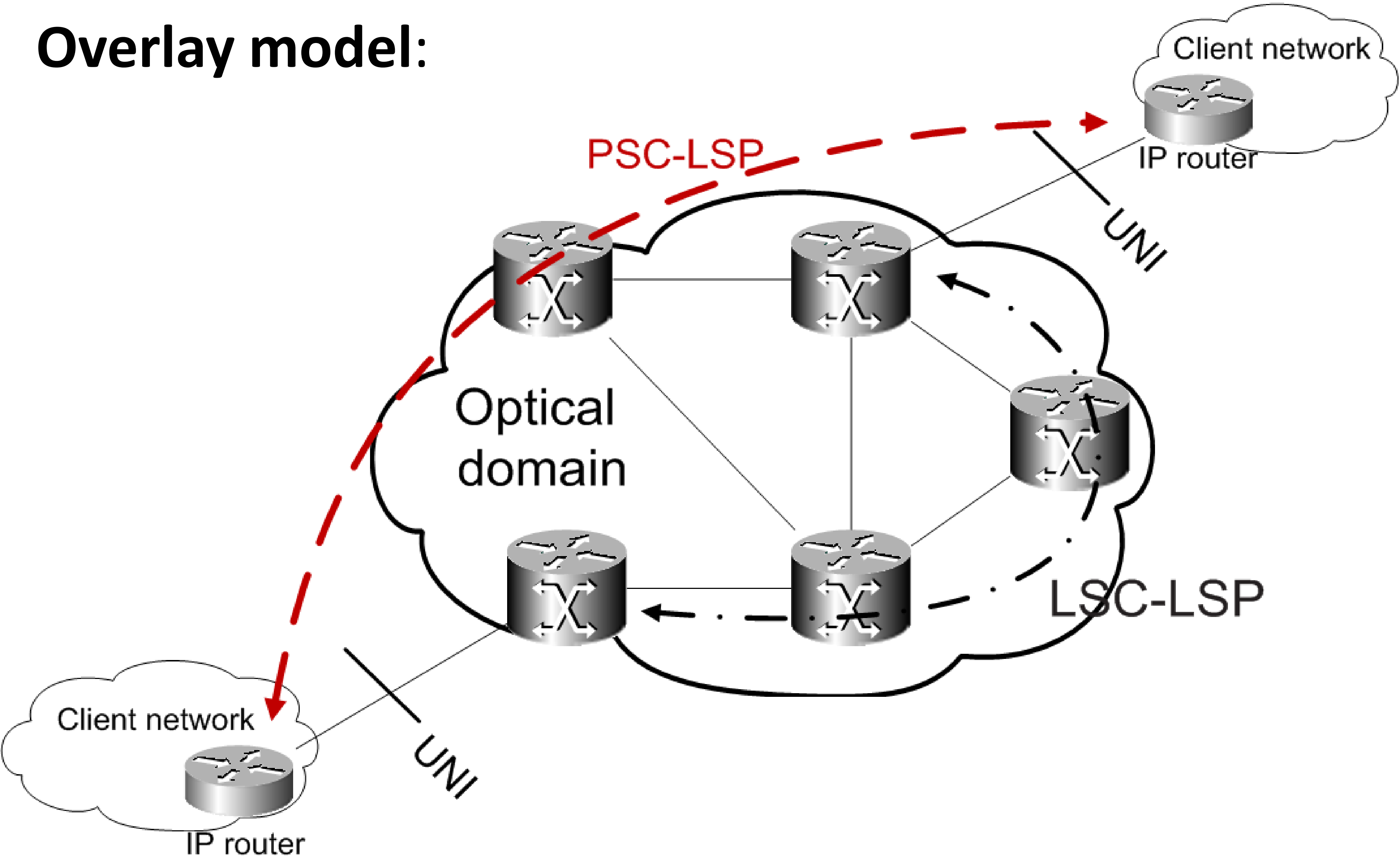
[2] R. Ramaswami, K. Sivarajan*, "*Optical Networks: A Practical Perspective*", 2nd Edition,* Morgan Kaufmann Publishers, 2009

Wavelength-routed optical networks

- To solve RWA problem we need a control plane that will compute, setup, and manage lightpaths
- To manage wavelength-routing networks the GMPLS control plane is used
- Two models are used for integration of IP and optical-networks using GMPLS:
  - Overlay model
  - Peer model

Wavelength-routed optical networks

Overlay model:



Wavelength-routed optical networks

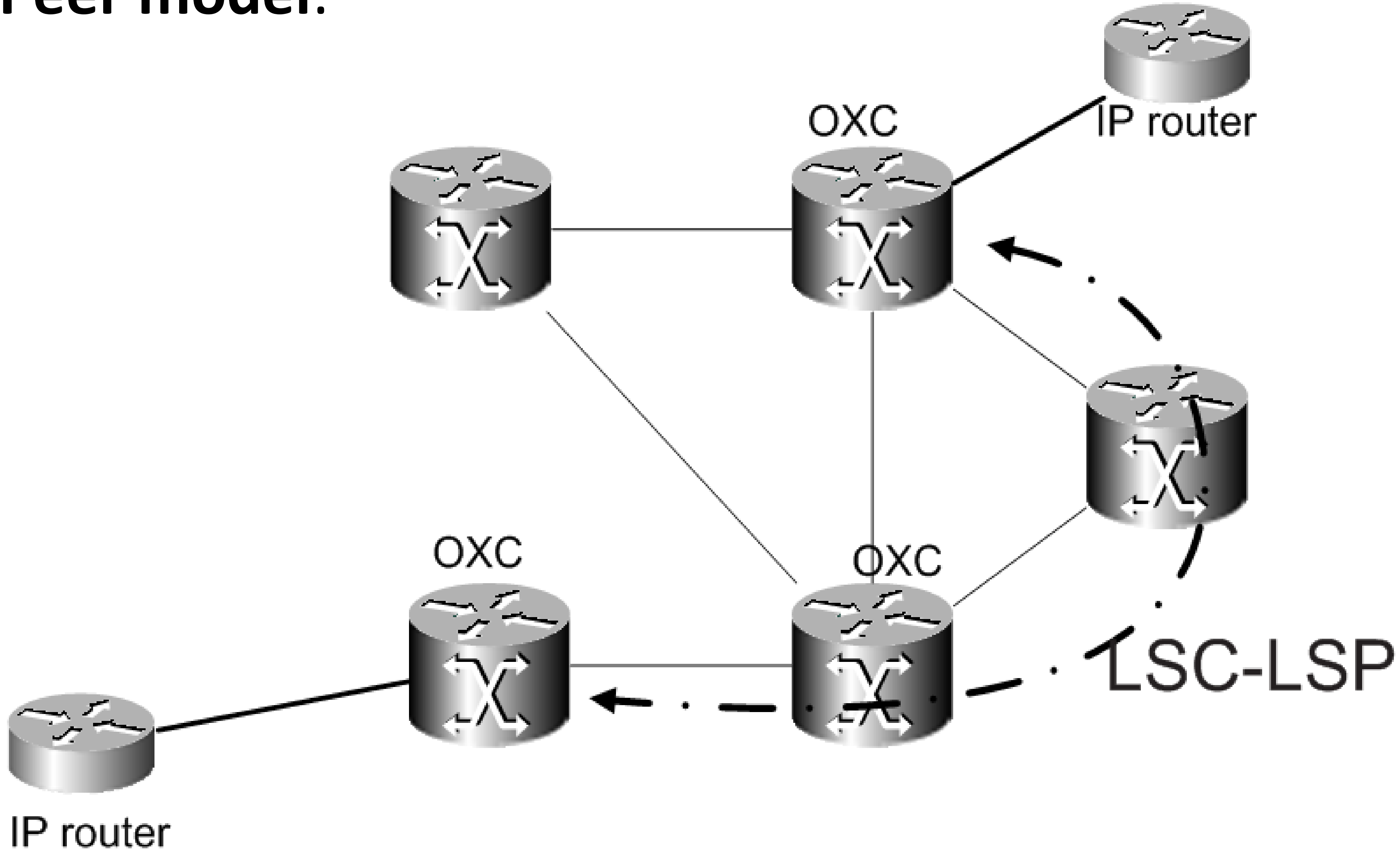
Overlay model:

- It is a client-server model where IP layer is a client of the optical domain
- Optical domain provides end-to-end PSC-LSP between IP domains
- IP layer does not know topology of optical layer and vice versa
- IP control plane interacts with an optical control plane via UNI (user network interface)
- Separation of the GMPLS control plane into two layers does not allow to fully use GMPLS functions *[3]*.

*[3] N. Yamanaka, K. Shiomoto, E. Oki, "*GMPLS Technologies: Broadband Backbone Networks and Systems*",* CRC Press, 2006

Wavelength-routed optical networks

Peer model:



Wavelength-routed optical networks

Peer model:

- IP routers are peers with OXCs
- IP routers and OXCs are controlled by a single control plane
- Have a common IP addressing space for control plane
- IP routers have a complete view of the whole (including optical domain) topology
- Possible to take full advantage of hierarchical LSPs and multilayer TE, since we have one control plane *[4]*
- link states of all the layers are advertised to each node → a lot of information need to be exchanged in the control plane + path computation will be more difficult

*[4] N. Yamanaka, K. Shiomoto, E. Oki, "*GMPLS Technologies: Broadband Backbone Networks and Systems*"*, CRC Press, 2006

Wavelength-routed optical networks

GMPLS-based lightpath routing framework:

- OSPF-TE or ISIS-TE gather topology information (including link properties and resource constrains) in Traffic Engineering Database (TED)
- One of the available constraint-based RWA algorithms is used to solve routing problem based on the information in TED
- RSVP-TE is used to signal a lightpath setup

Content

1. Optical Routing issues and challenges

2. Resource/Topology Discovery

3. Lightpath Computation issues and challenges

Optical routing issues and challenges

- The differences between IP-based and optical networks.
  - Hop-by-hop basis vs. end-to-end connection (lightpath)
  - Routing protocols not involved with data forwarding
  - Separation of control plane and data plane topology
    - out-of-band channels (ex. TDM or Optical Supervisor Channel OSC)

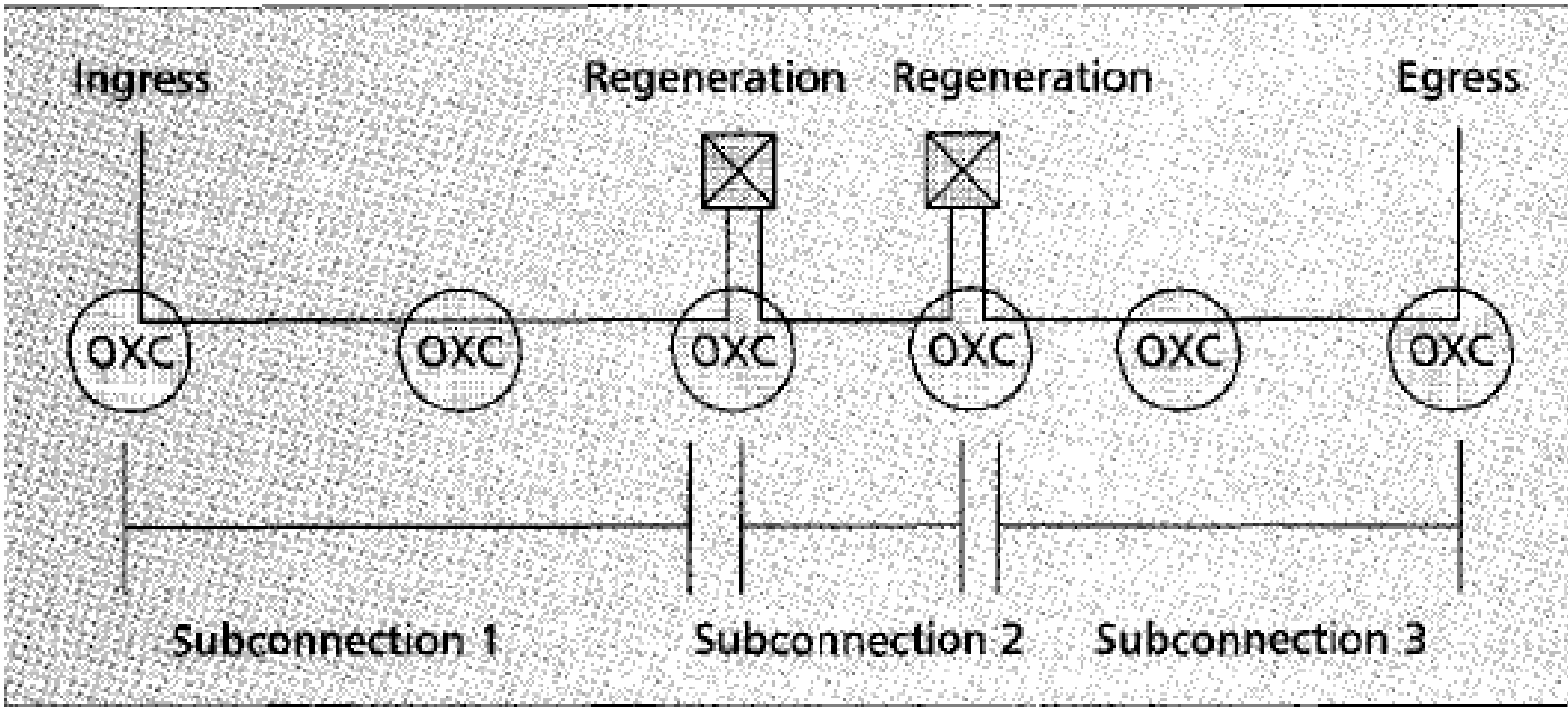
Physical Layer Constraints

- Transparent networks suffer from various analog transmission concernes
  - Require provisioning with respect to state information advertisment/update
    - Physical constraints based on nonlinearities : power budget at source node, polarization mode dispersion PMD, amplifier spontaneous emission ASE, cross-talk between channels, etc.
- Usually assumed that routes have adequate signal quality

Solutions based on physical constraints

1. Partition all-optical networks in subnetworks of limited size
2. In case of large domain transparency, include various physical layer constraints into the state information
3. If the physical layer information increase the amount of information to be distributed, use the concept of subconnections

Optical subconnections



Optical subconnections

- The endpoints are DWDM transmitter and receiver, terminations of optical-electronic conversions.
  - The subconnection is defined by the need for regeneration
- all-optical layer routing determines the subconnections that will be interconnected to form the LSP
- Optical-electronic layer treats them as adjacencies and advertises them through OSPF/IS-IS

Wavelength Conversion Constraints

- In transparent optical networks, wavelength continuity has to be preserved end-to-end.
- A single wavelength has to be available on all fiber links on the selected path.
  - Scalability problems
- Probe along a path for available wavelengths
  - Modification to the existing routing logic.

Diversity Routing Requirements

- Service survivability : maintain an acceptable level of performance in case of network/equipment fault events.
- Survivability schemes:
  - Protection, provisioned based on user demand, ranging 1+1 to 1;1 to 1:n
  - Restoration, reactive techniques to recover failed connections, compute routes dynamically after failure.

Diversity Routing Requirements

- Diversity routing
  - 2 lightpaths are diverse if they don't have a single point of failure
  - A new link attribute shared risk link group SRLG, includes links within an optical domain
  - A general shared risk group SRG includes links, nodes and domains in case of interdomain routing.

Interdomain Routing

- GMPLS framework, topology and resource discovery are limited to a single domain
- Mapping areas and AS to domains concepts
- Type of information flooded between domains
- Interdomain reachability between end-users is required
- BGP constraints the knowledge of diverse routes
  - Only best routes advertised with eBGP

Summary

- Challenges and issues facing lightpath routing:
  1. Physical layer constraints
  2. Wavelength resource information
  3. Wavelength continuity requirement
  4. Explicit routing vs. per-hop routing
  5. Route computation algorithms
  6. Diversity routing
  7. Interdomain routing

Resource/Topology Discovery

- Resource and topology discovery is the procedure of determining the topology and resource state of all links in a network.
- Three processes:
  1. Neighbor discovery (data/control channel)
  2. Link viability monitoring (data/control channel)
  3. Routing and distribution (control channel)

Neighbour discovery

- Data plane topology can be discovered:
  1. Static configuration
  2. Link Management Protocol (LMP)
     - Between neighbours
     - Maintain control channel connectivity
     - Verify data-bearing link connectivity
     - Isolate link/fibre/channel failures
- Control plane topology discovery by running IGP

Link Viability Monitoring

- In IP-based networks are used protocol control messages
  - KEEPALIVE periodic exchange on a neighbour basis.
- Control channel monitoring uses Hello msg of traditional routing protocols.
- Data channel monitoring is complicated:
  1. Control/data planes are decoupled
  2. May be impossible to send/receive control information on all the links

Link Viability Monitoring

- LMP uses PING-type test messages over data-bearing links in opaque networks
- Vendor specific proprietary mechanisms in transparent networks

Routing and Distribution

- Enhanced IP link state routing protocol through opaque LSA mechanisms
  1. Optical resource information
     - Wavelength resource information (id, frequency, availability and bandwidth)
     - Physical layer constraints (PMD, ASE, etc)
     - SRLG information
     - Link protection information (several types are defined: extra or lower-priority traffic, unprotected, shared, dedicated 1:1, dedicated 1+1)

  2. Traffic Engineering resource information

Lightpath Computation Issues and Challenges

- Lightpath vs. generic IP path
  1. Is defined by nodes, links and *channels*
  2. Consider various physical constraints when computing the valid lightpath
  3. Is required to compute explicit end-to-end routes in the form of explicit route objects (ERO) that include all the nodes, ports and wavelength along the route.
  4. Produce diverse routes

Route selection and wavelength assignment

- The RWA problem of efficiently managing optical network resources
- Differs from topology design because this last one deals with static long-terms constraints
- Divide and conquer :
  - Route selection
  - Wavelength assignment

Route selection problem

- Route selection:

  1. Fixed, choose a fixed route for each src-dst pair based on the SPF algorithm

  2. Fixed-alternate, select a route among a number of predetermined routes

  3. Adaptive, select a route based on the state of the network at the time of the lightpath request

Wavelength assignment problem

- Heuristic algorithms, mostly used and better performance:
  - Relative capacity loss (RCL)
  - Distributed relative capacity loss (DRCL), suited for distributed control and adaptive routing
- Label set in GMPLS framework, limit the label (wavelength) choices of the downstream nodes

Wavelength Continuity

- The constraint of wavelength continuity in all-optical with no wavelength conversion capability networks
    1. Decompose the network into layers that represent the connectivity for a particular wavelength
        - Scalability issues
    2. Adding optical-electronic converters and/or optical-switches with wavelength conversion

Centralized vs. Distributed

- Centralized
  - Traditional approach
  - Static configurations or infrequently changes
  - Easily manipulated
  - Common Open Policy Servers (COPS)
- Distributed
  - CSPF RWA algorithm
  - Scalable, adaptive to failures

Diverse Path with SRLG constraints

- Pre-computed multiple end-to-end diverse lightpaths for protection
- The SRLG constraint, implies a lower probability of simultaneous lightpath failure
- Dynamic SPF for path recalculation and reoptimization
- The lightpath computation is still vendor proprietary unlike the standardized GMPLS routing and signalling control plane

Conclusions

- Lightpath routing in optical networks is a complex process that can be partitioned in several steps under the GMPLS framework.
- Optical networks pose unique consideration and constraints.
- IGPs need to be extended to support the network specific information.
- New lightpath computation algorithms to be developed.