Wavelength Routed Optical Networks

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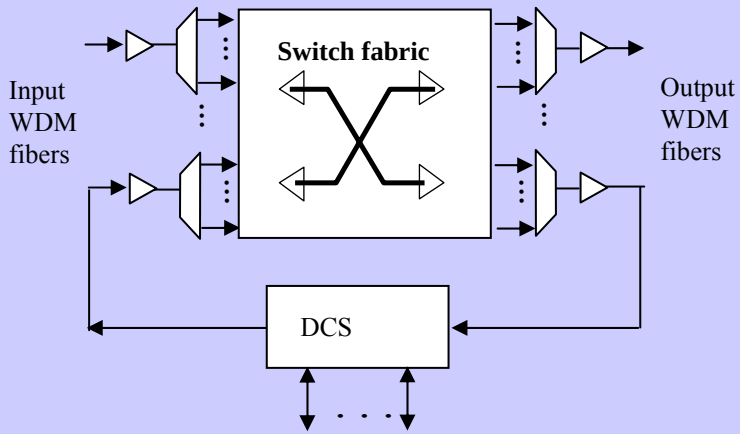
TOPICS

- Wavelength routing networks
- Protection schemes
- WDM rings

A wavelength routing network

This is an optical network that consists of OXCs interconnected by WDM fibers, with each fiber consisting of W wavelengths

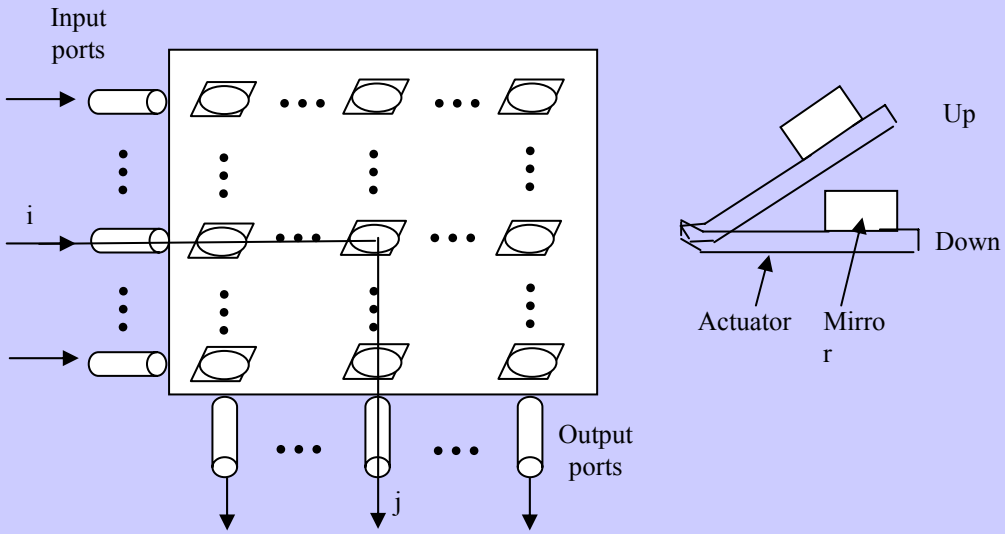


Switch technologies

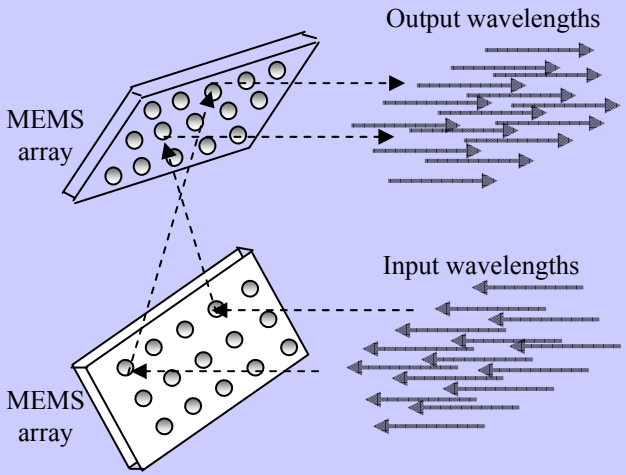
Several different technologies exist:

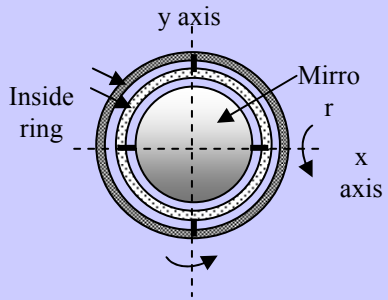
- *micro electronic mechanical systems (MEMS)*
- *semiconductor optical amplifiers (SOA)*
- *micro-bubbles*
- *holograms*
- Also, 2x2 directional coupler , such as the *electro-optic switch*, the *thermo-optic switch*, and the *Mach-Zehnder interferometer*, can be used to construct large OXC switch fabrics

2D MEMS switching fabric



3D MEMS switching fabric

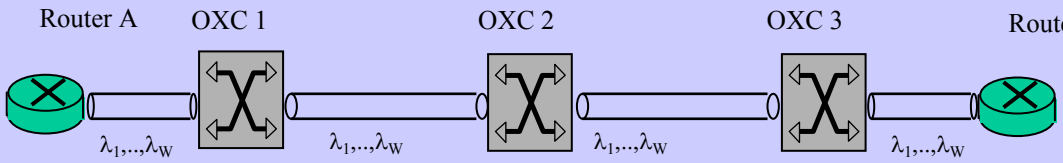




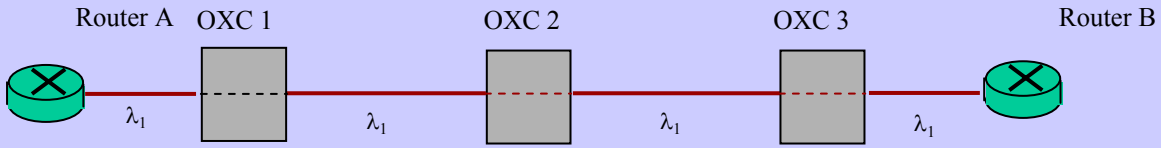
Lightpaths

- Wavelength routing networks are circuit-switched networks.
- In order for a user to send data to a another user, a connection has to be first setup.
- This connection is a circuit-switched connection and it is established by allocating a wavelength on each hop along the connection's path

An example of a lightpath



A three-node wavelength routing network



A lightpath between routers A and B

The wavelength continuity constraint

- When establishing a lightpath over a wavelength routing network, the same wavelength has to be used on every hop along the path.
- If the required wavelength is not available at the outgoing fiber of an OXC through which the lightpath has to be routed, then the establishment of the lightpath is blocked, and a notification message is sent back to the user.

Converters

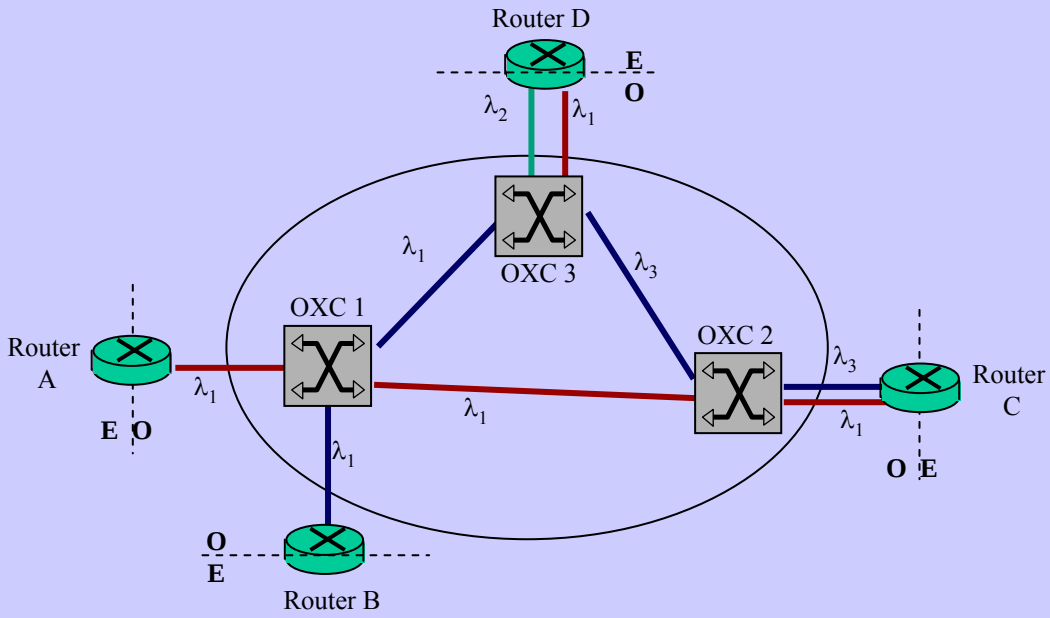
- In order to decrease the probability that a lightpath is blocked, the OXC can be equipped with converters.
- A converter can transform the optical signal transmitted over a wavelength to another wavelength.

In an OXC, for each output fiber with W wavelengths, there may be c converters, where $0 \leq c \leq W$.

- *No conversion:* c=0
- *Partial conversion:* $0 < c < W$
- *Full conversion:* c=W

A converter can only transform a signal on a wavelength λ to another wavelength which is within a few nm from wavelength λ.

An example of different lightpaths



Lightpaths

A -> C: λ_1

B -> D:λ_1 and λ_2

C -> D:λ_3 and λ_1

OXCs 1 and 2: no converters

OXC 3 has converters

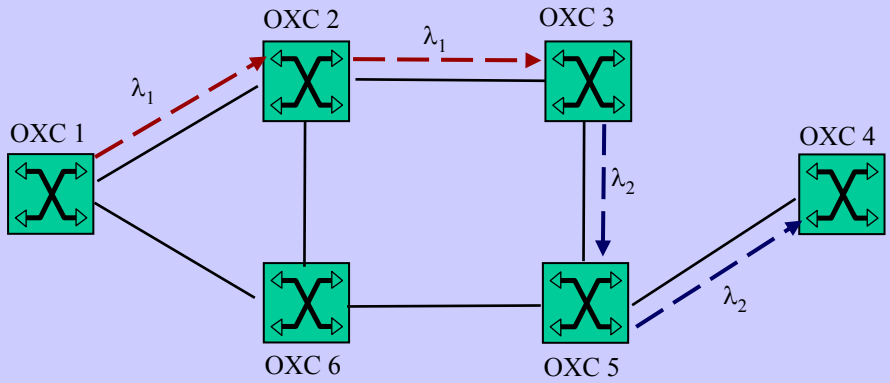
Traffic grooming

- A lightpath is exclusively used by a single client.
- Often the bandwidth a client requires is significantly less than the wavelength's bandwidth. This means that part of the lightpath's bandwidth is unused. Also, the user pays for more bandwidth than required.
- Traffic grooming permits mane user to share the same lightpath.

Sub-rate units

- The bandwidth of a lightpath is divided into *sub-rate* units so that it can carry traffic streams transmitted at lower rates.
- For instance a 2.5 Gbps (OC-48) bandwidth can be available in sub-rate units of 50 Mbps (OC-1)
- A client can request one or more of these sub-rate units. This improves wavelength utilization and lowers user's costs.

An example of traffic grooming



- Established lightpaths:
  - OXC 1 to OXC 3
  - OXC 3 to OXC 4
- Wavelength capacity: 2.488 Gbps (OC-48/STM-16)
- 16 sub-rate units of 155 Mbps (OC3/STM-1)

Protection schemes

Optical networks will be used by telecommunications companies and other network providers, which typically require a *carrier grade* reliability.

That is, the network has to be available 99.999% of the time, which translates to an average downtime for the network of 6 minutes per year!

Types of failures:

- Link failures are very common and they occur when a fiber cable is accidentally cut.
- A link can also fail if an amplifier that boosts the multiplexed signal of all the wavelengths on the fiber fails.
- An individual wavelength within a fiber may also fail if its transmitter or receiver fails.
- Finally, an OXC can fail, but this is quite rare due to built-in redundancies.

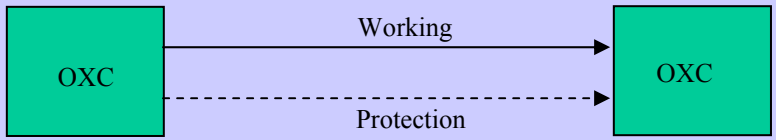
Path and link protection

Protection can be performed at the level of an individual lightpath or at the level of a single fiber.

- *Path protection* denotes schemes for the restoration of a lightpath, and
- *Link protection* denotes schemes for the restoration of a single fiber, whereby all the wavelengths are restored simultaneously.

Point-to-point links

- The simplest optical network is a point-to-point WDM link that connects two nodes.
- Link protection schemes: *dedicated 1+1 non-dedicated 1:1 or 1:N*



Path protection

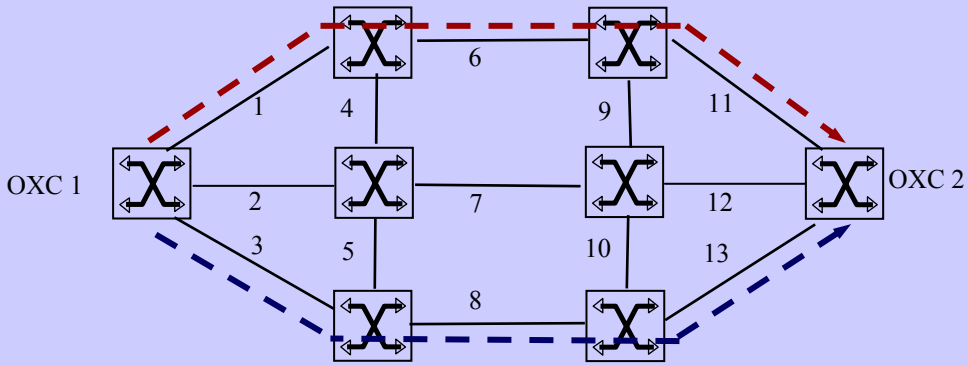
- 1:1 path protection
  - In the case of the 1:1 path protection, the user signal is carried over a working lightpath. The back-up protection lightpath has also been established, but it is not used.
  - If the working lightpath fails, the source and destination switches to the protection lightpath.

- 1:N path protection
  - This is a generalization of the 1:1 path protection, where N different working lightpaths share the same protection path.
  - Obviously, only one working lightpath can be protected at any time

Shared risk link group (SRLG)

- An SRLG is a group of links that share the same physical resource, such as a cable, a conduit, and an OXC.
- Failure of this physical resource will cause failure of all the links.
- When setting up a working and a protection lightpath, care is taken so that the two lightpaths are not routed through the same SRLG.

An example

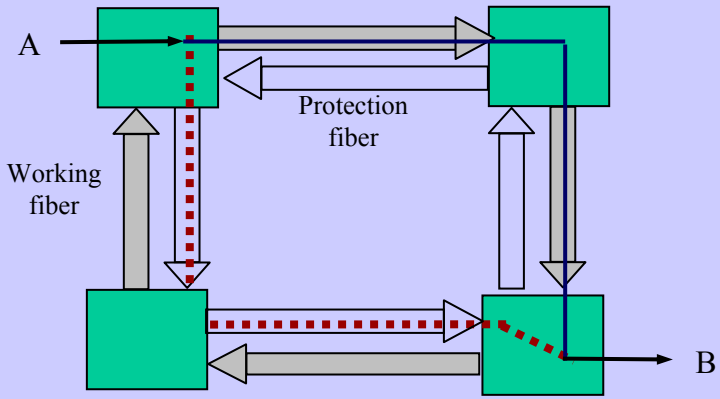


- The working lightpath from OXC 1 to OXC 2 uses links {1,6,11} and its protection lightpath uses links {3,8,13}.
- That is, they are SRLG-disjoint.

WDM optical rings

- WDM optical rings can be seen as an extension of the SONET/SDH rings in the WDM domain.
- Many different WDM ring architectures have been proposed, such as:
  - *optical unidirectional path sharing ring* (OUPSR),
  - *two-fiber optical bidirectional link sharing ring* (2F-OBLSR)
  - *four-fiber optical bidirectional link sharing ring* (4F-OBLSR).

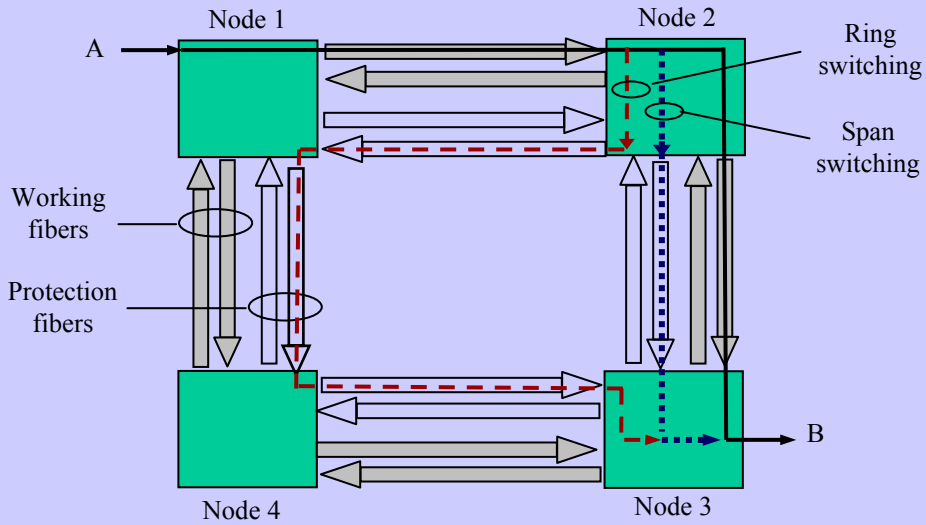
An optical unidirectional path sharing ring (OUPSR)



- Features
  - It consists of a working and a protection ring transmitting in opposite directions
  - It used as a metro edge ring, and it connects a small number of nodes, such as access networks and customer premises, to a *hub* node, which is attached to a metro core ring.
  - The traffic transmitted on the ring is static and it exhibits hub behavior. That is, it is directed from the nodes to the hub and from the hub to the nodes. Static lightpaths are used.

- Features
  - Transmission is unidirectional.
  - The 1+1 protection scheme is used to implement a simple path protection scheme. That is, a lightpath, is split at the source node and it is transmitted over the working and protection ring.
  - The destination selects the best signal.

The four-fiber optical bidirectional link shared ring



Features

- It utilizes two working fibers and two protection fibers.
- Protection can be done at both the fiber level or at the lightpath level.
- Fiber protection switching is used to restore a network failure caused by a fiber cut or a failure of an optical amplifier. Lightpath protection switching is used to restore a lightpath that failed due to a transmitter or receiver failure.

Span switching

- If the working fiber from node 2 to 3 fails, then all the lightpaths will be switched onto its protection fiber from node 2 to 3.

Ring switching

- If all four fibers are cut between nodes 2 and 3, then the traffic will be diverted to the working fibers in the opposite direction.
- In this case, the lightpath from A to B will be routed back to node 1, and then to node 3 through node 4.

Mesh optical networks

- Both path and link protection can be implemented in a mesh network.
- Link protection can be implemented using the point-to-point 1+1, 1:1, and 1:N schemes
- Path protection is achieved by using dedicated or shared back-up paths.

Control plane architectures

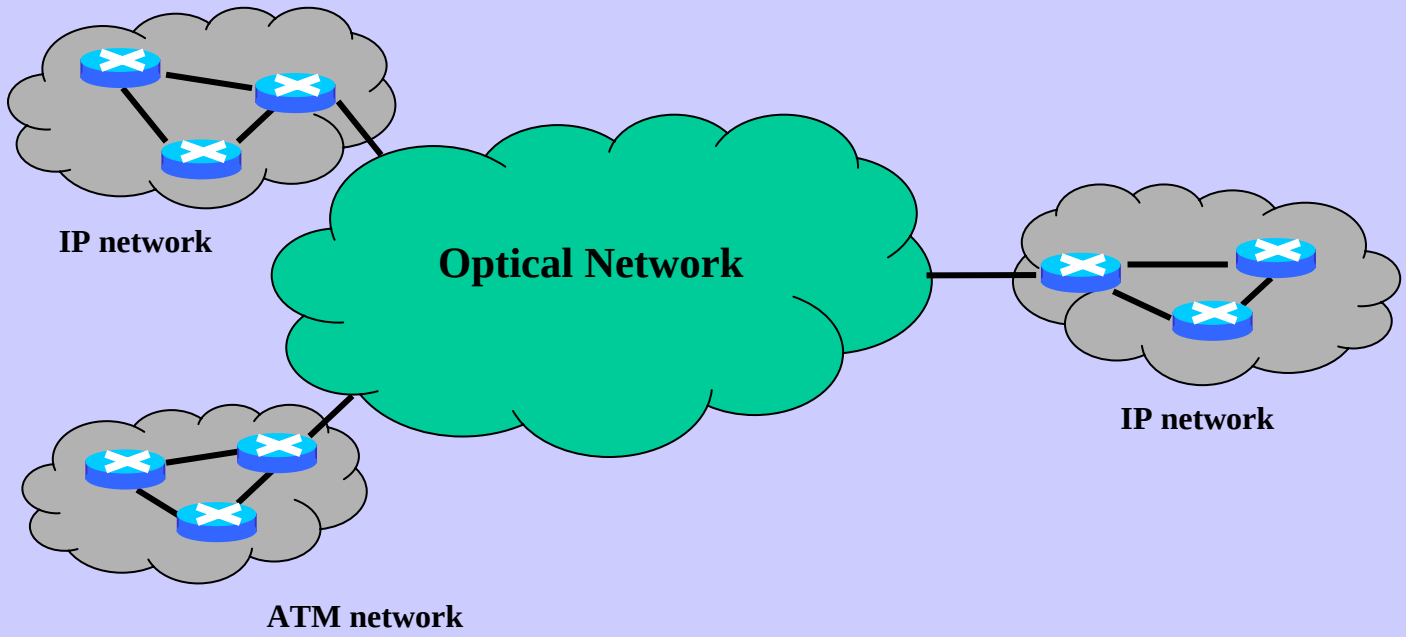
- The control plane consists of protocols that are used to support the data plane, which is concerned with the transmission of data.
- The control plane protocols are concerned with signaling, routing, and networking management.

There are two different control plane architectures:

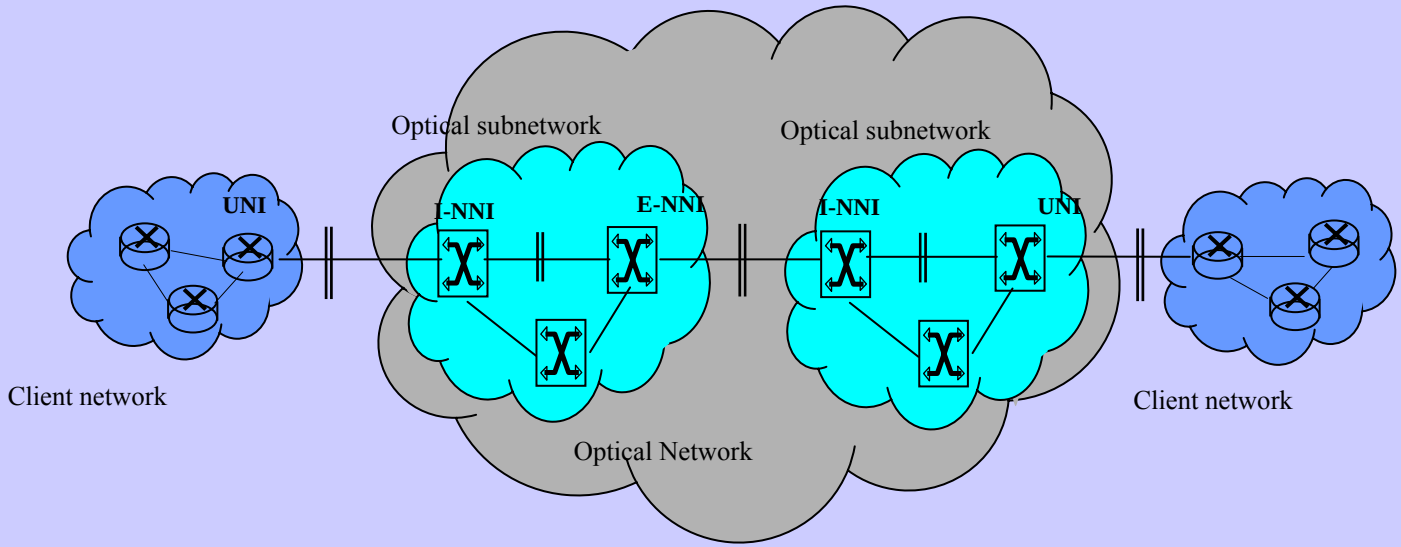
- In the first control plane architecture:
  - The user is isolated from the network via a user-network interface (UNI)
  - The user is not aware of the network's topology, its control plane, and its data plane.
  - The nodes inside the network interact with each other via a network-node interface (NNI).
  - ATM is a good example of this architecture

In the second control plane architecture:

- The user is not isolated from the network through a UNI
- The nodes inside the network do not interact with each other via a separate NNI.
- All users and nodes run the same set of protocols
- The IP network is a good example of this architecture



An optical network provides inter-connectivity to client networks, such as IP, Frame Relay, ATM and SONET/SDH



- Interfaces defined in the first control plane architecture:
  - User-network interface (UNI)
  - Internal network-node interface (I-NNI)
  - External network-node interface (E-NNI)

The OIF UNI

- OIF has specified a UNI which provides signaling for clients to automatically create a connection.
- The UNI is based on LDP and RSVP-TE protocols

IETF control plane architectures

- IETF has defined the following three control plane architectures:
  - Peer model
  - Overlay model
  - Augmented model

The peer model

- The peer model utilizes the second control plane architecture.
- That is, the client networks and the optical networks are treated as a single network from the point of view of the control plane.
- The generalized MPLS (GMPLS), an extension of MPLS, is used in the control plane.

The overlay model

- This model utilizes the first control plane architecture.
- An IP client network is connected to the optical network via an edge IP router which has an optical interface to its ingress optical node, i.e. the optical node to which it is directly attached.
- An edge IP router has to request the establishment of a connection from its ingress optical node, before it can transmit over the optical network. This is done using a signaling protocol.

- A connection over the optical network may be a permanent or a switched lightpath or sub-channel.
- The edge router is not aware of the topology of the optical network nor is it aware of its control and data planes.
- The control plane of the optical network may be based on GMPLS. However, a strict separation of the client networks and the optical network is maintained through the UNI.