Next Generation Network
- Wavelength Division Multiplexing (WDM) Network

下一世代網路 – 分波多工網路

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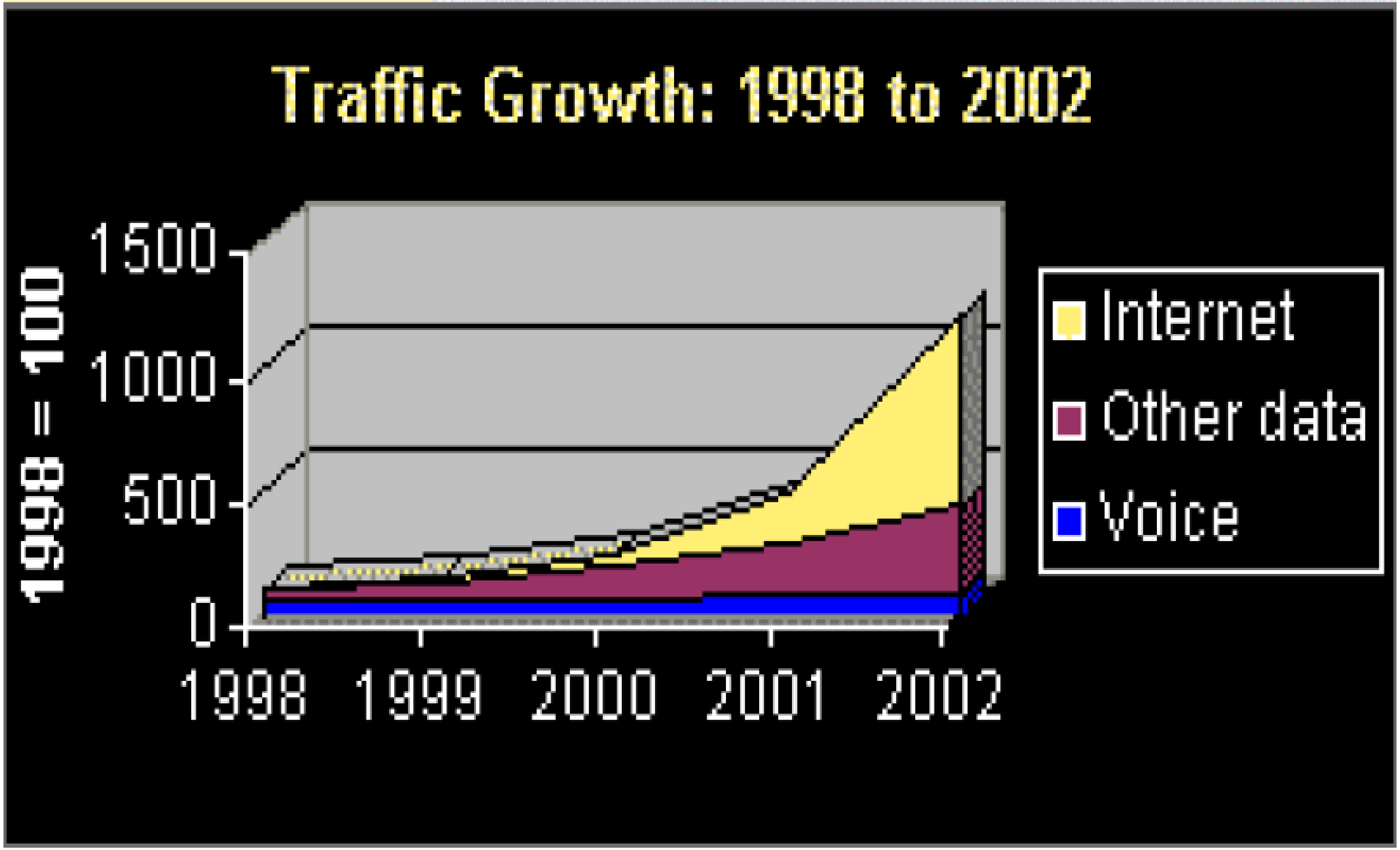
Outline

- Introduction
- Optical Technology
- Single-hop & Multi-hop WDM Network
- Wavelength Routed WDM Network
- Research Issues

Introduction

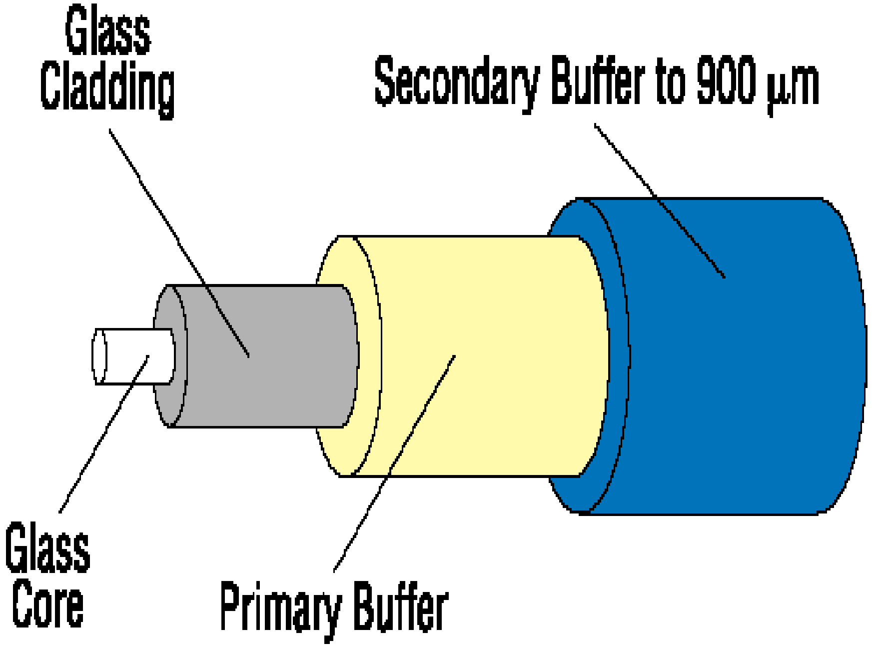
Why WDM?


Traffic Growth: 1998 to 2002
1998 = 100
1500
1000
500
0
1998
1999
2000
2001
2002
Internet
Other data
Voice

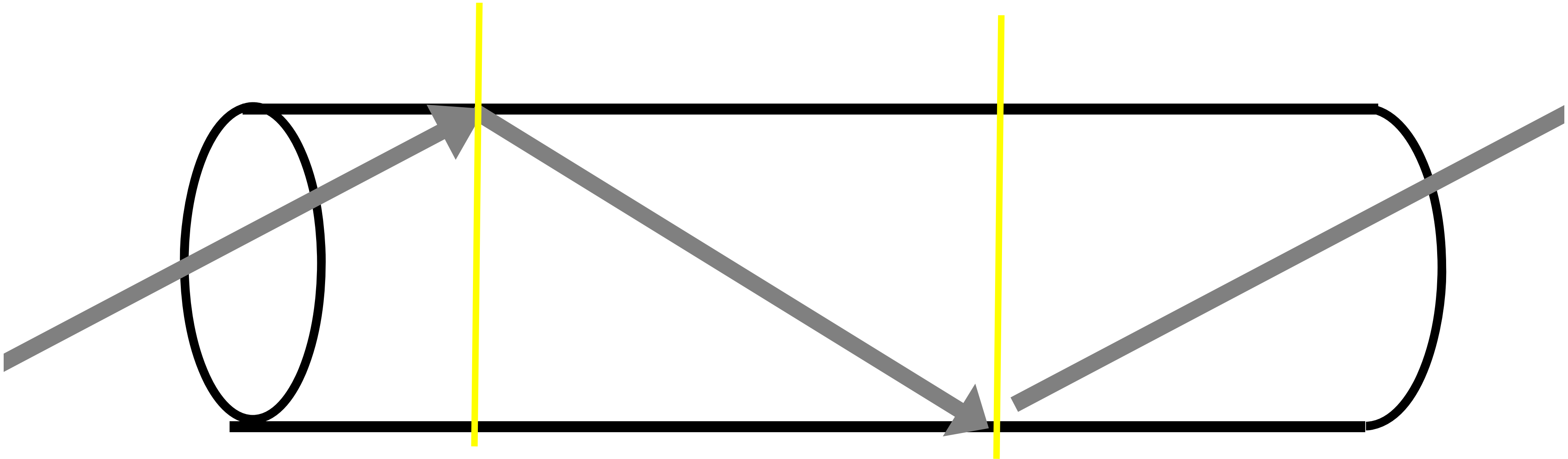
Need +Promise =Challenge

- Life in our increasingly information-dependent society requires that we have access to information at our finger tips *when we need it, where we need it, and in whatever format we need it.*
- ***Problem solving***
  - **Network lag.**
  - **Not enough bandwidth today.**
  - **Exponential growth in user traffic.**

Fiber


Glass
Cladding
Secondary Buffer to 900 µm
Glass
Core
Primary Buffer

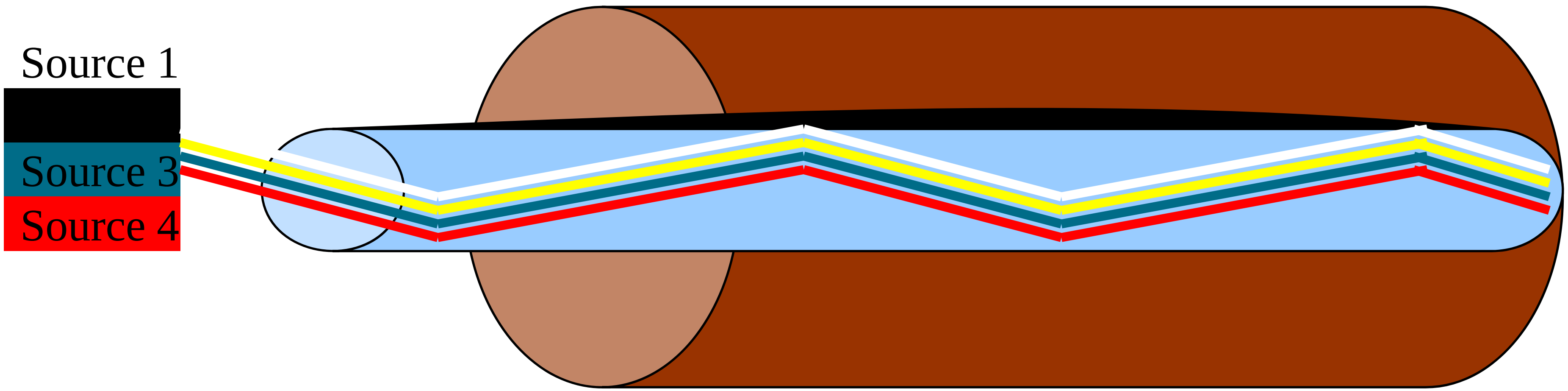
Internal Reflection in a fiber



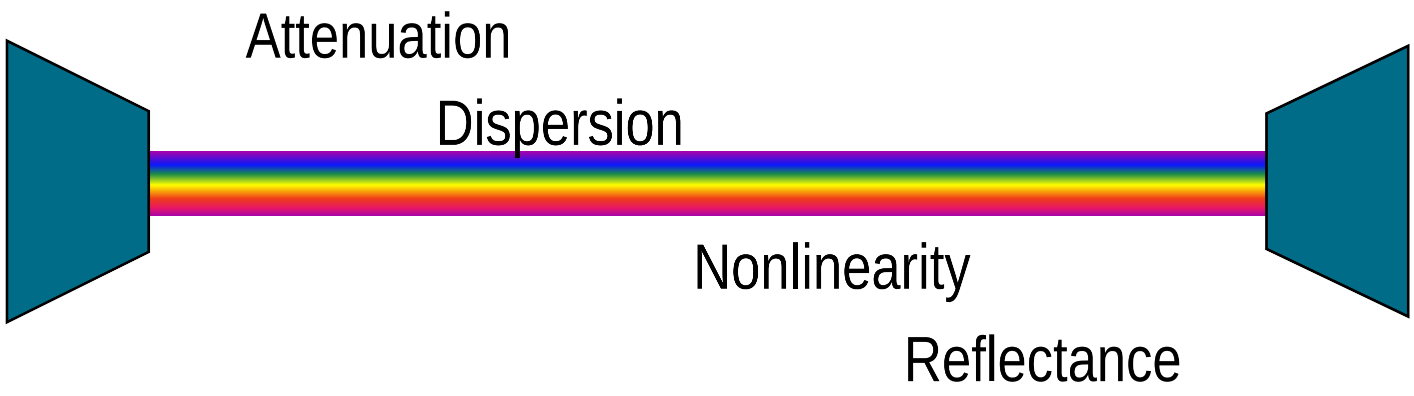
Optical Fiber

Basic Concept

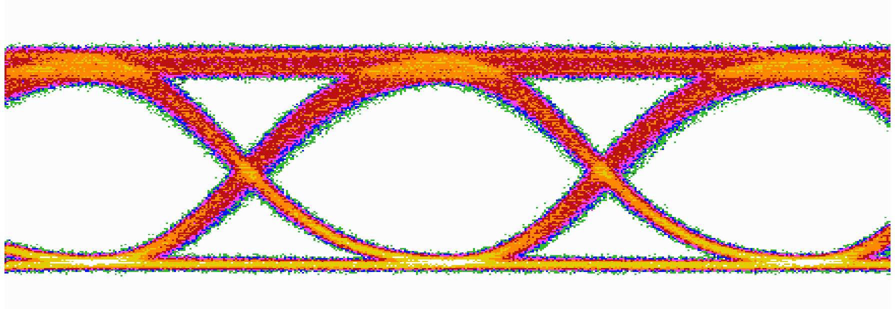
- **WDM is the ability to combine**
  - **Multiple sources of data using**
  - **Multiple wavelengths (colors) of light on**
  - **One strand of fiber cable**



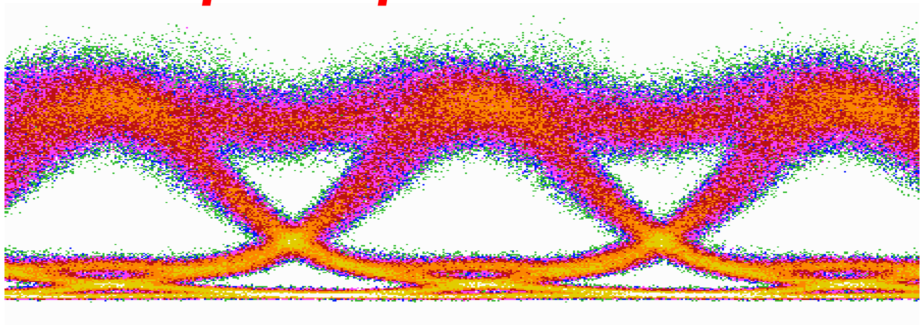
Its Analog Transmission



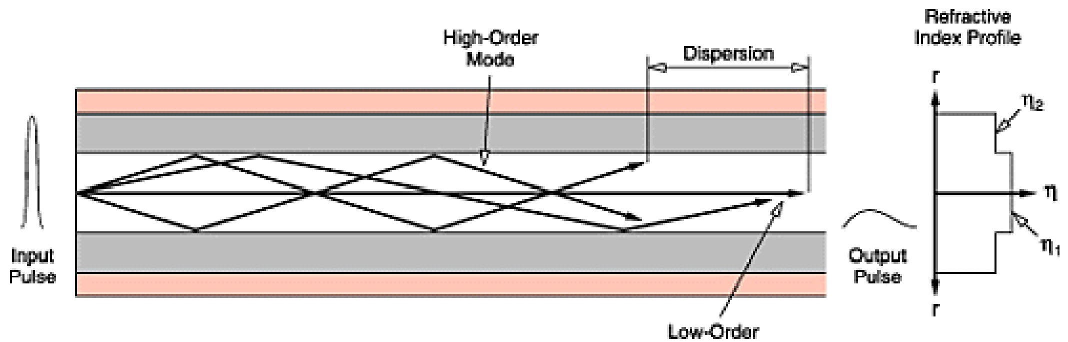
Transmitted data waveform

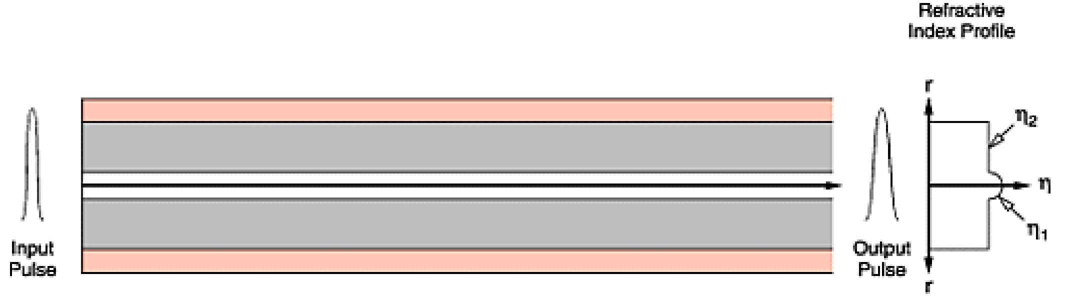


Waveform after 1000 km



Fiber Types ...

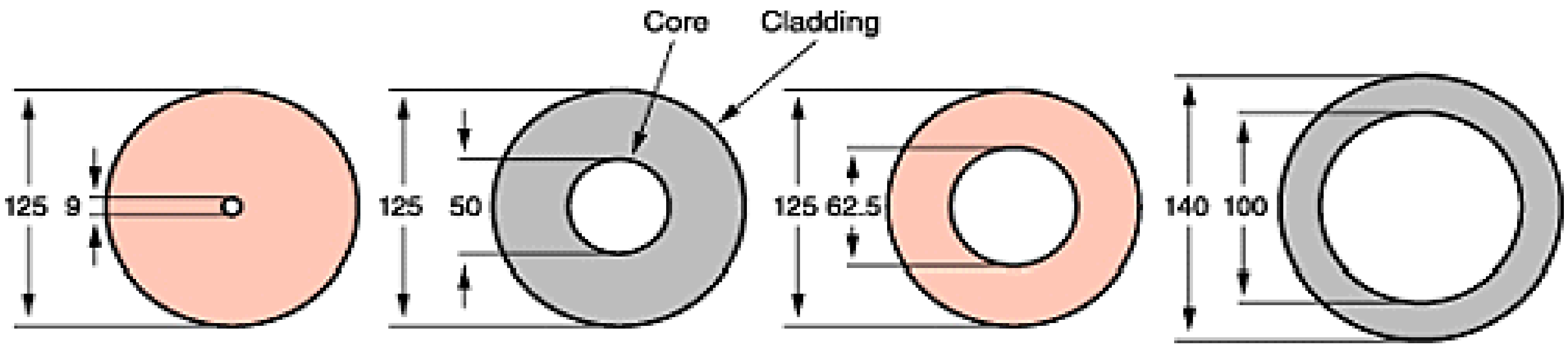




Single-Mode Step Index

Multi-mode fiber allows multiple modes of light to propagate along its length at various angles. Typically: 62.5/125um, 50/125um

Single-mode fiber allows a single mode of light to propagate along its core efficiently. Typically: 8/125um, 8.3/125um, 9/125um

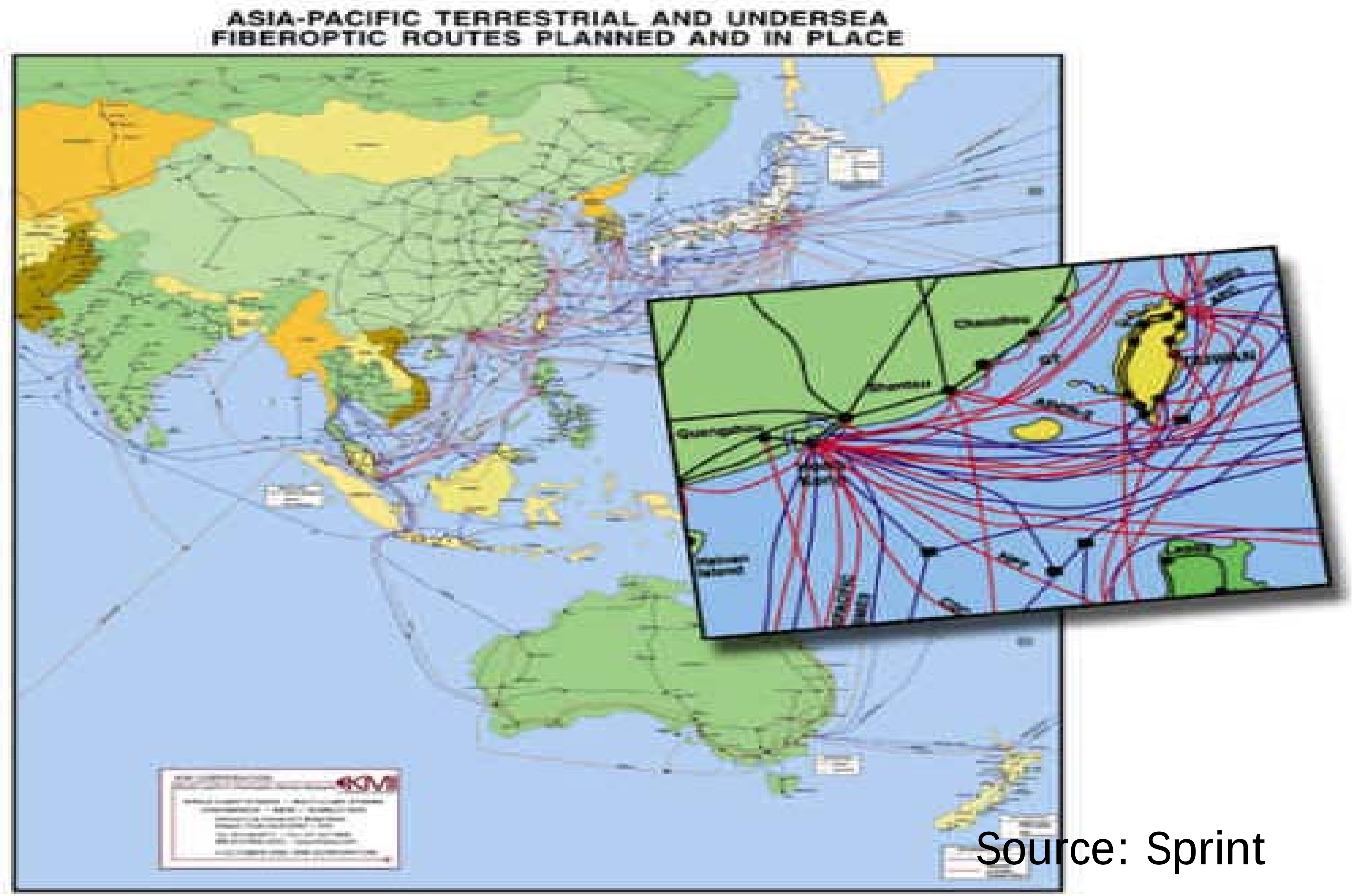


Typical Core and Cladding Diameters (µm)

Fiber optic properties

- **huge bandwidth (nearly 50 terabits per second (Tbps),**
- **low signal attenuation (as low as 0.2 dB/km),**
- **low signal distortion,**
- **low power requirement,**
- **low material usage,**
- **small space requirement, and**
- **low cost.**

Fiber networks

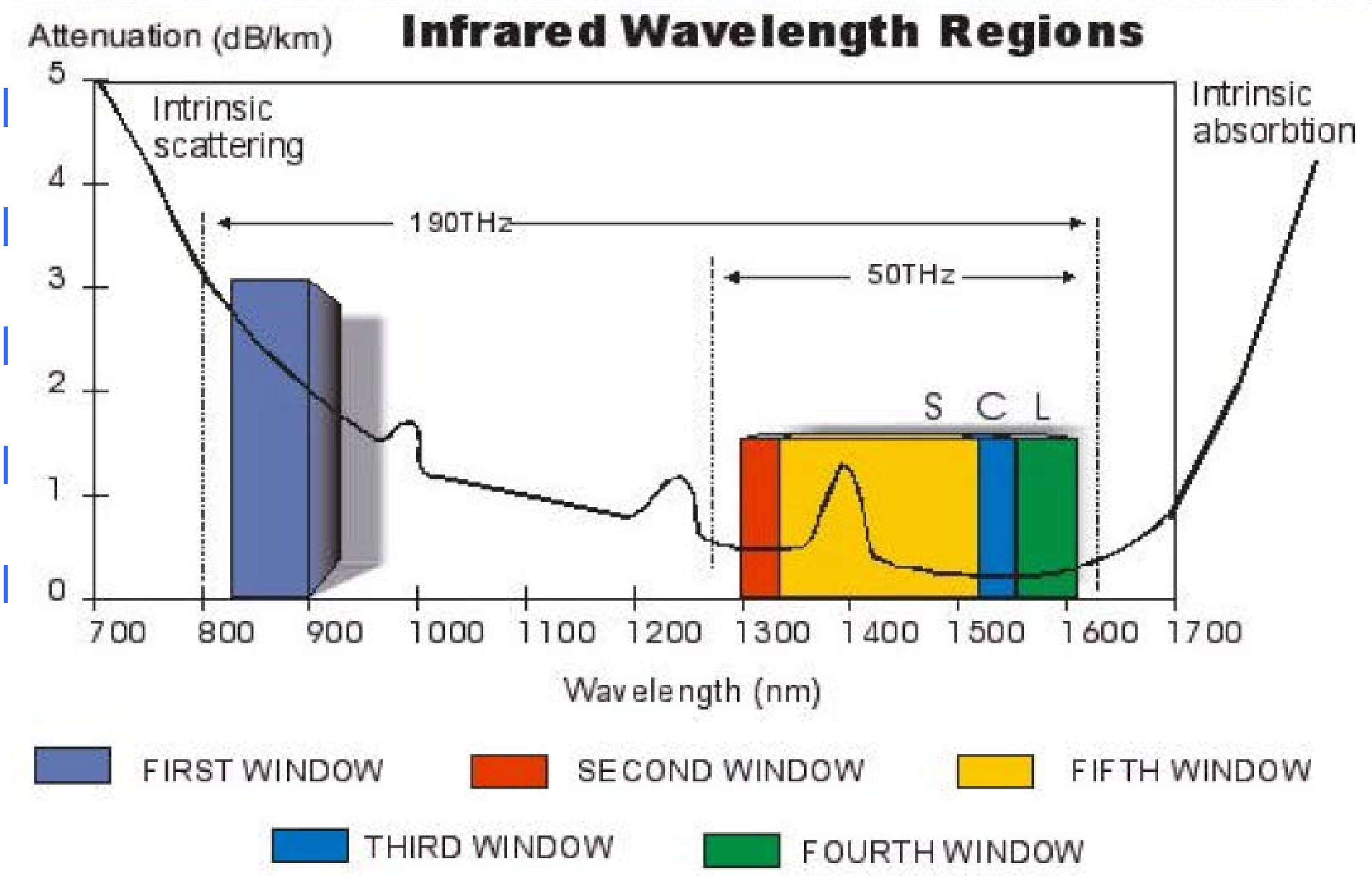


Source: Sprint

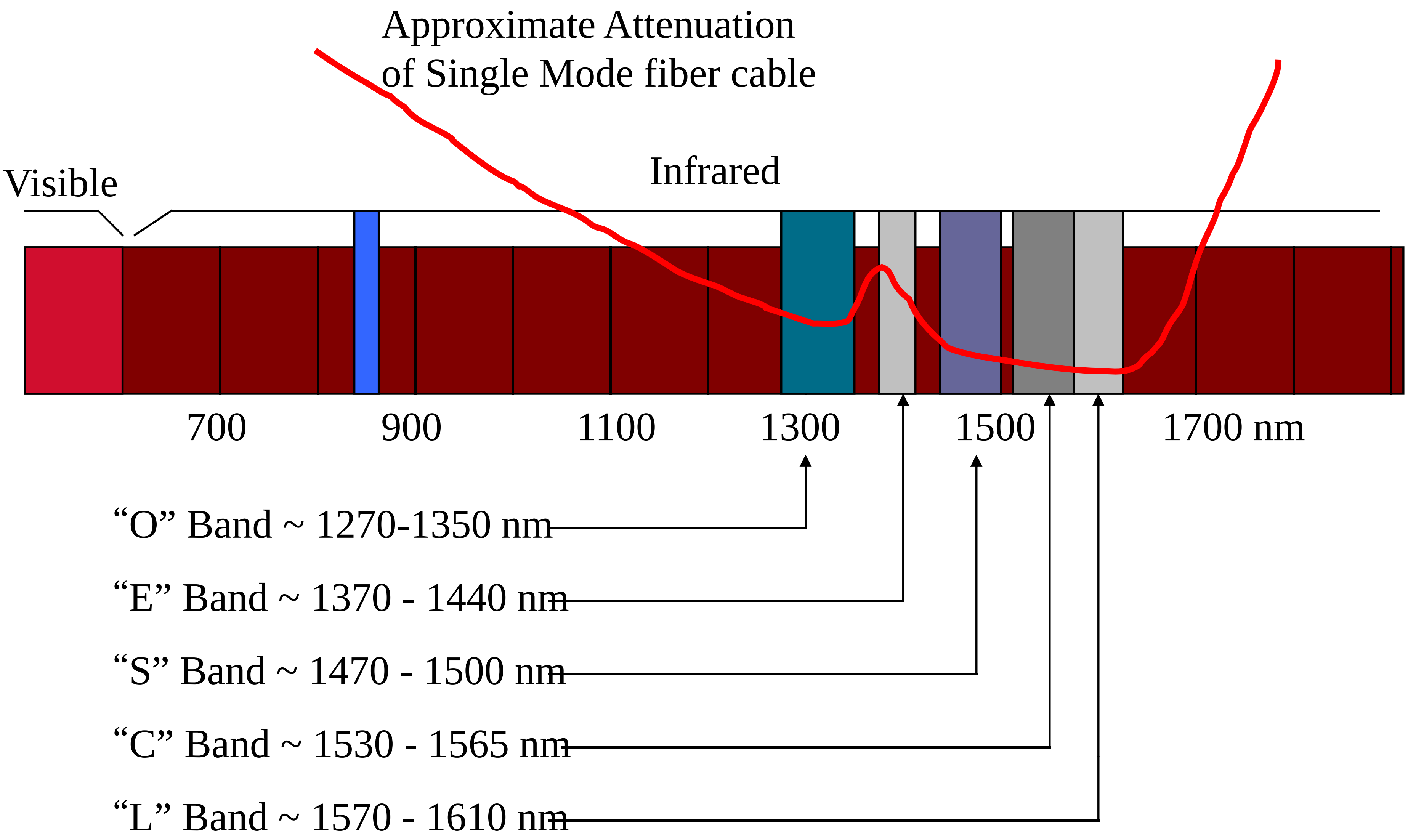
opto-electronic bandwidth mismatch

- **single-mode fiber**
  - **potential bandwidth is nearly 50 Tbps,**
  - **electronic data rates of a few gigabits per second (Gbps),**
  - **four orders of magnitude $O(10^4)$**
  - **opto-electronic bandwidth mismatch.**

ITU recommended Bands



Light Spectrum

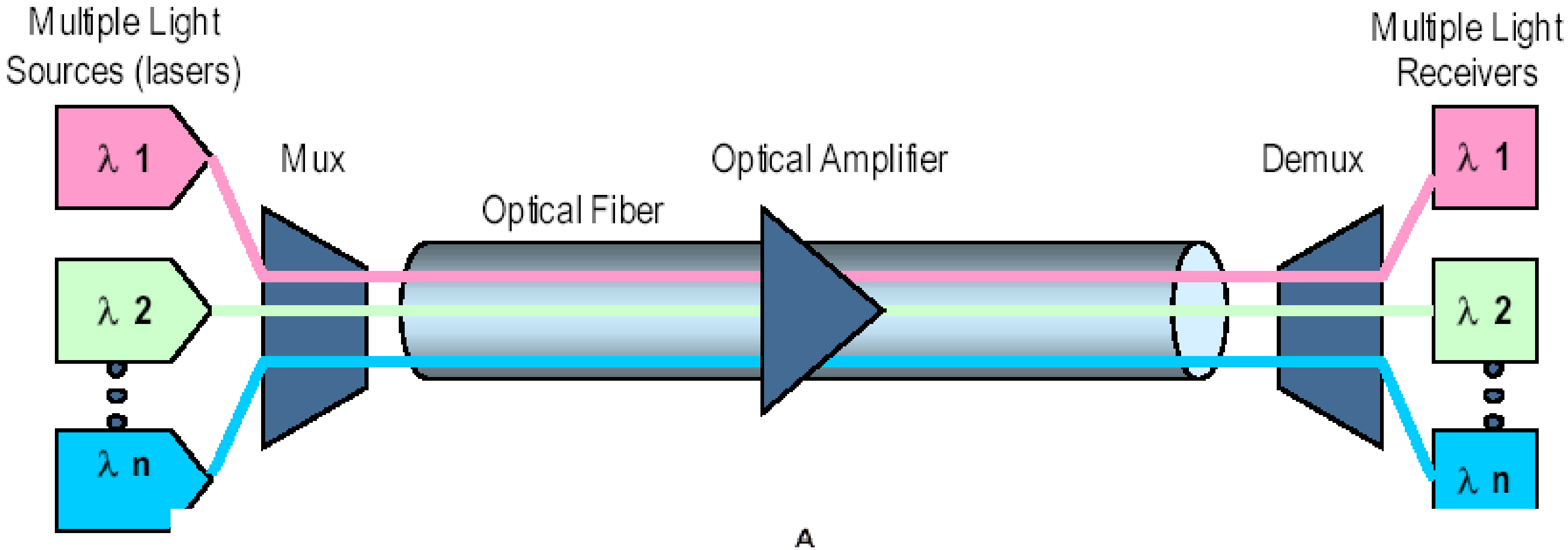


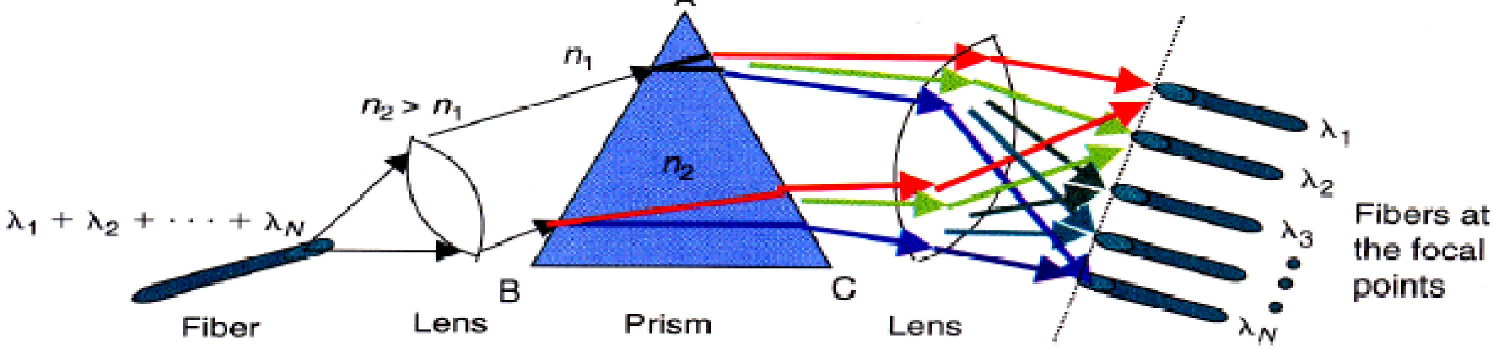
Solution in Optical Network

- **In an optical communication network, this concurrency may be provided according to either**
  - **wavelength or frequency [wavelength-division multiplexing (*WDM*)],**
  - **time slots [time-division multiplexing (*TDM*)], or**
  - **wave shape [spread spectrum, code-division multiplexing (*CDM*)].**

WDM-routed networks

- **Optical signal and wavelength:**





Resonate/suppress

Why WDM?

- Provide huge bandwidth using fiber
  - Fiber has about 50 terabits per second
  - Multiple WDM channels provide huge aggregate bandwidth in a single fiber
- Avoid the bottleneck of increasing baud rate
  - Current peak rate is about only 10 Gbps
  - Implementation of higher bit rate using fiber for long-distance transmission is more difficult
  - Multiple WDM channels with peak rate can achieve huge capacity
- Upgrade network capacity without fiber re-deployment

WDM and DWDM

DWDM

- Dense Wavelength Division Multiplexing
- Introduced since 1995
- Typically, multiplex more than 16 λ per fiber, (single-mode fiber).
- Now have reached 40 λ (much more in lab)
- Goal: 1024 λ, 2048 λ or more

Optical Technologies & Devices

What makes up WDM?

Photonic layer –

Optical Fiber

Optical Amplifiers

Transmitters and receivers, tunable filters

(E/O and O/E conversion)

Wavelength Multiplexer/Demultiplexer

Transforms a single wavelength point-to-point optical signal into a wavelength division

Add/Drop Multiplexers

(adding and extracting signals from the network)

Optical Cross-connects (OXC)

Transmitter

Laser or LED

Laser: is an acronym for *Light Amplification by Stimulated Emission of Radiation. (Single Mode Fiber)*

LED: (Multi-Mode Fiber)

Semiconductor Diode Lasers

Tunable or Fixed

tuning range,

tuning time,

continuously tunable,

discretely tunable,

Receiver

Tunable or Fixed

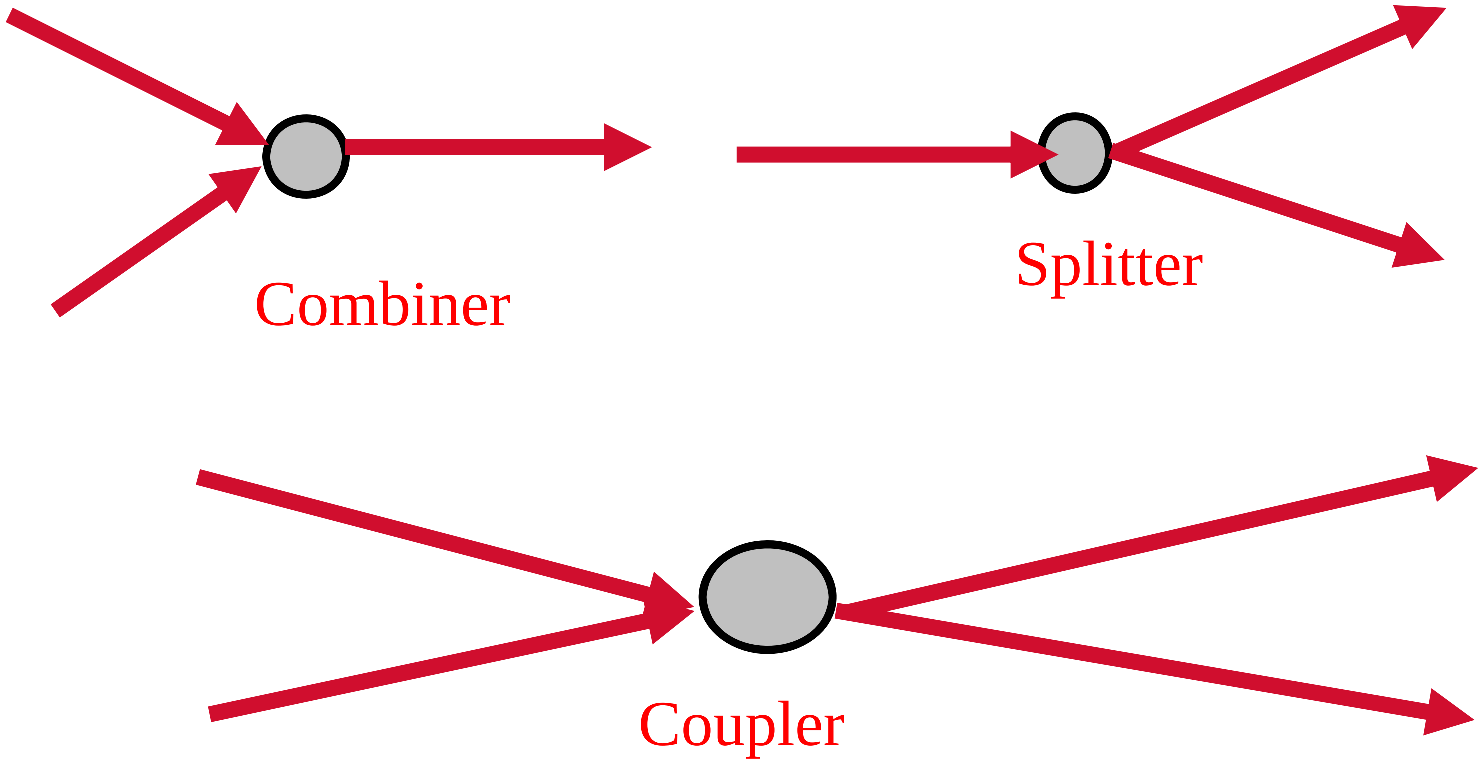
tuning range,

tuning time,

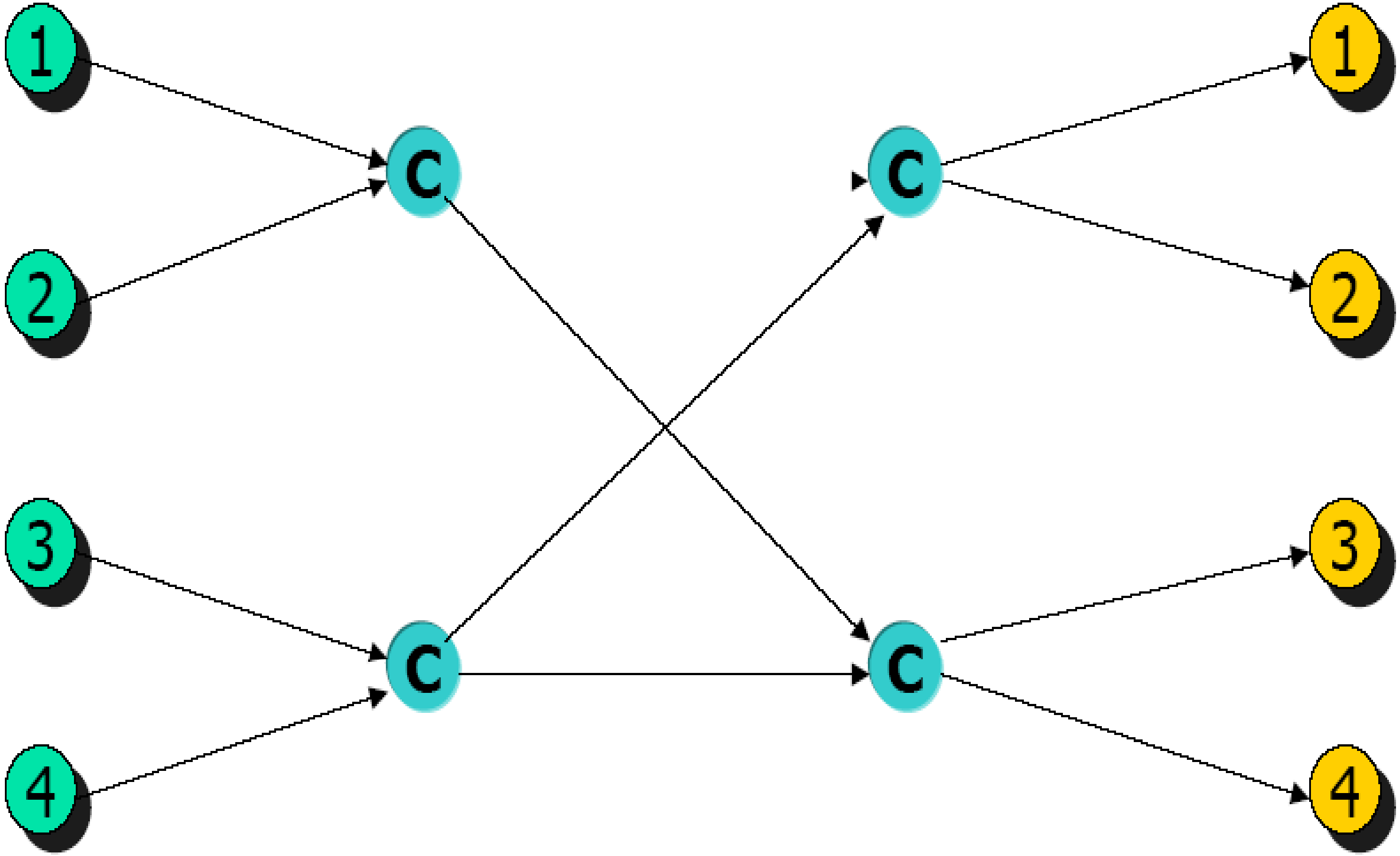
continuously tunable,

discretely tunable,

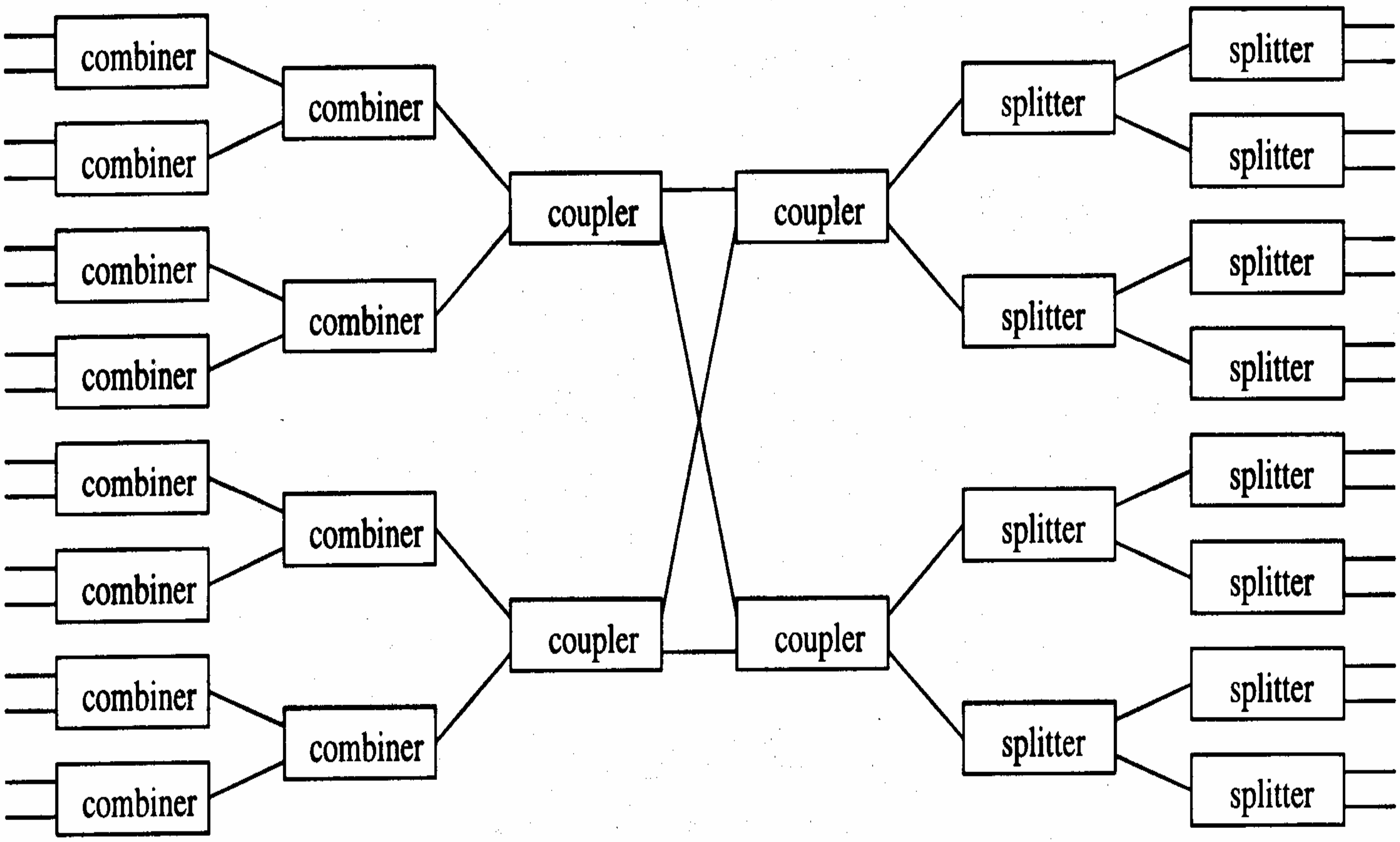
Splitter, Combiner, Coupler



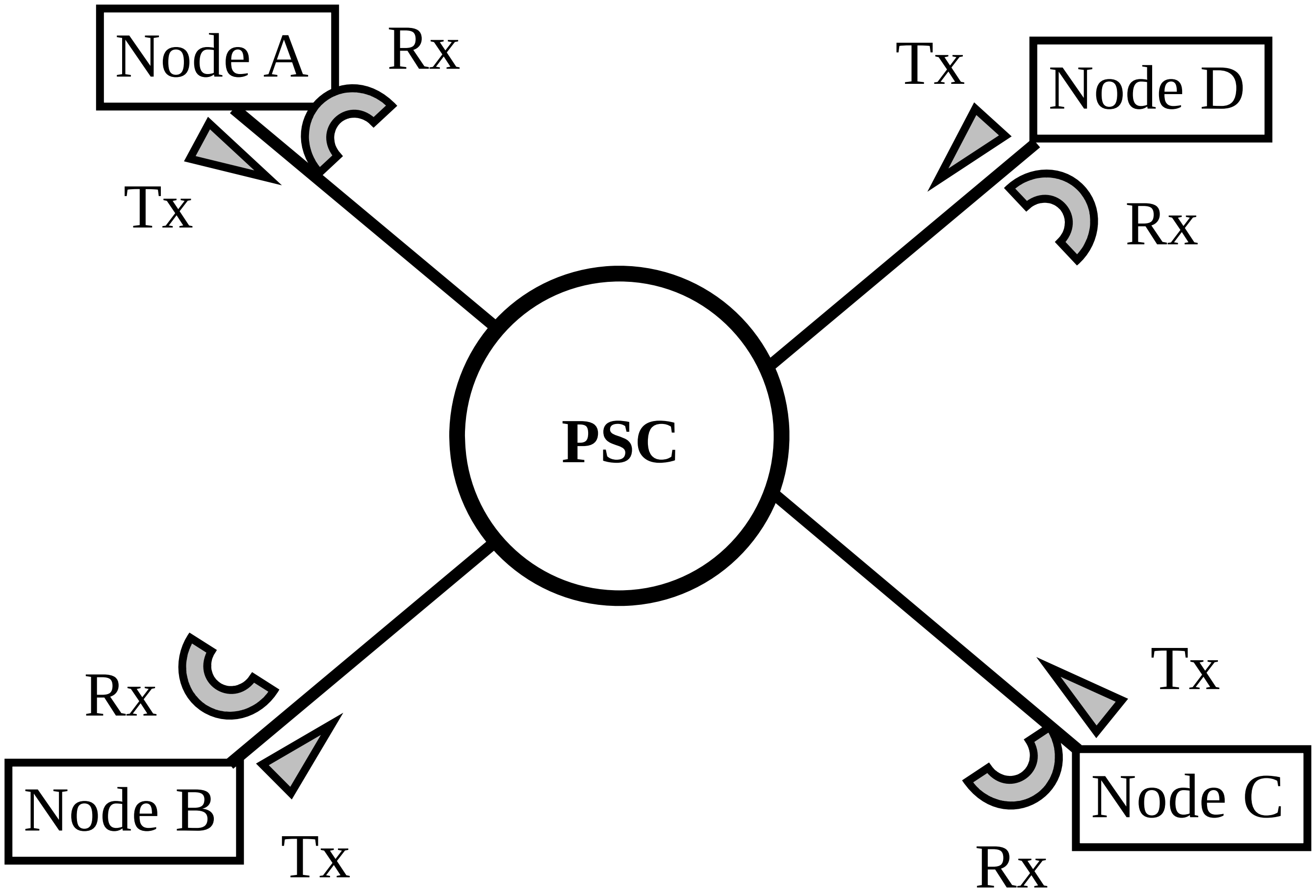
4x4 Star Coupler



16x16 Star Coupler



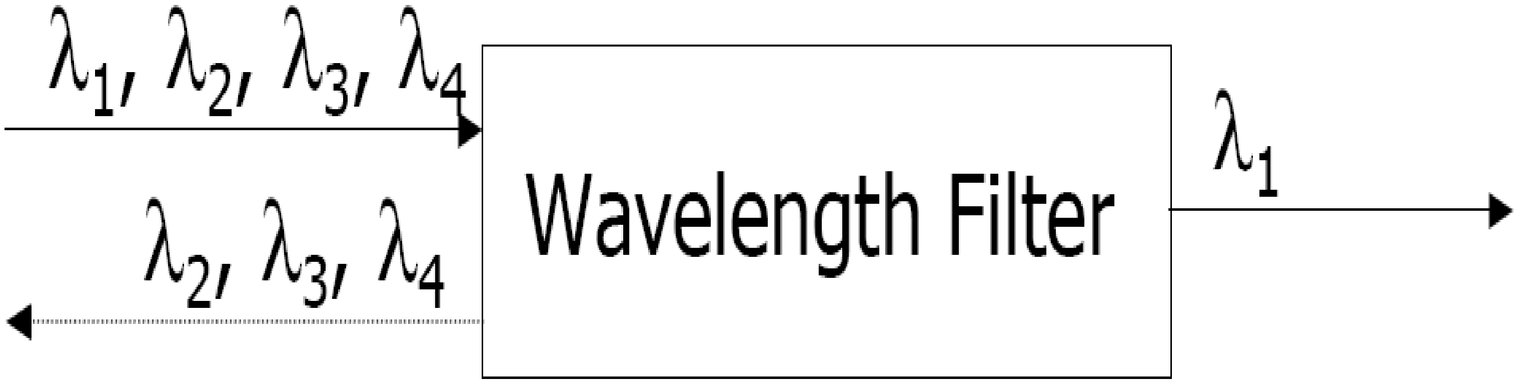
Passive Star Coupler



Filters

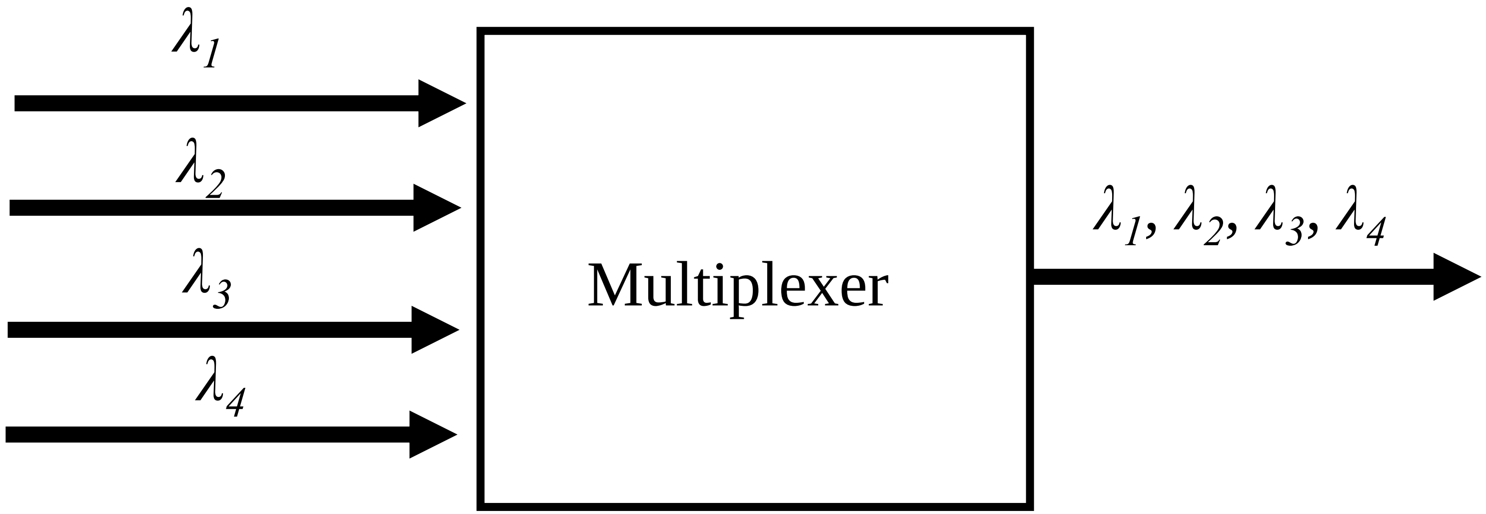
Essential to selecting (dropping) wavelengths from the fiber (de-multiplexing).

Filters can be tunable

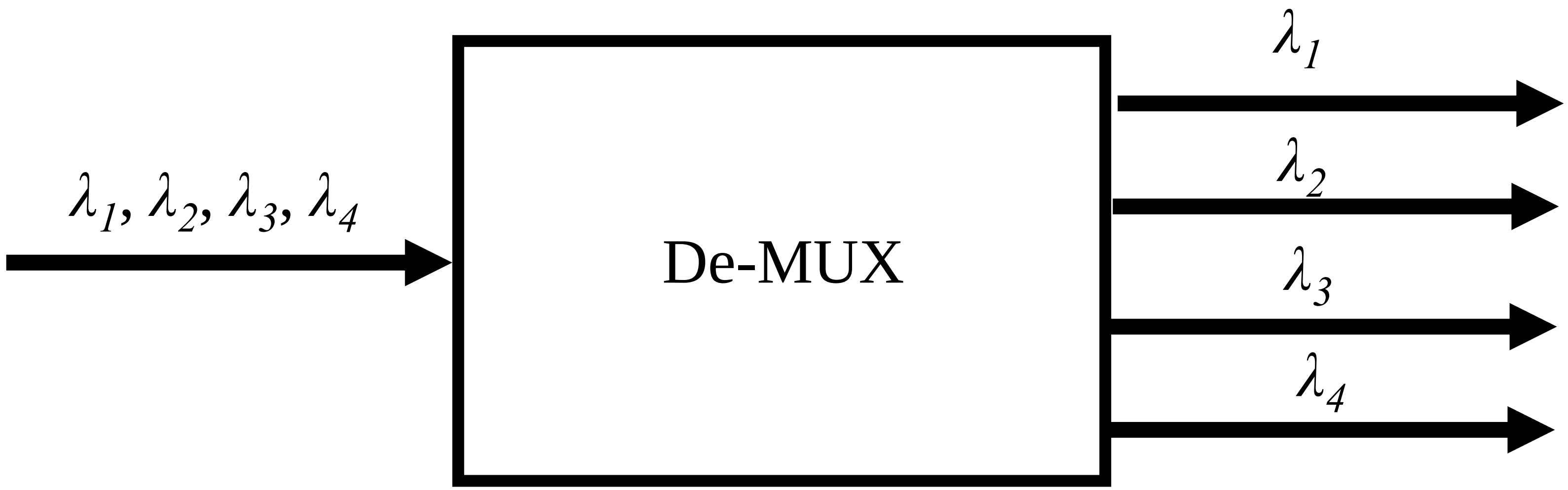


Multiplexers

Essential to combine wavelengths onto one fiber.



De-Multiplexers



Optical Modulation

In order to transmit data across an optical fiber, the information must first be **encoded**, or **modulated**, onto the laser signal.

Analog techniques include

- amp-litude modulation (AM),
- frequency modulation (FM), and
- phase modulation (PM).

Digital techniques include

- amplitude-shift keying (ASK),
- frequency-shift keying (FSK), and
- phase-shift keying (PSK).

Optical Amplifiers

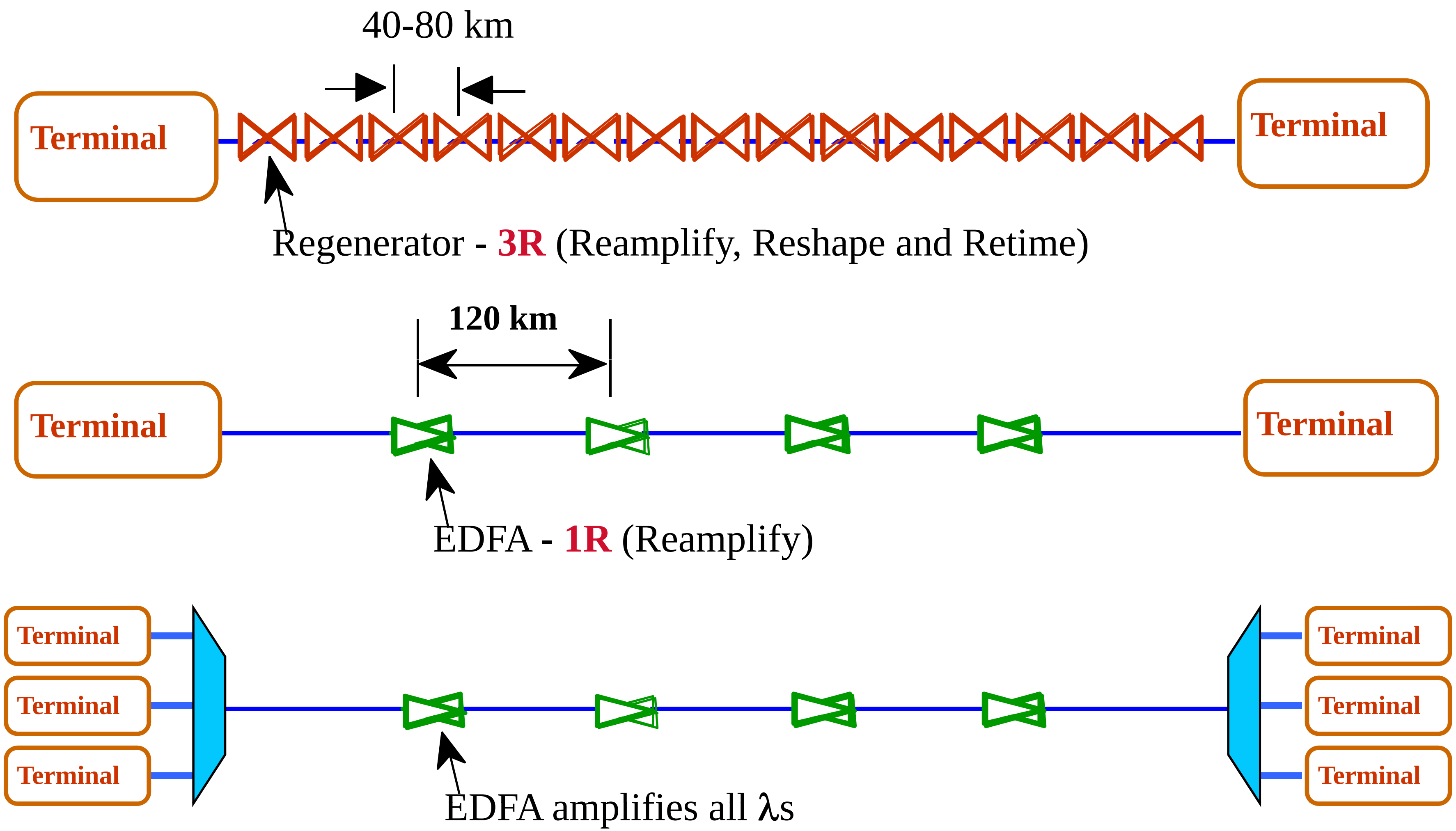
All-optical amplification may differ from opto-electronic amplification in that **it may act only to boost the power of a signal, not to restore the shape or timing of the signal**.

This type of amplification is known as **1R (re-generation),** and it provides total ***data transparency*** (the amplification process is independent of the signal's modulation format).

3R (regeneration, re-shaping, and reclocking).

2R (regeneration and reshaping),

EDFAs Enable DWDM



Switching Elements

Digital Switching:

Most current networks employ electronic processing and use the optical fiber only as a transmission medium.

Switching and processing of data are performed by converting an optical signal back to its "native" electronic form.

These switches provide a high degree of flexibility in terms of switching and routing functions;

The speed of electronics is unable to match the high bandwidth of an optical fiber.

An electrooptic conversion at an intermediate node in the network introduces extra delay.

Optical Switching

all-optical networks

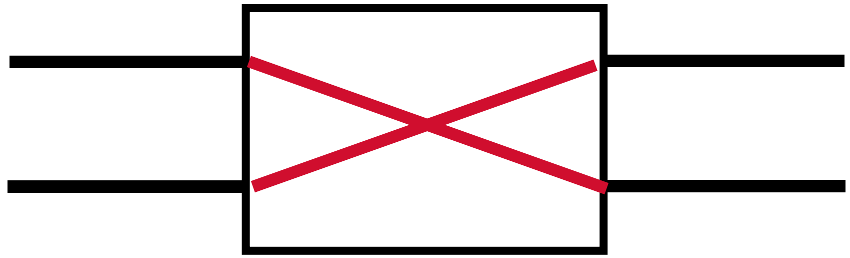
Optical switching components are able to switch high-bandwidth optical data streams without electrooptic conversion.

transparent switching allows the switch to be independent of the data rate and format of the optical signals.

Cross-connect (XC)

A fiber cross-connect element switches optical signals from input ports to out-put ports.

Bar State



Cross State

WADM

Architecture:

DEMUX

A set of 2x2 switches (one switch per wavelength)

MUX

States:

Bar state: If all of the 2 x 2 switches are in the "bar" state, then all of the wavelengths flow through the WADM "undisturbed."

Cross state: the signal on the corresponding wavelength is "dropped" locally, and a new **data stream can be "added" on to the same wavelength at this WADM location.**

Wavelength Add/Drop Multiplexer (WADM)

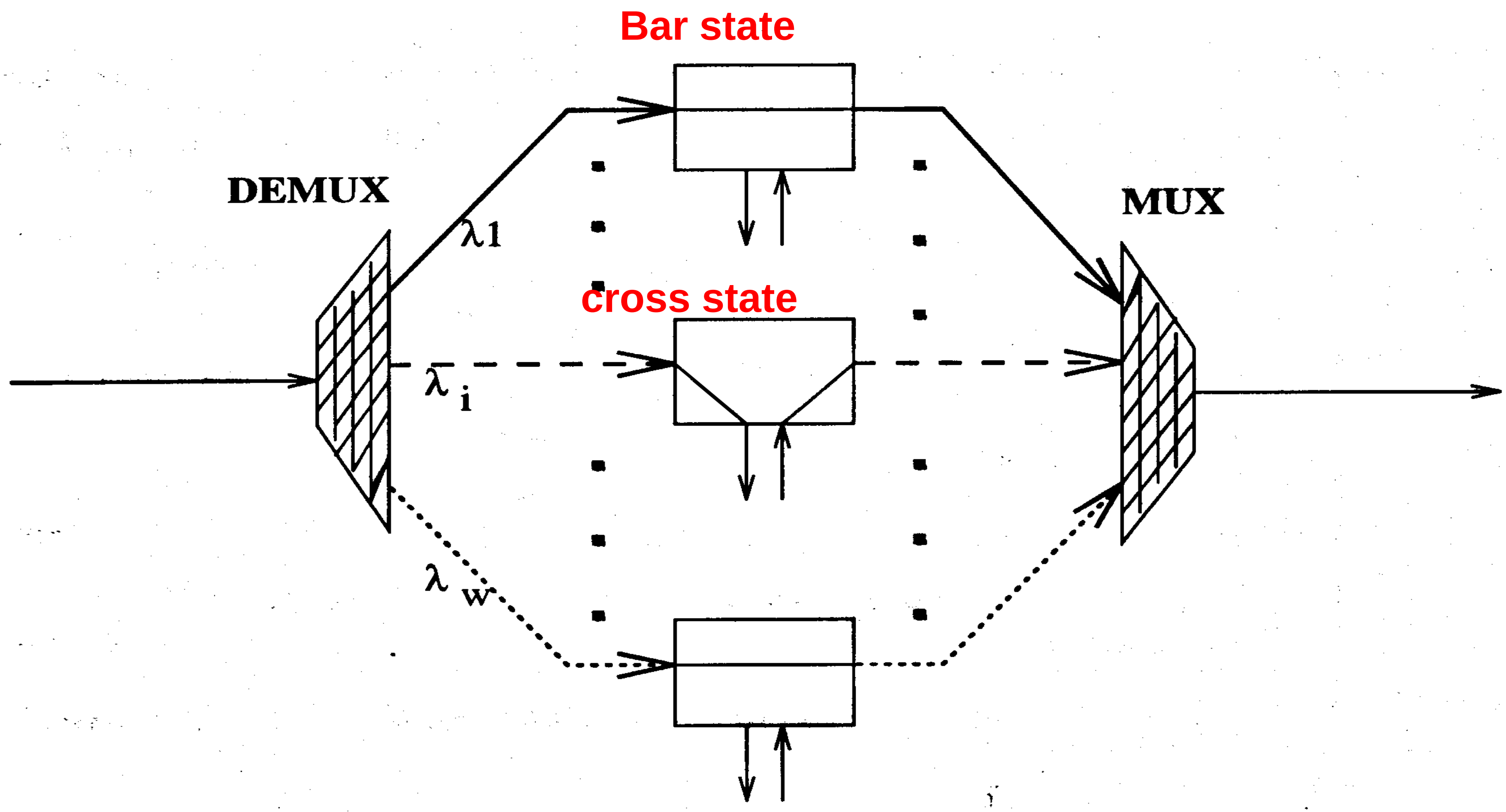
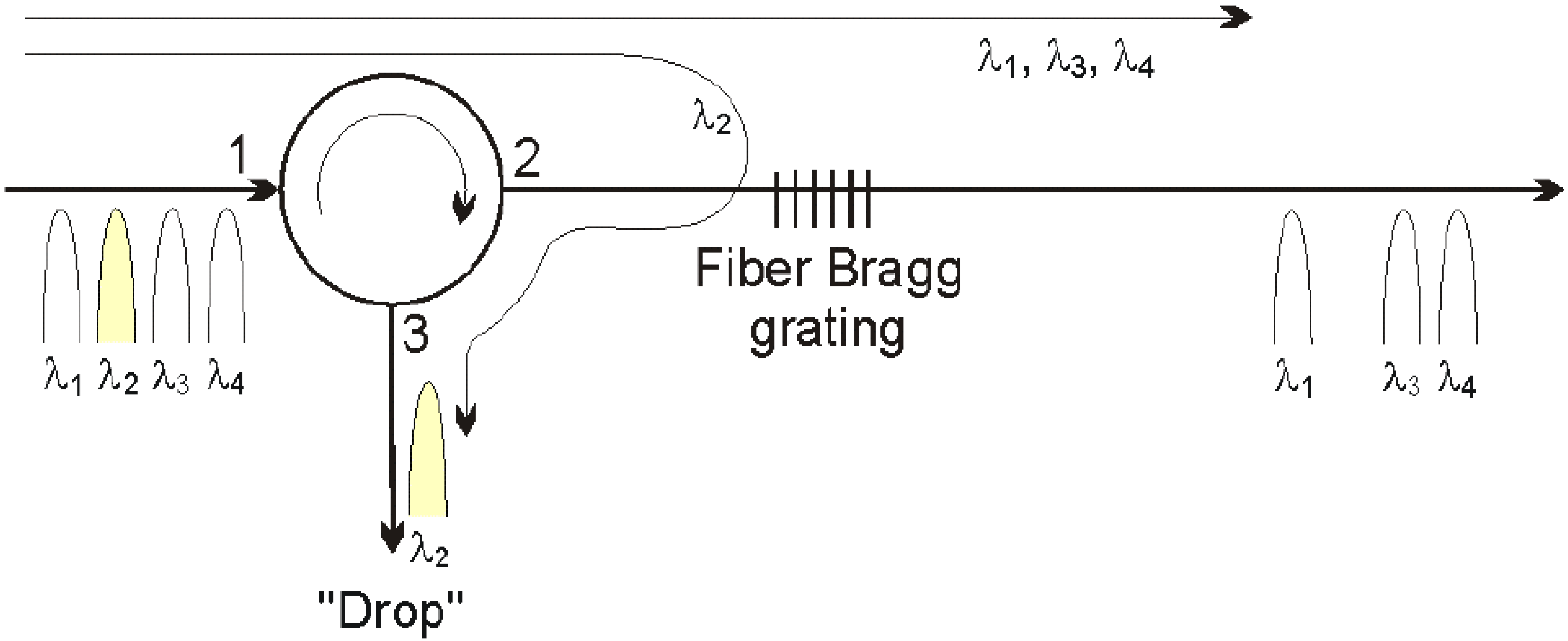


Figure 1.3 A Wavelength Add/Drop Multiplexer (WADM).

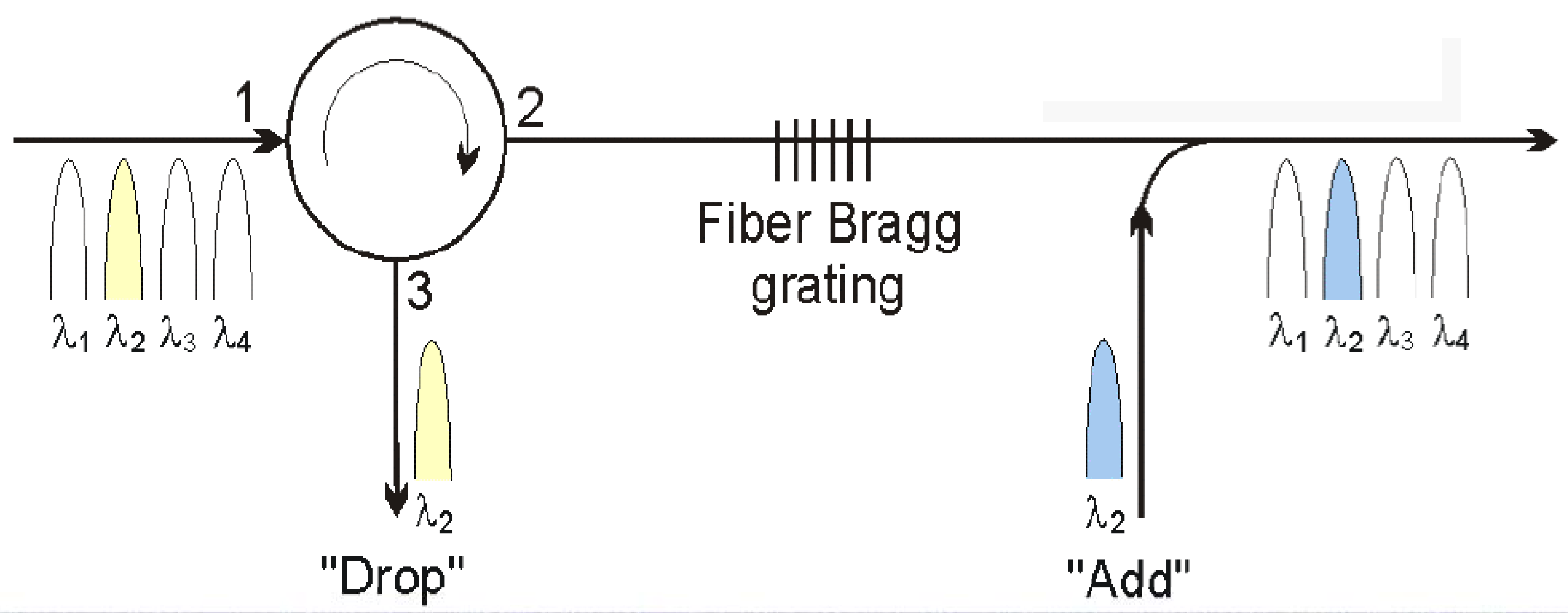
OADM

Drop



OADM

Add/Drop



wavelength-routing device

A wavelength-routing device can route signals arriving at different input fibers (ports) of the device to different output fibers (ports) based on the wavelengths of the signals.

Wavelength routing is accomplished:

by demultiplexing the dif-ferent wavelengths from each input port,

optionally switching each wavelength separately, and then

multiplexing signals at each output port.

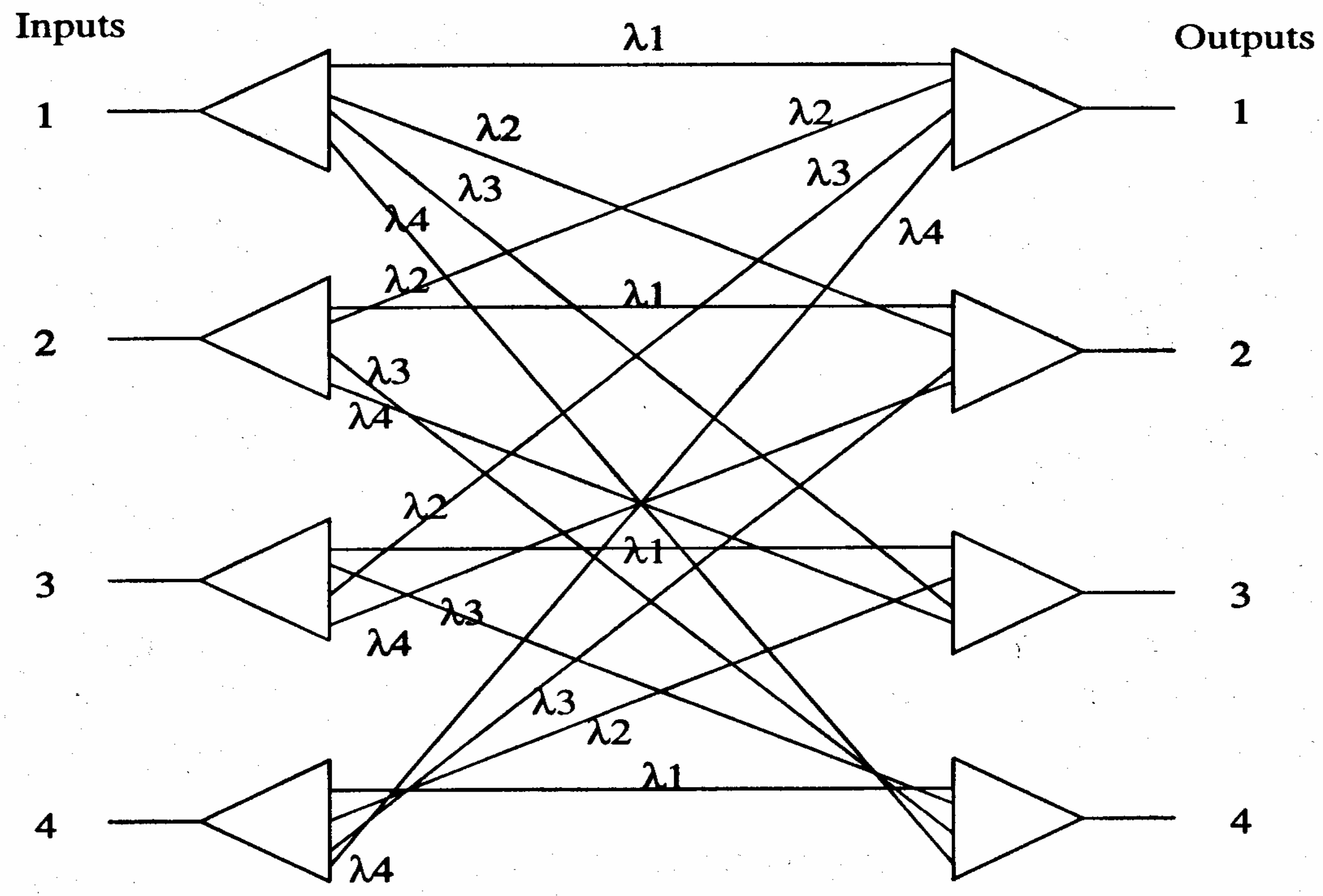
Device

Two Types of wavelength-routing devices

***Nonreconfigurable** :* there is no switching stage between the demultiplexers and the multiplexers, and the routes for different signals arriving at any input port are fixed.

***Reconfigurable**:* The routing function of the switch can be controlled electronically.

nonreconfigurable wavelength router
Passive Router



Reconfigurable Wavelength-Routing Switch

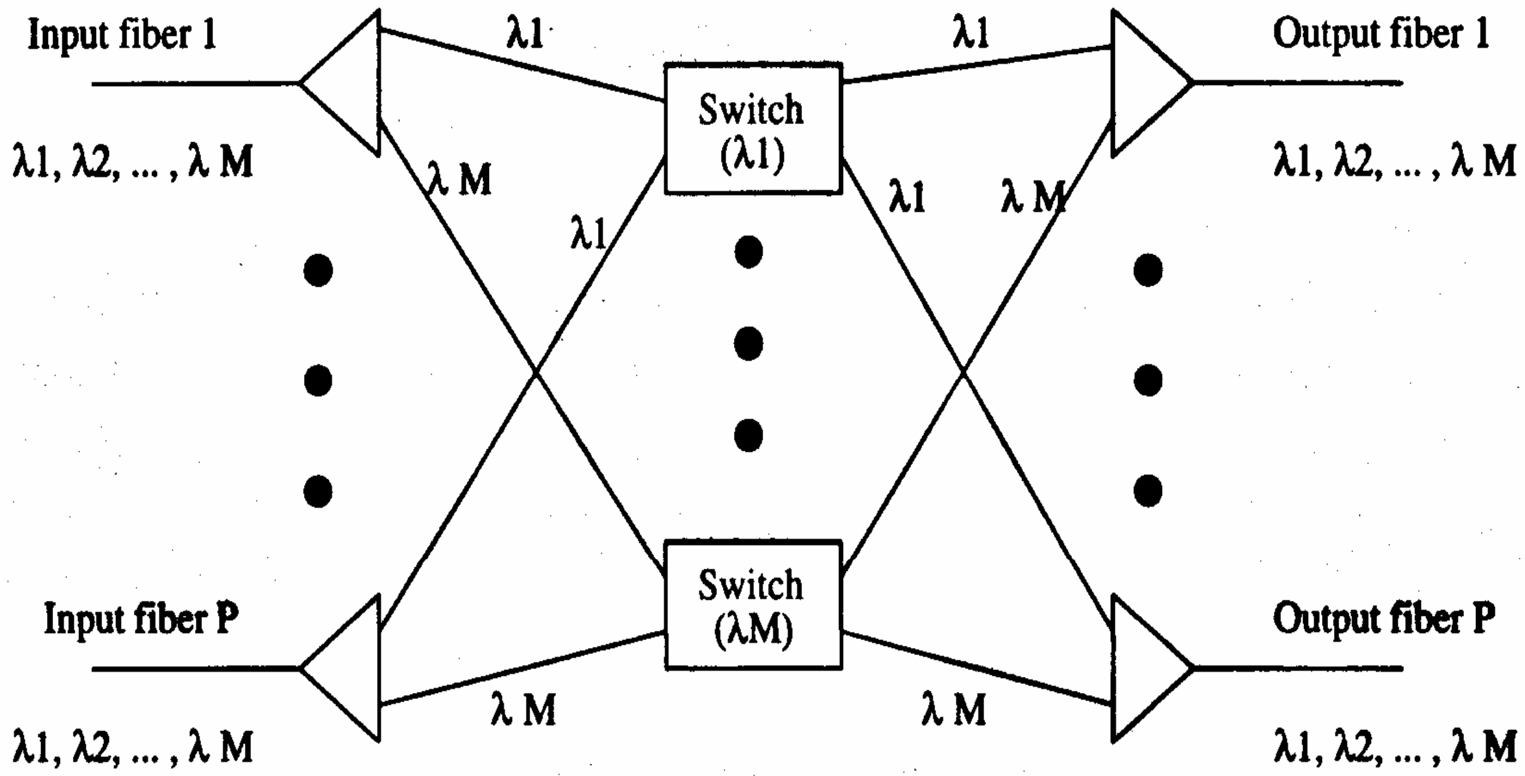
A reconfigurable wavelength-routing switch (WRS), also referred to as a wavelength selective crossconnect (WSXC), uses photonic switches inside the routing element.

The WRS has *P* incoming fibers and *P* outgoing fibers. On each incoming fiber, there are M wavelength channels. Similar to the nonreconfigurable router, the wavelengths on each incoming fiber are separated using a grating demultiplexer.

more flexible than passive, non-reconfigurable, wavelength-routed networks, because they provide additional control in setting up connections.

The routing is a function of both the wavelength chosen at the source node, as well as the configuration of the switches in the network nodes.

Reconfigurable Wavelength-Routing Switch (Active Switch)



A P × P reconfigurable wavelength-routing switch with M wavelengths.

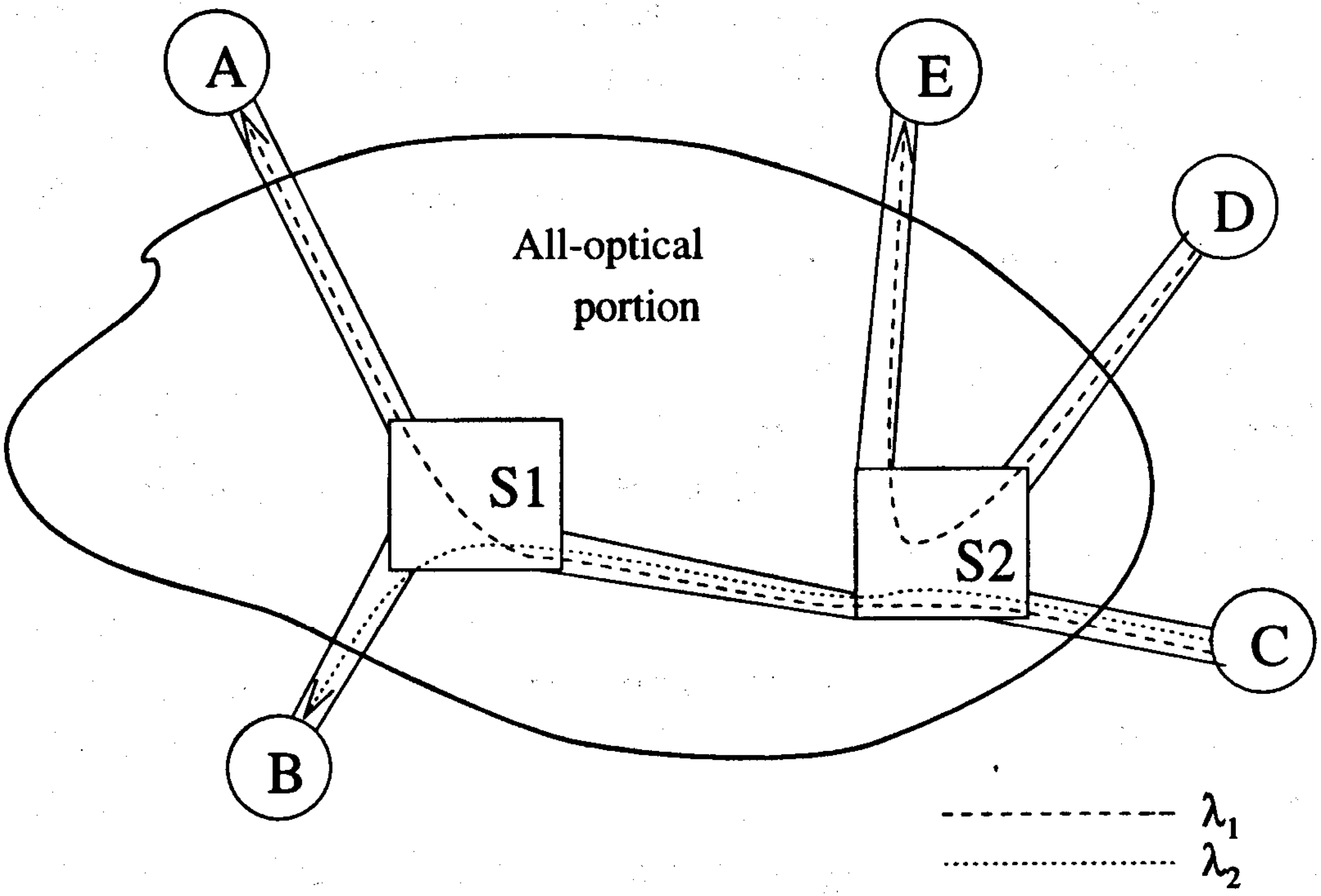
Wavelength Conversion

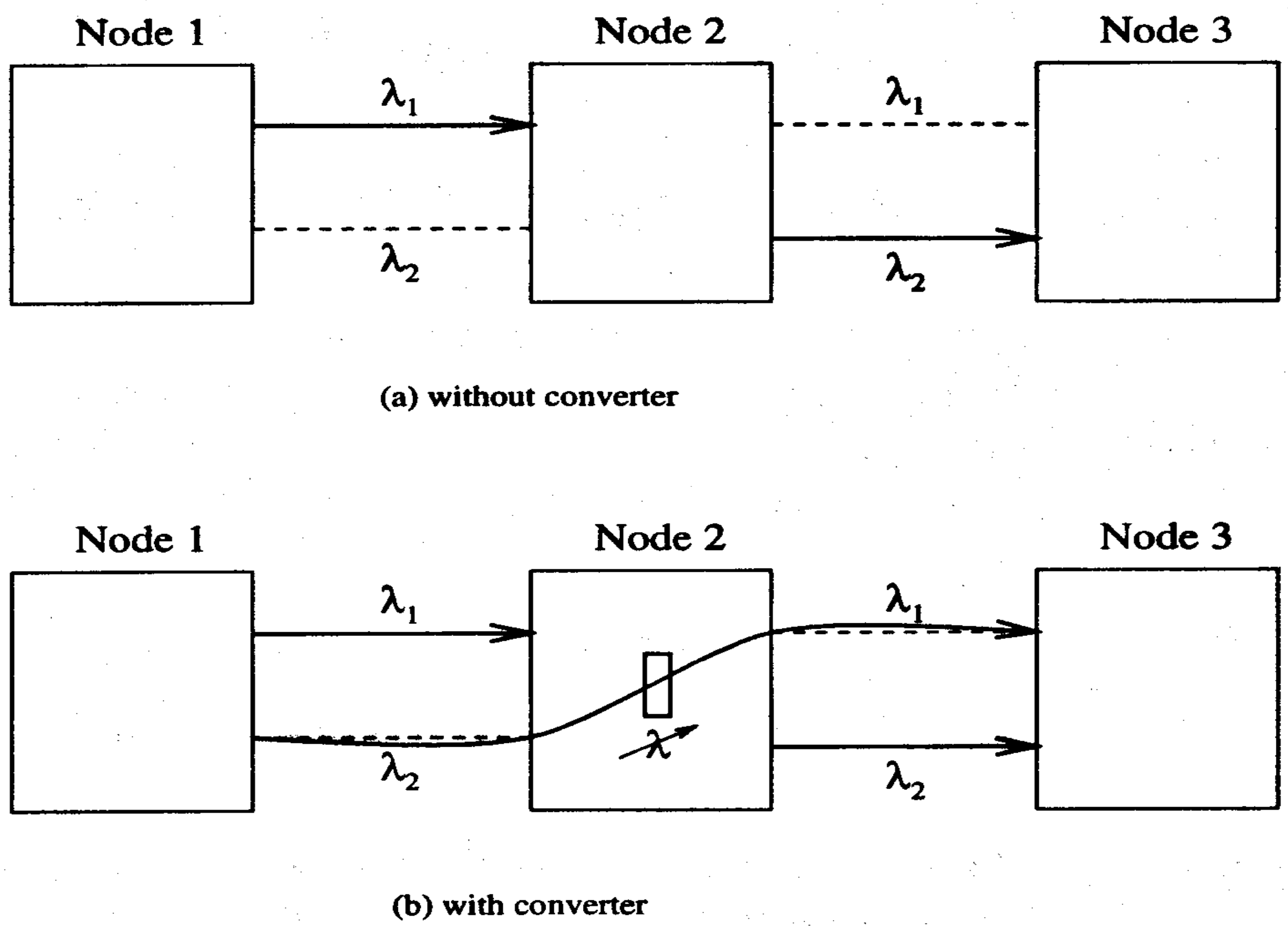
To establish a lightpath, we require that the *same* wavelength be allocated on all the links in the path.

This requirement is known as the *wavelength-continuity constraint (e.g.,* see [BaMu96]).

This constraint distinguishes the wavelength-routed network from a circuit-switched network which blocks calls only when there is no capacity along any of the links in the path. assigned to the call.

All-Optical Network





·e 2.26 Wavelength-continuity constraint in a wavelength-routed network

Wavelength conversion

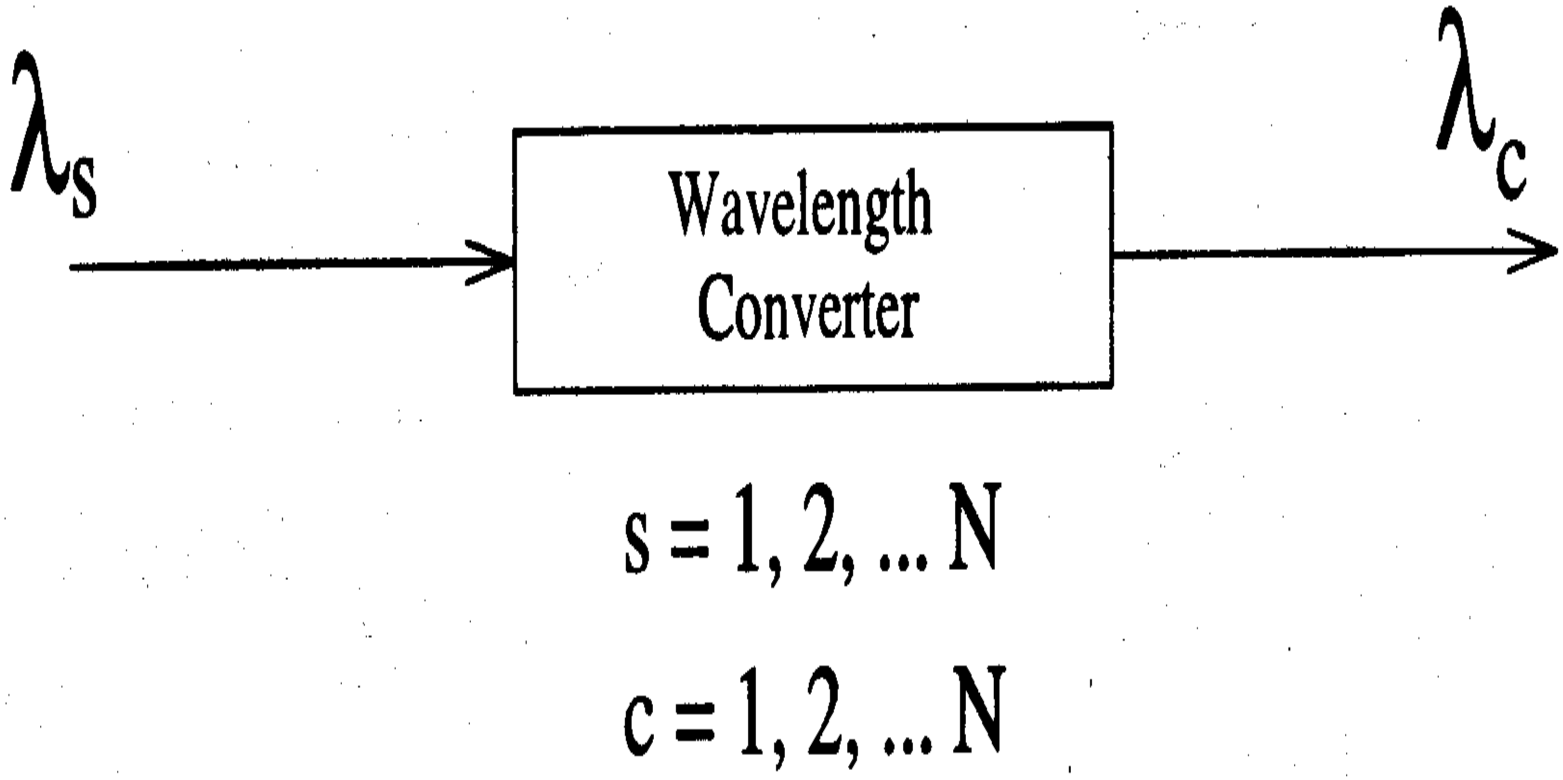
wavelength conversion:

It is easy to **eliminate the wavelength-continuity constraint**, if we were able to *convert* the data arriving on one wavelength along a link into another wavelength at an intermediate node and forward it along the next link.

a single lightpath in such *a wavelength-convertible network* can use a different wavelength along each of the links in its path.

Thus, wavelength conversion may improve the efficiency in the network by resolving the wavelength conflicts of the lightpaths.

Wavelength converter



2.27 Functionality of a wavelength converter.

Characteristics of WC

transparency to bit rates and signal formats,

fast setup time of output wavelength,

conversion to both shorter and longer wavelengths,

moderate input power levels,

possibility for same input and output wavelengths (i.e., no conversion),

insensitivity to input signal polarization,

low-chirp output signal with high extinction ratio7 and large signal-to-noise ratio, and

simple implementation.

Wavelength Conversion Technologies

Wavelength conversion techniques can be broadly classified into two types:

- *opto-electronic wavelength conversion:* the optical signal must first be converted into an electronic signal; and
- *all-optical wavelength conversion:* the signal remains in the optical domain.

WDM-based LAN

Single-hop systems

- The source node's transmitter and the destination node's receiver always tune to the same wavelength.
- Direct transmission without store-and-forward by intermediate nodes.
- Transmission coordination is necessary to avoid channel collision and receiver collision.

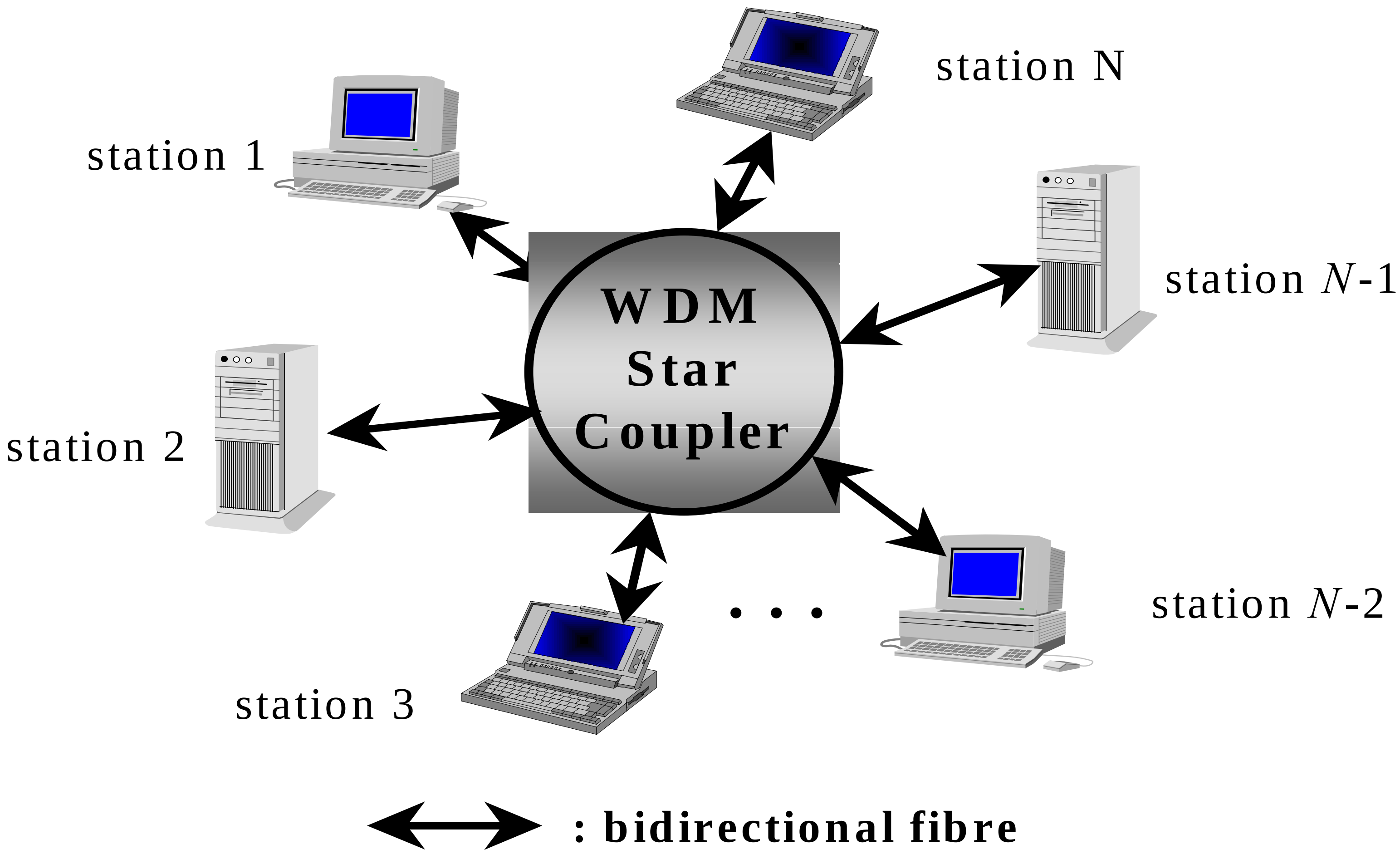
Multi-hop systems

- Only some pair of nodes have direct transmission.
- Traffic between two nodes may be stored-and-forwarded via intermediate nodes.
- Wavelength converter is need

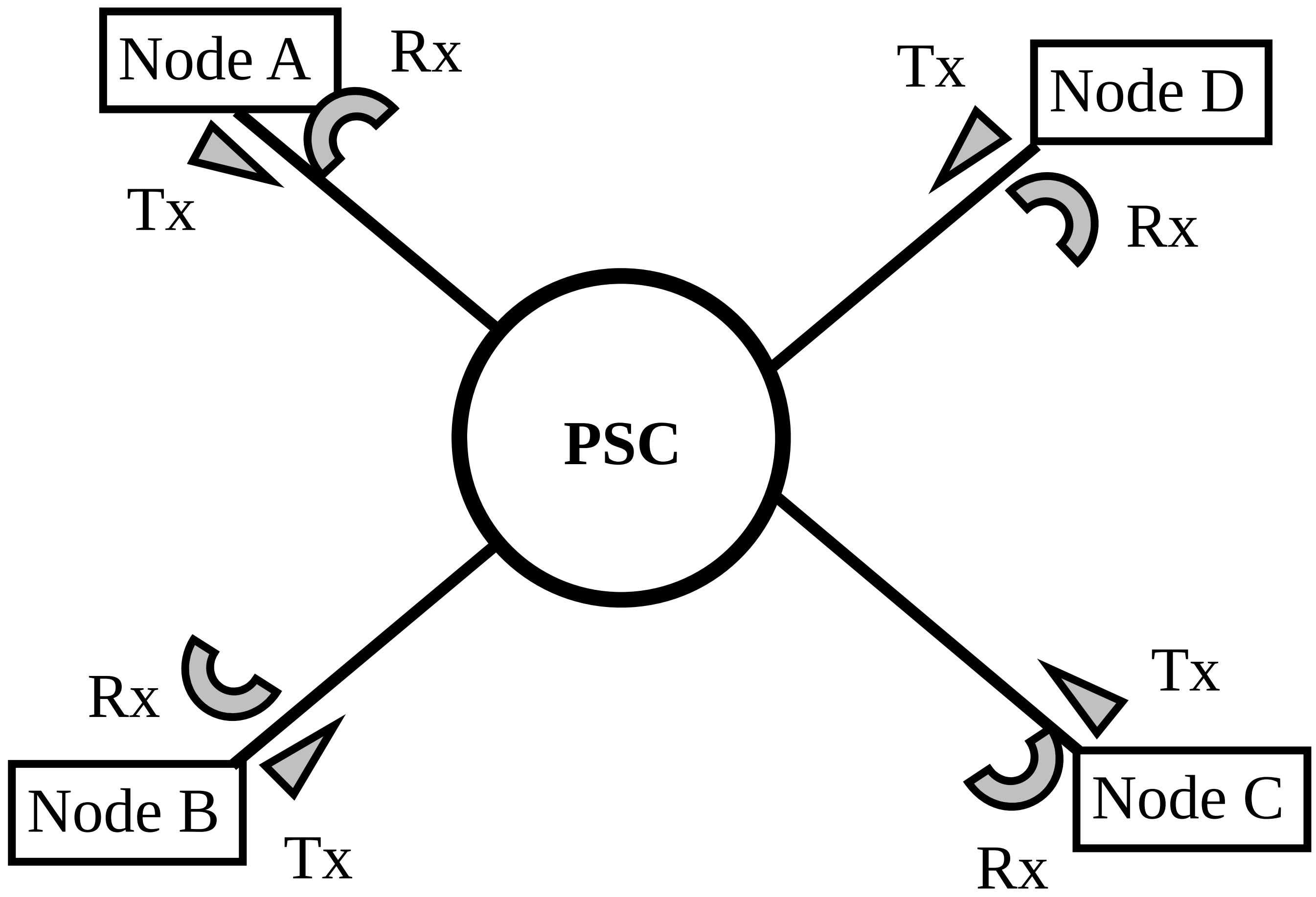
Single-Hop WDM Network

Network Model

A broadcast-and-select star-coupler topology is considered.



Passive Star Coupler



WDM Network Construction

Broadcast-and-Select (Local) Optical WDM Network

A local WDM optical network may be constructed by connecting network nodes via two-way fibers to a passive star,

The information streams from multiple sources are optically combined by the star and the signal power of each stream is equally split and forwarded to all of the nodes on their receive fibers.

A node's receiver, using an optical filter, is tuned to only one of the wavelengths; hence it can receive the information stream.

the passive-star can support "***multicast***" services.

Classified

Based on whether the nodal transceivers are tunable or not.

A node's network interface unit (NIU) can employ one of the following four structures:

- **Fixed Transmitter's and Fixed Receiver's:** *(FT -FR) suited for multi-hop system*
- **Tunable Transmitter(s) and Fixed Receiver(s):** *(TT -FR)*
- ***Fixed Transmitter(s) and Tunable Receiver(s)*** *(FT -TR)*
- ***Tunable Transmitter(s) and Tunable Receiver(s) -****(TT -TR)*

Experimental WDM Systems

British Telecom Research Lab (BTRL) [86] proposed multi-wavelength network.

IBM's **Bainbow**[93]

Columbia's TeraNet[91]

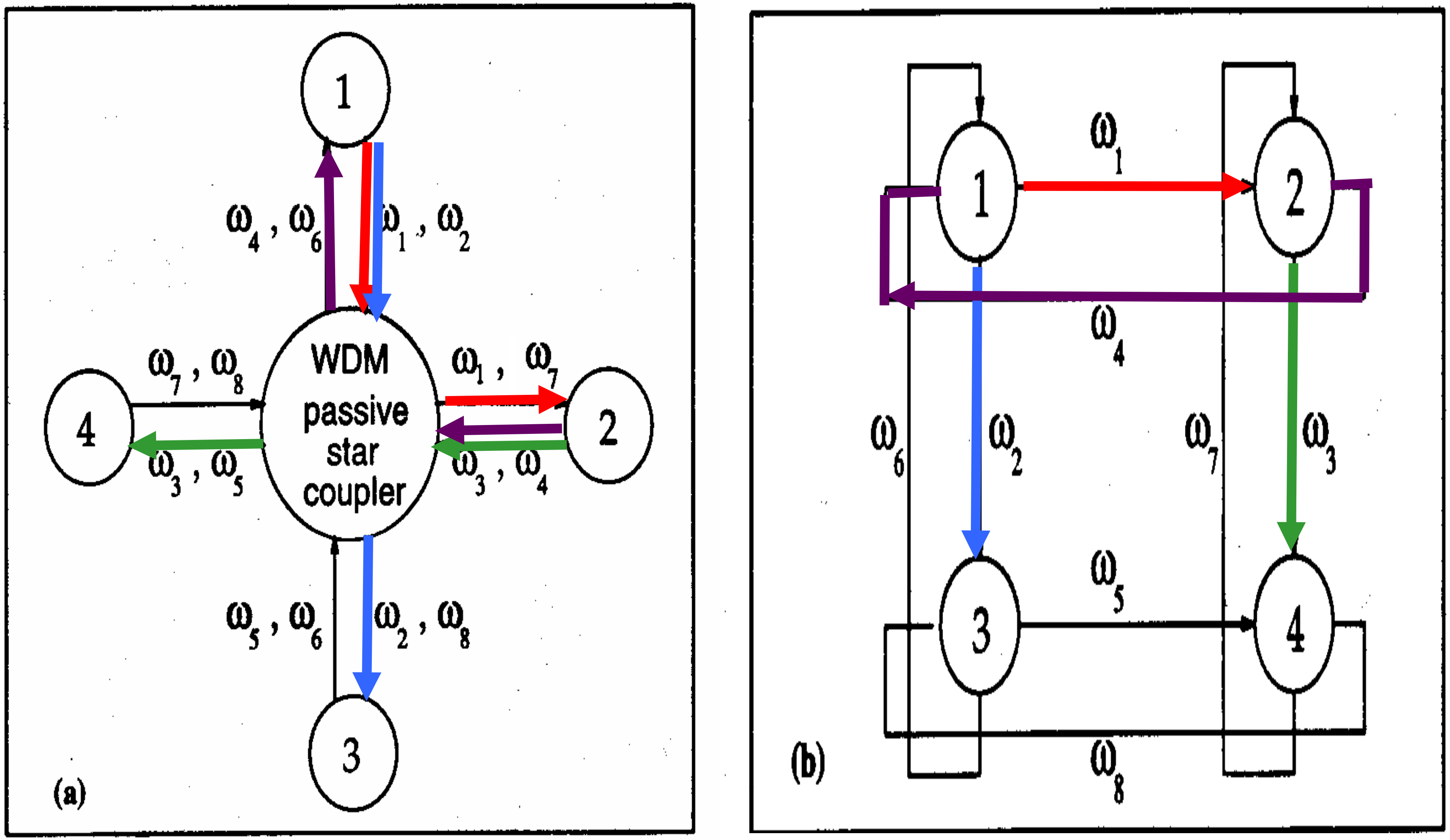
Stanford's **STARNET**[93]

Multi-Hop WDM Network

Characteristics of a Multihop System

the channel to which a node's transmitter or receiver is *static*,

this assignment is normally not expected to change except when a new global reassignment of all transceivers is deemed to be beneficial.


1
ω4 , ω6
ω1 , ω2
WDM
passive
star
coupler
ω7 , ω8
ω1 , ω7
4
2
ω3 , ω5
ω3 , ω4
ω5 , ω6
ω2 , ω8
3
(a)
ω1
1
2
ω4
ω6
ω2
ω7
ω3
ω5
3
4
ω8
(b)

How to design a good virtual topology

First, the virtual structure chosen must be close to "optimal" in some sense,

the structure's *average (hop distance)* between nodes must be small,

the average packet delay must be minimal, or

the maximum flow on any link in the virtual structure must be minimal.

Two nodes are at a hop *distance of h* ***if*** **the** ***shortest*** **path between them requires** ***h*** **hops.**

In a multi-hop structure, each such hop means "travel to the star and back."

The ***maximum hop distance*** **between any two nodes is referred to as the structure's** *diameter***.**

Multi-hop networks with small h and small diameter are desirable.

How to design a good virtual topology

Simple routing mechanisms must be employed.

A routing-related subproblem is the *buffering strategies* at the intermediate nodes.

- **Some approaches propose the use *of* "**deflection routing**" under which a packet, instead *of* being buffered at an intermediate node, may be intentionally misrouted but still reach its destination over a slightly longer path.**

Wavelength-Routed WDM Network

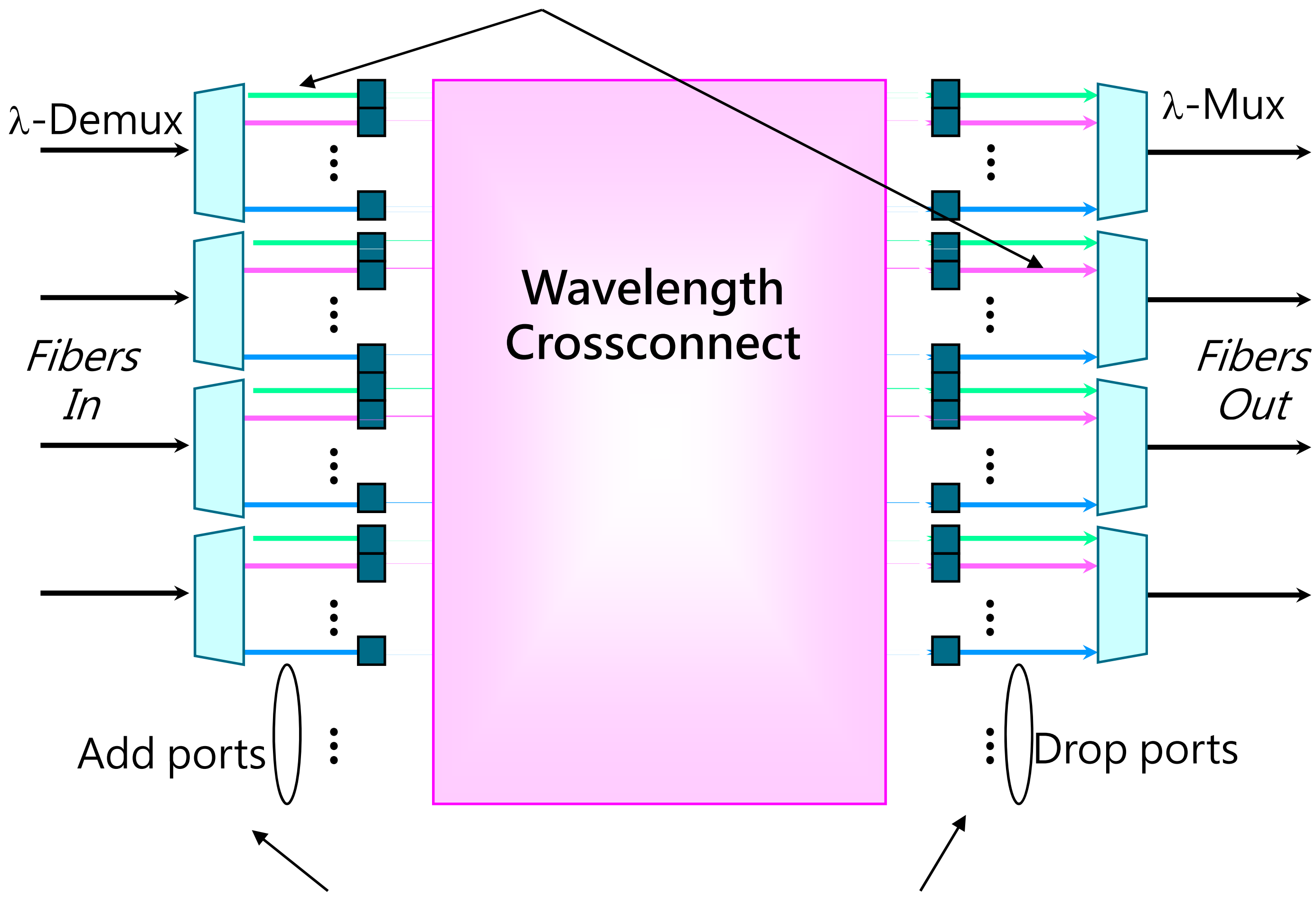
Wavelength-Routed (Wide-Area) Optical Network

The network consists of a *photonic switching fabric*, comprising "active switches" connected by fiber links to form an arbitrary physical topology.

Each end-user is connected to an active switch via a fiber link. The combination of an end-user and its corresponding switch is referred to as a network node.

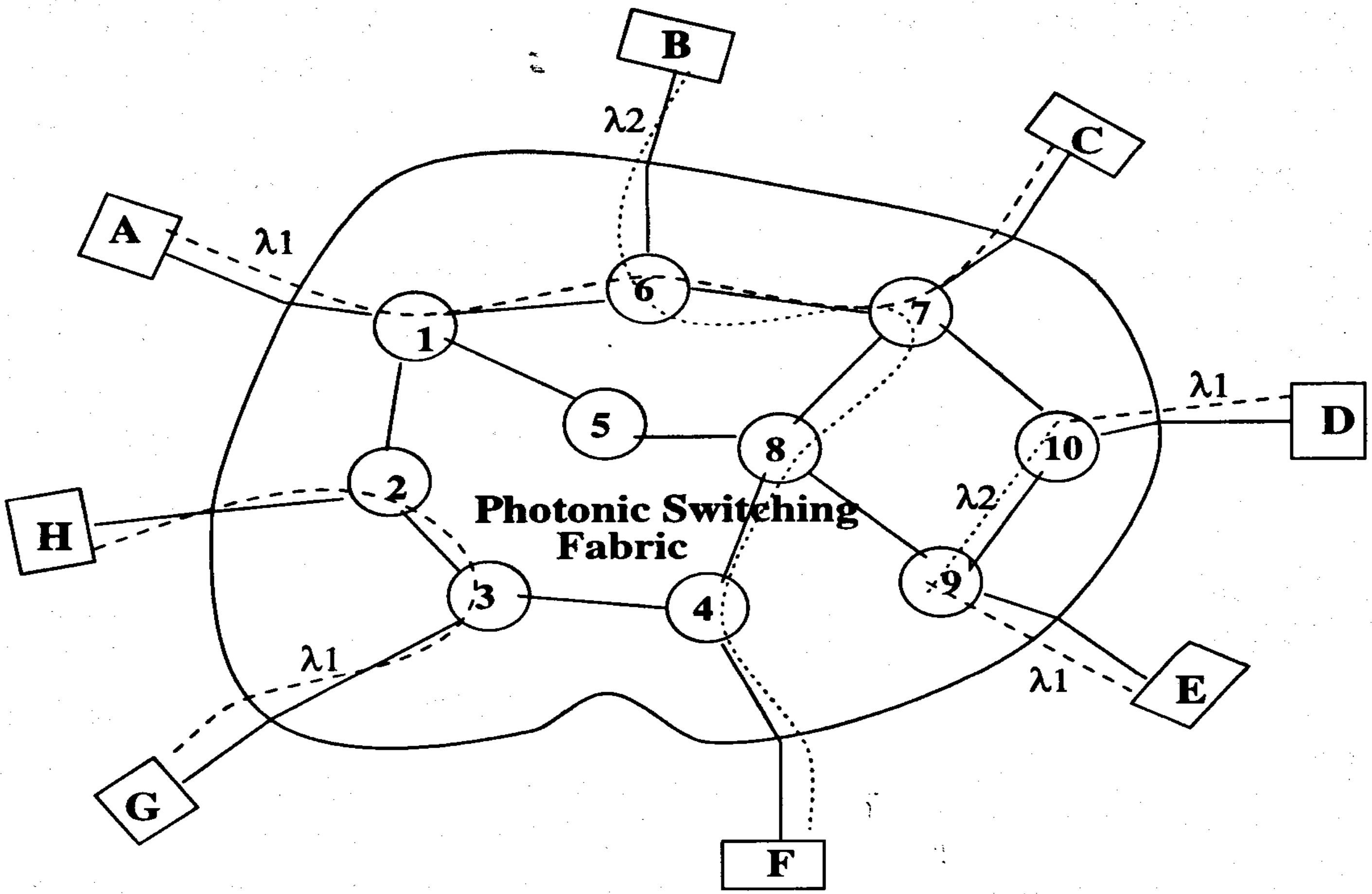
Each node (at its access station) is equipped with a set of transmitters and receivers, both of which may be wavelength tunable. A transmitter at a node sends data into the network and a receiver receives data from the network.

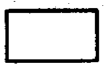
Optical Crossconnect (OXC)



Add-Drop Multiplexer (ADM)

Wavelength-Routed Network



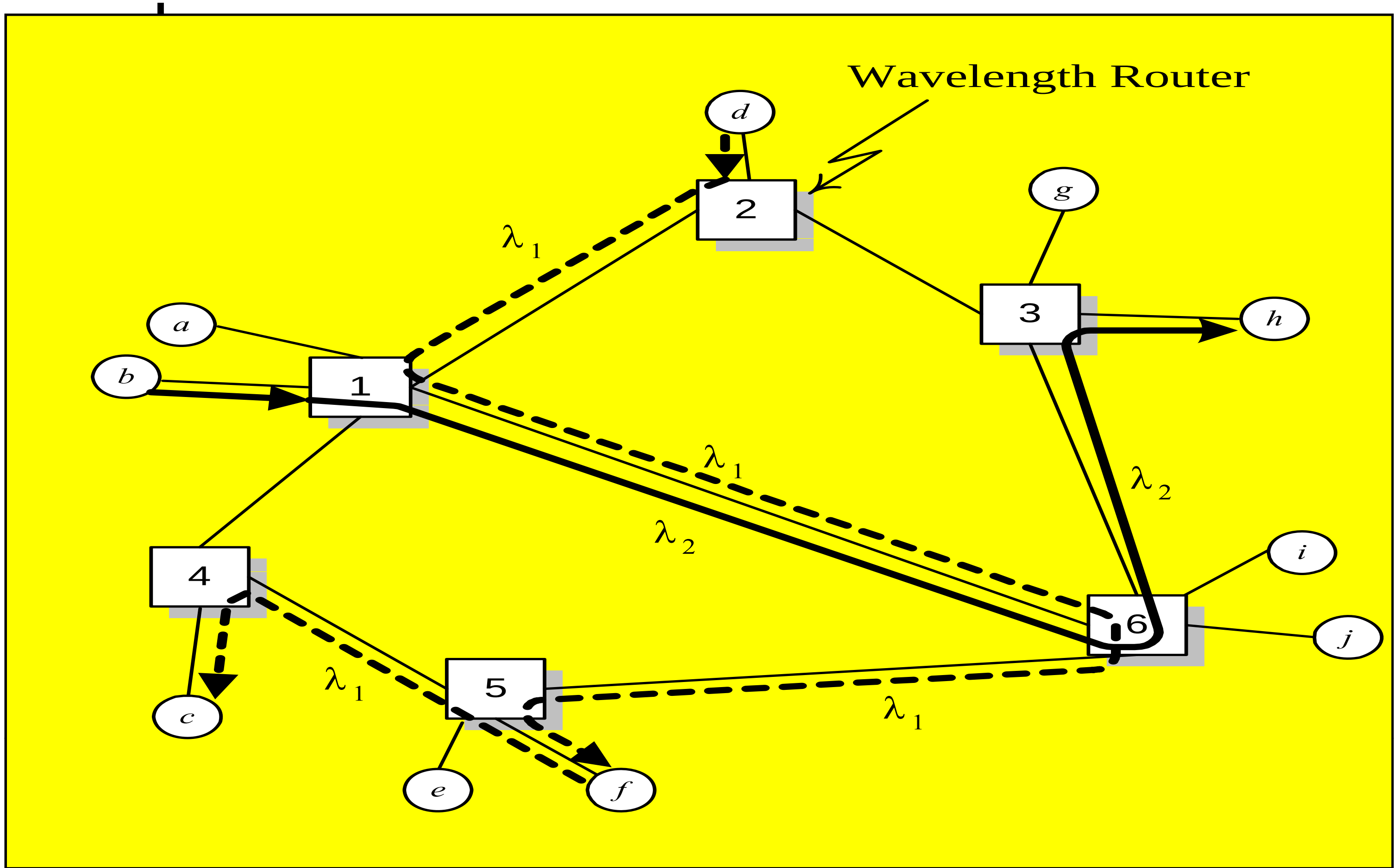


Access Station: Contains (tunable) transmitters and receivers.

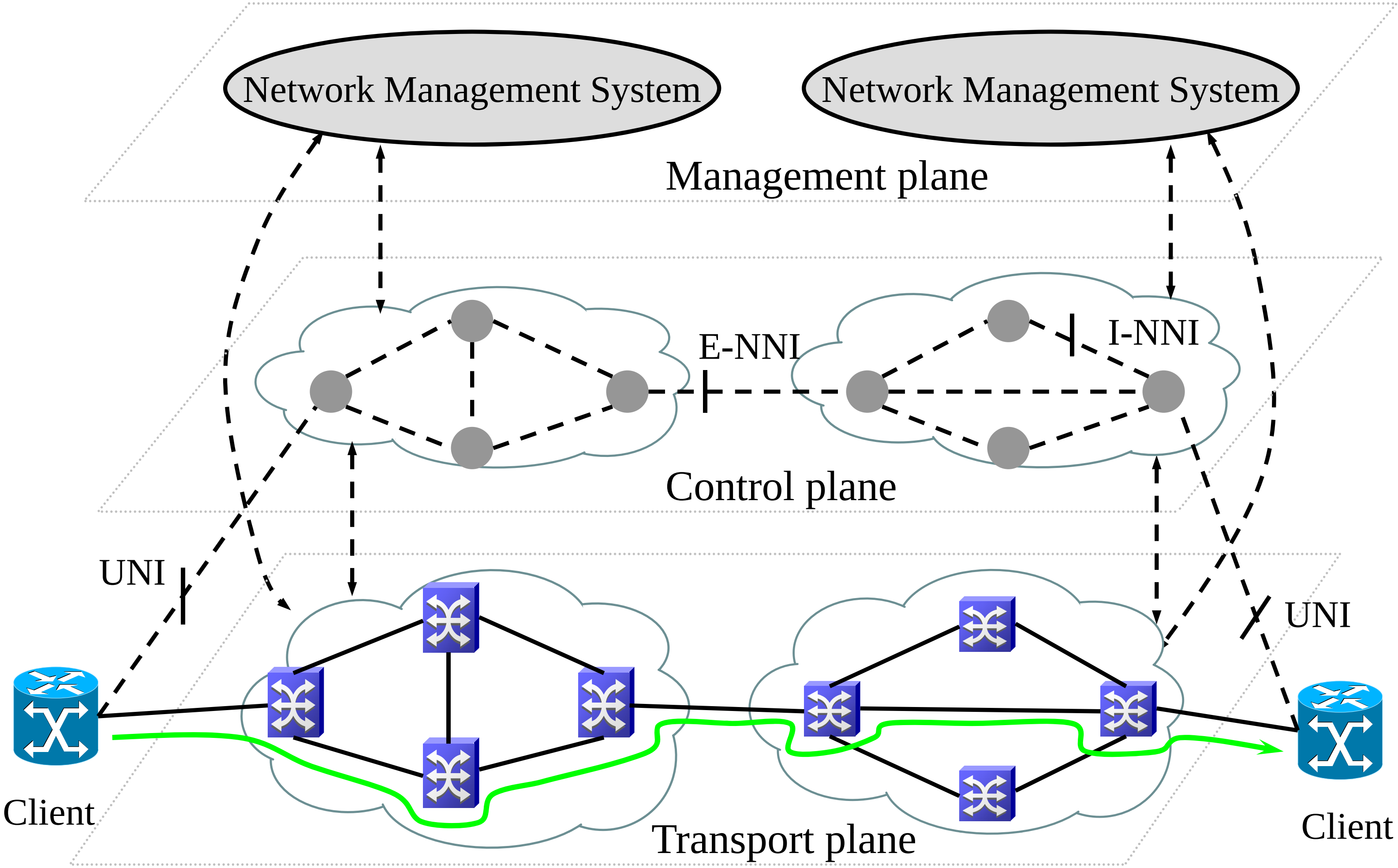
Switch: Contains photonic switch, and perhaps photonic amplifiers, wavelength converters, etc.

Wavelength-Routed Network

Light-path: the all-optical communication channel between two



Wavelength-Routed WDM Networks

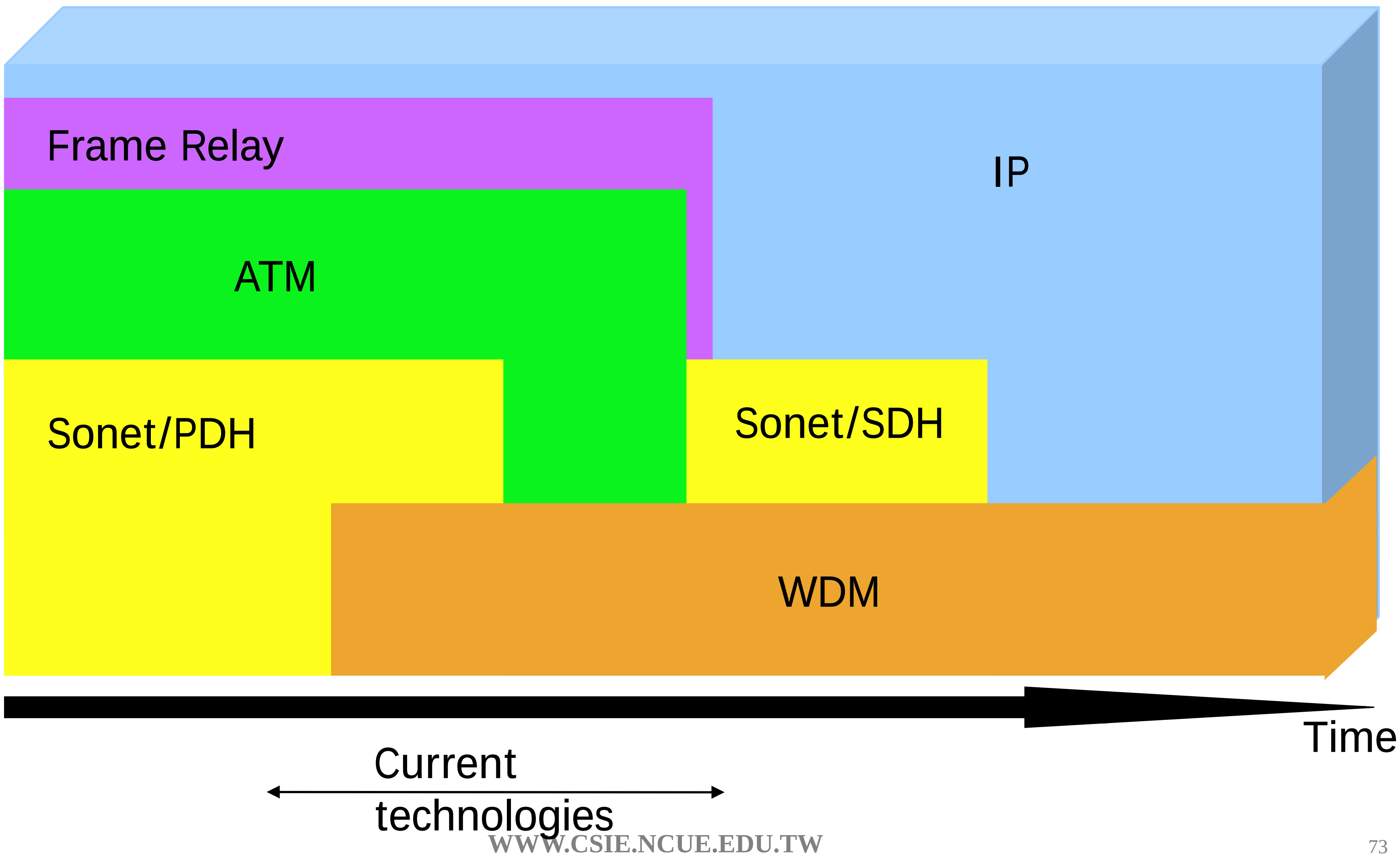


Wavelength-Routed Network

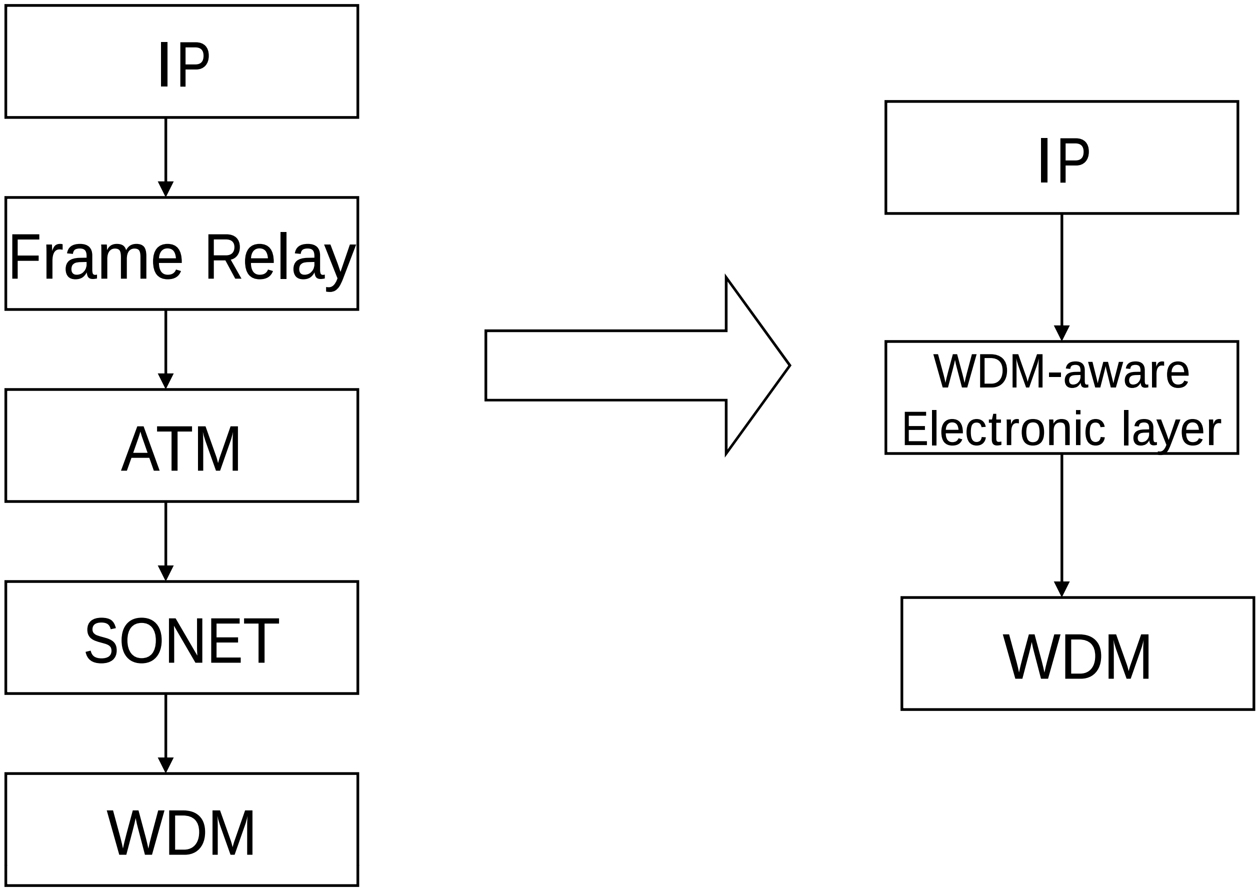
- Wavelength continuity
  - A light-path is required to be on the same wavelength throughout its path.
  - Wavelength converter can be used to change the wavelength in one light-path.
- Different light-paths traversing the same fiber must be on different wavelengths

Research Issues

EVOLUTION of IP PROTOCOL STACK



Simplified Protocol Stacks?

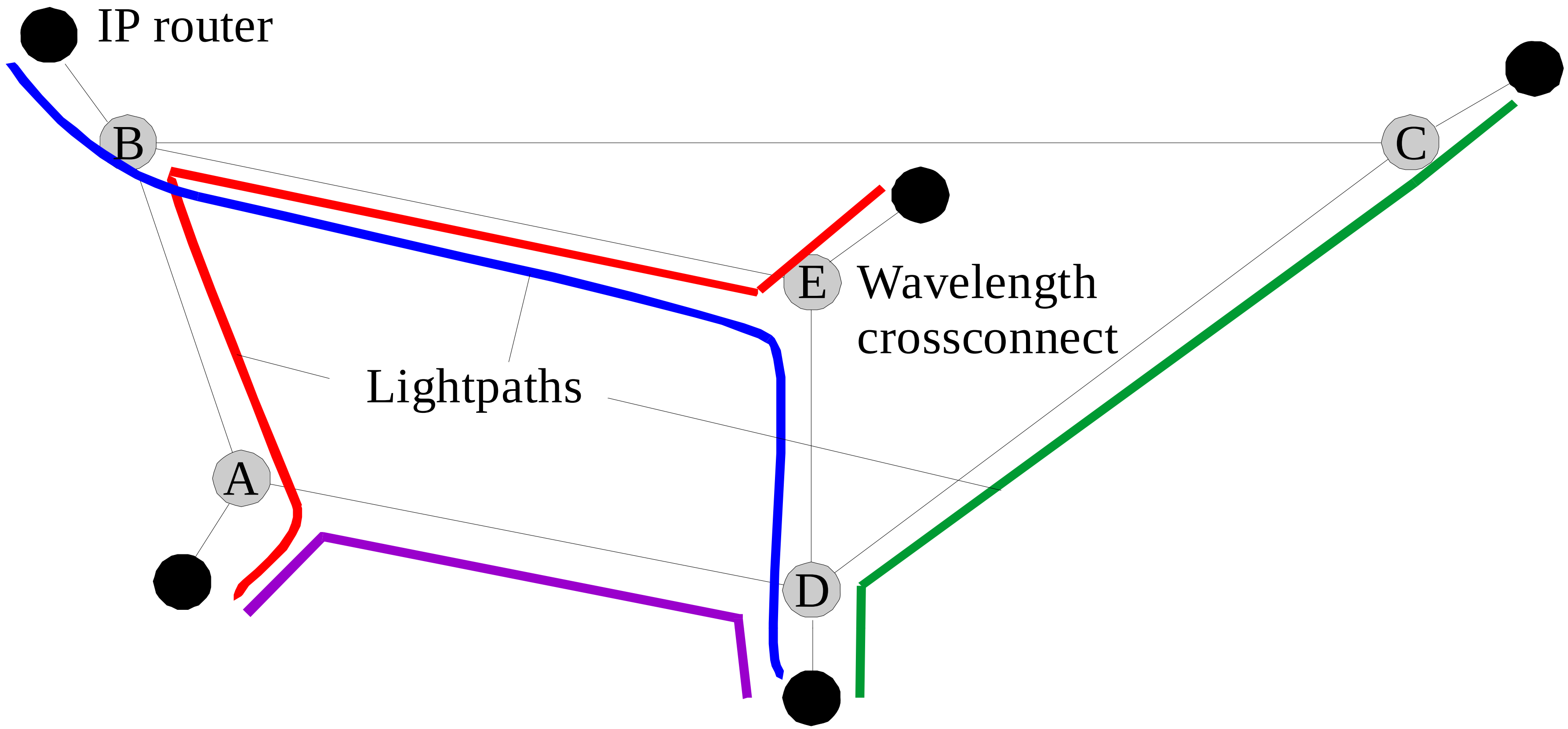


Current Typical Protocol Stack   Simplified Protocol Stack

IP Directly Over WDM?

Establish high-speed optical layer connections (lightpaths)

IP routers connected through lightpaths rather than fiber



Protocol Extensions

MPλS (Multi-protocol Lambda Switching)

an extension of MPLS to support lightpath,

A Label in MPλS is a λ that data are transmitted on.

maps an incoming wavelength to an outgoing wavelength

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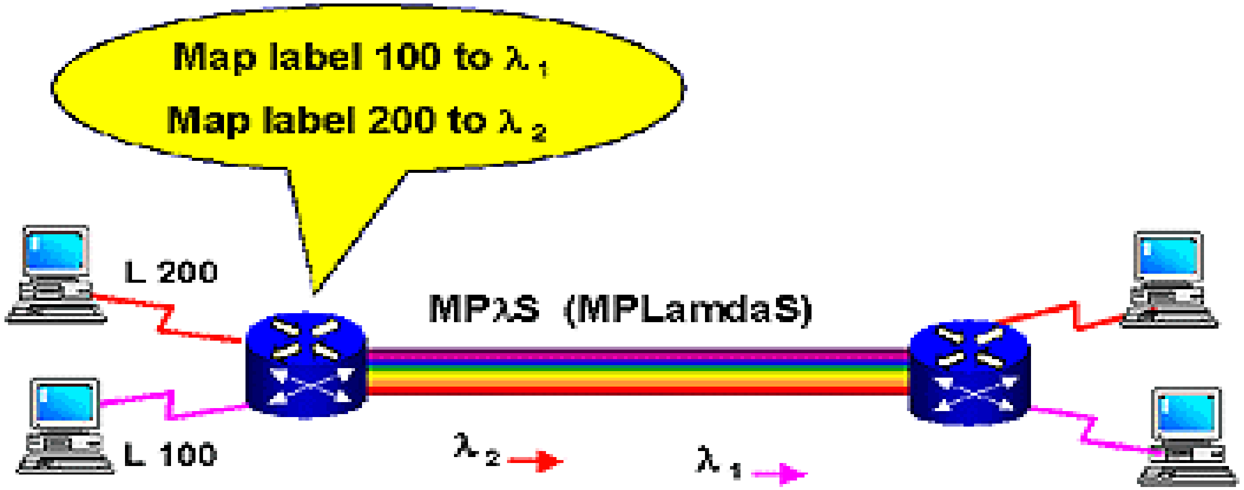
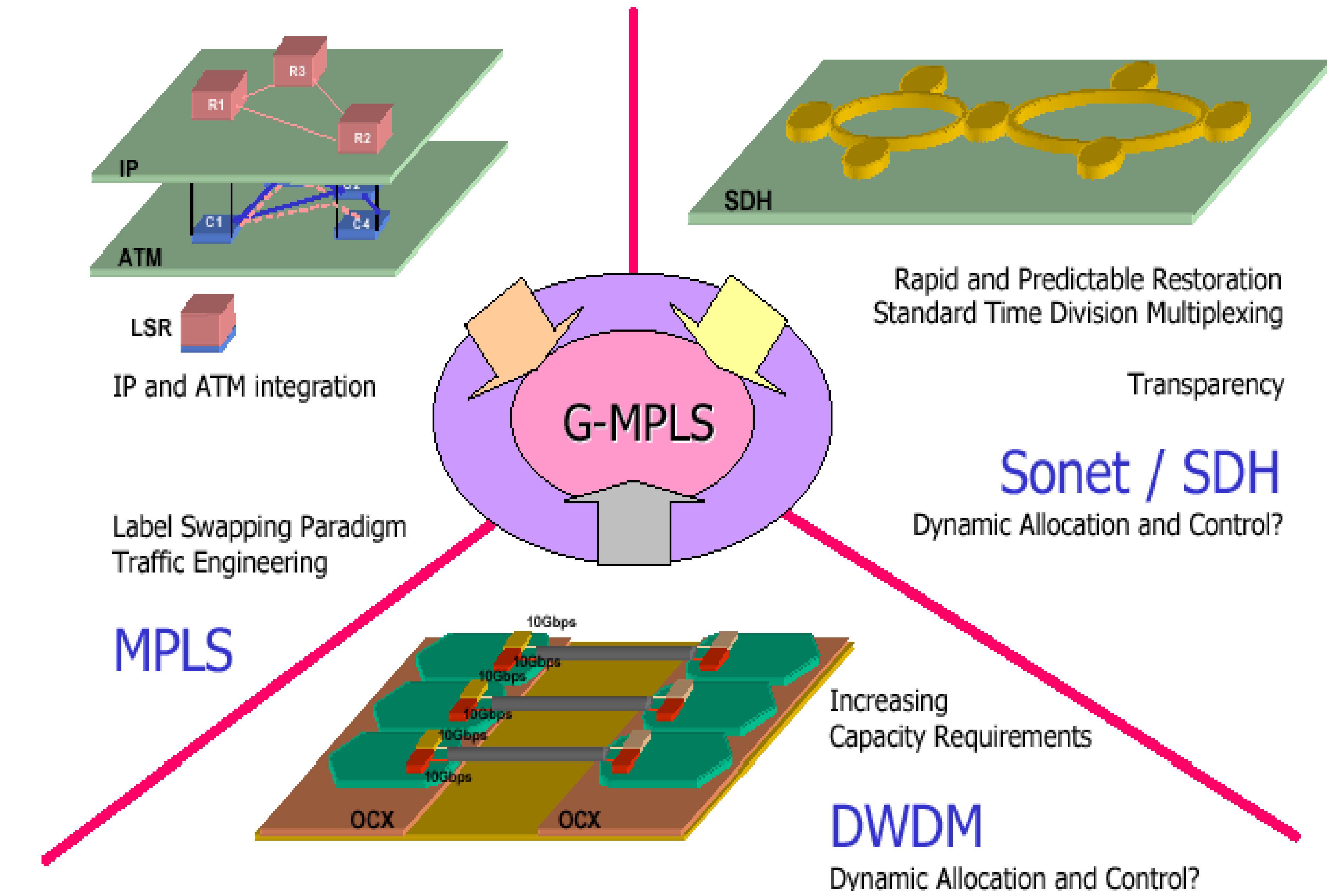


Protocol Extensions...

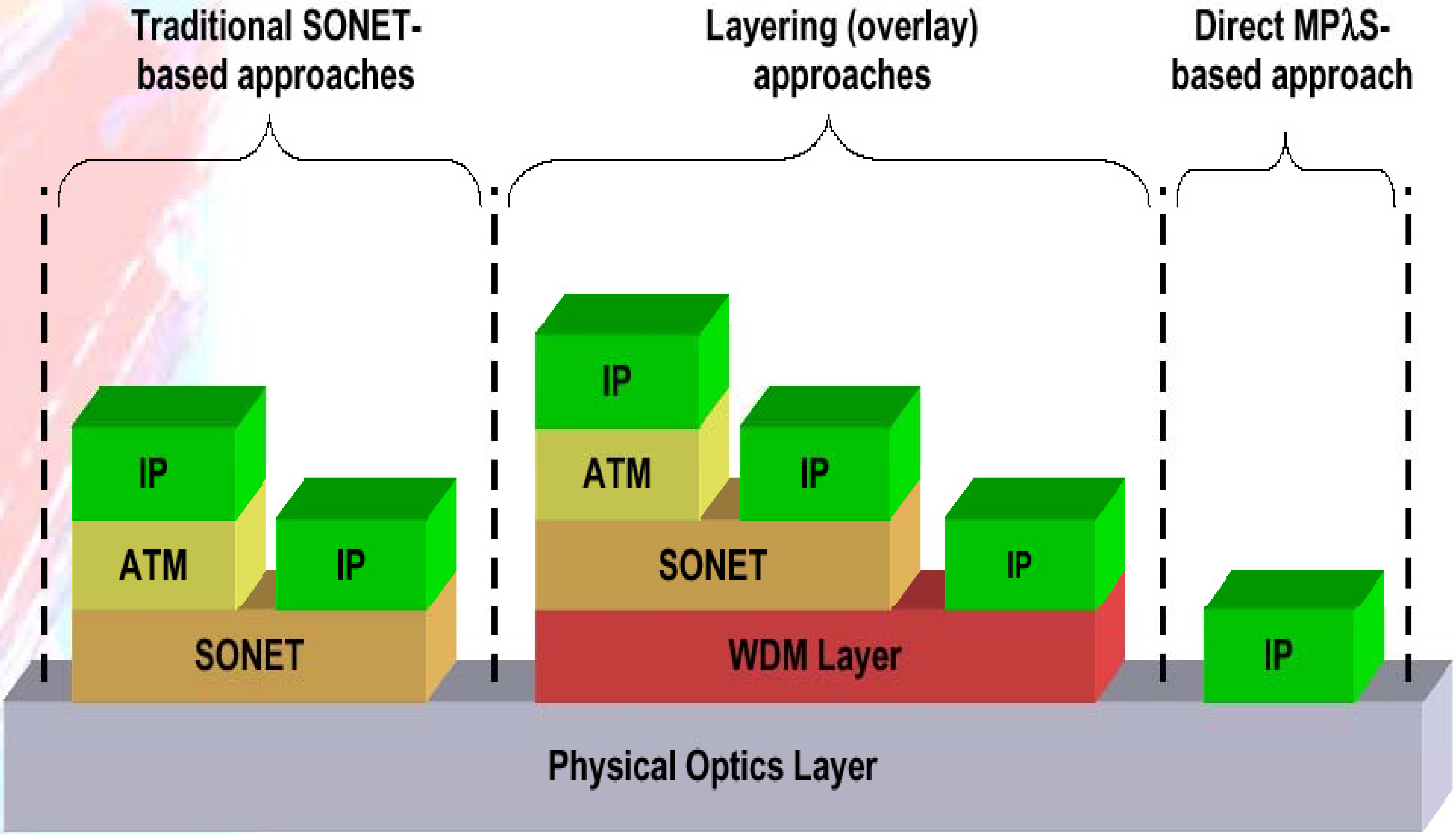
Generalized MPLS (GMPLS)

- Is based on older MPλS (MPλS is a subset of GMPLS)
- Proposes a single unified control plane
  - Signaling extensions (suggested labels)
  - Routing extensions
  - Link Management Protocol (IMP)
- Tries to integrate different switching paradigms
  - TDM switching (for SONET, time slots are the labels)
  - FDM switching (electromagnetic frequency is the label)
  - Lambda switching (λ is the label)
  - more

Historic Evolution



High-Level Overview of Network Integration Models



Challenges

Complexity?

GMPLS will be very complex when to be actually implemented.

Customer need not absorb the increasing complexity of the network to provision end-to-end services.

Interoperability?

It lies in the fact that as the optical networking has evolved.

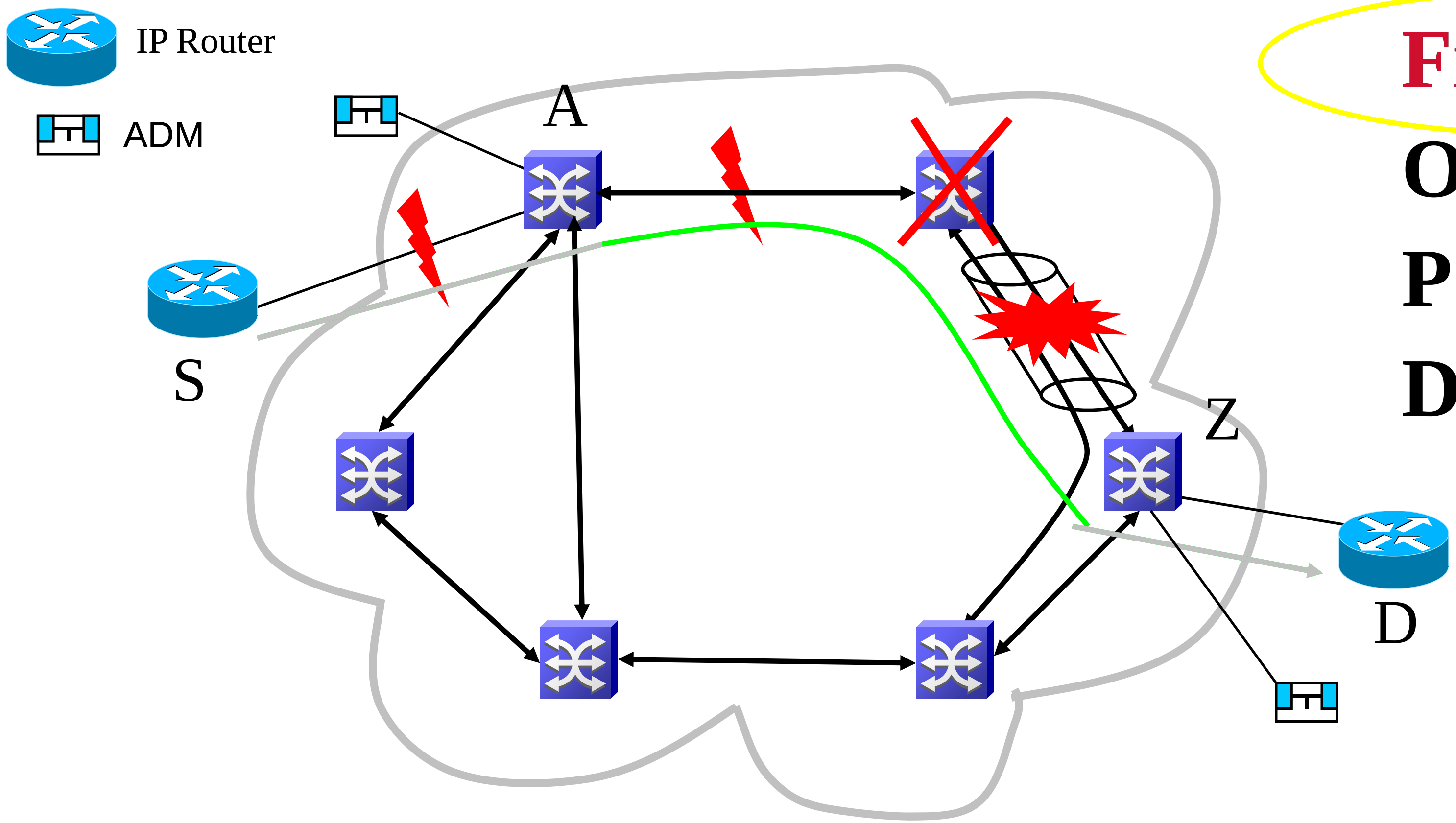
Protection and Restoration

Since the fiber link carries high-speed traffic, if a link goes down then the disruption is significant.

Resiliency achieved by

- ***Protection:*** **pre assign capacity to ensure survivability**
- ***Restoration:*** **in case of link-failure re-route the traffic using available capacity.**

Why Survivability?



Fiber cut

OXC

Port

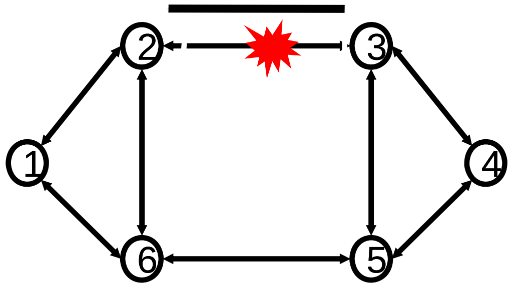
Duct

Single-fiber cut: 160λ/fiber * OC192/λ ≅ 307.2 Tb/s

WDM Mesh Protection

Mesh Protection

Link Protection



Before Fault

Fault Occurs

Recovery
After Fault

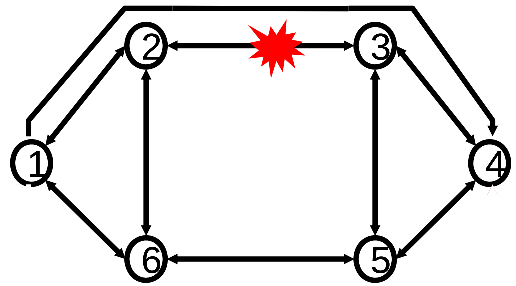
------- Resources to back up “link (2,3)” failure (backup for other links not shown here)

- Inefficient use of backup resources
- Fast protection-switching time

Dedicated L.P.

Shared L.P.

Path Protection



Before Fault

Fault Occurs

Recovery
After Fault

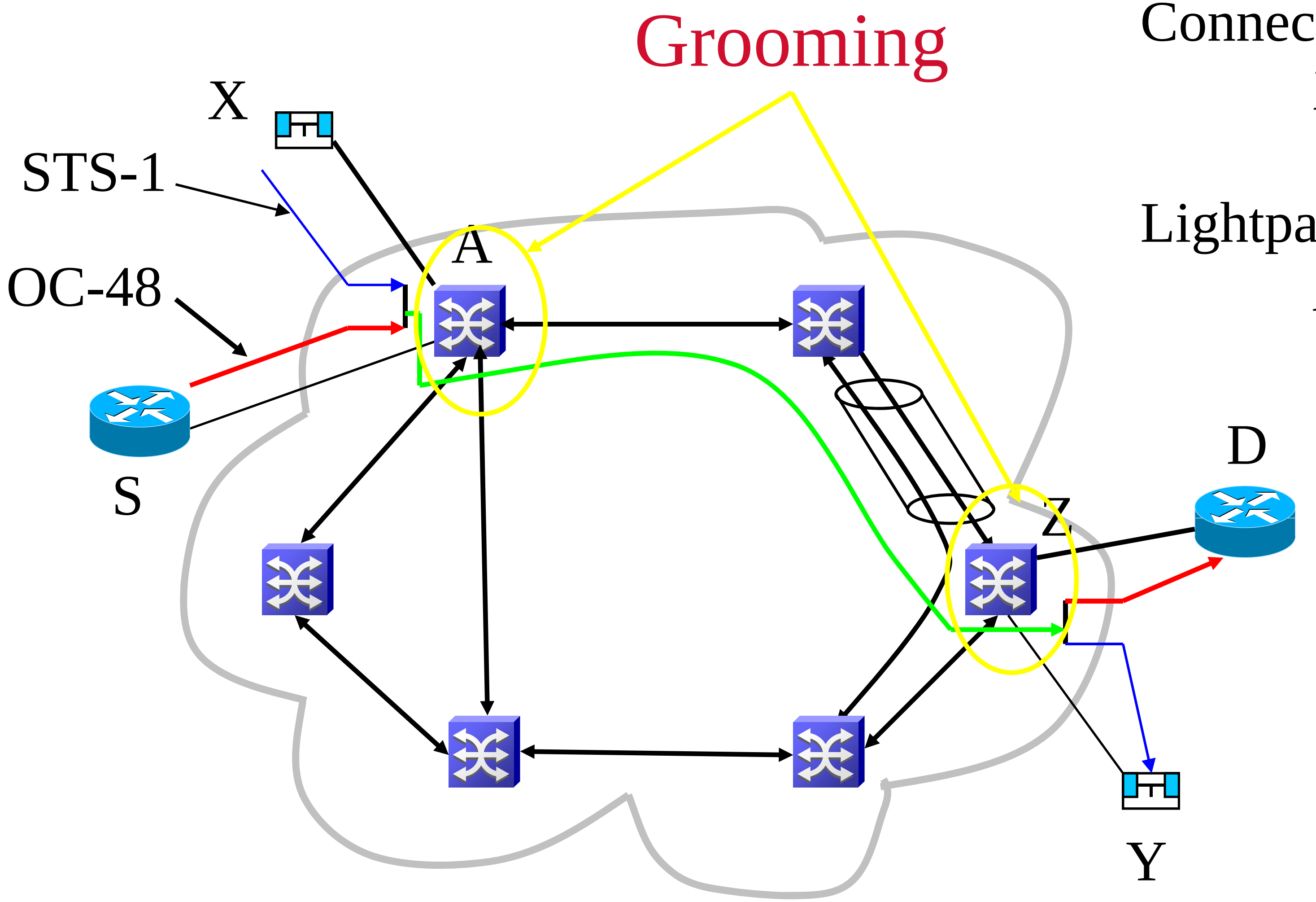
------- Backup (end-to-end) lightpath

- Lot more efficient than L. P.
- Long routes may require somewhat longer switching time

Dedicated P.P. (1+1, 1:1)

Shared P.P. (M:N)

Traffic Grooming



Connections:

X to Y, STS-1

S to D, OC-48

Lightpath:

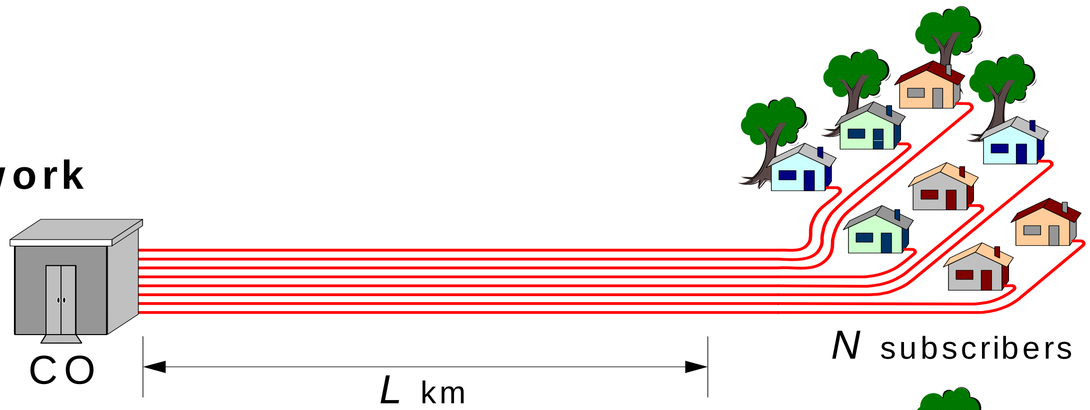
A to Z, OC-192

Point to Point vs. PON

(a) Point-to-point network

N fibers

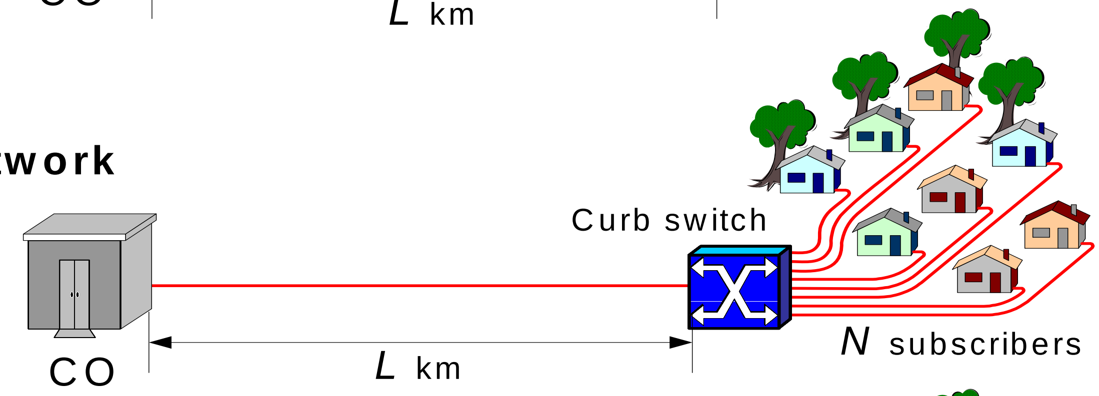
2*N* transceivers



(b) Curb-switched network

1 fiber

2*N*+2 transceivers



(c) Passive optical network

1 fiber

N transceivers