Optical Network Technologies Overview

KIS FRI ZU
PrS II

Roman Kaloč, Richard Wittlinger

Terminology

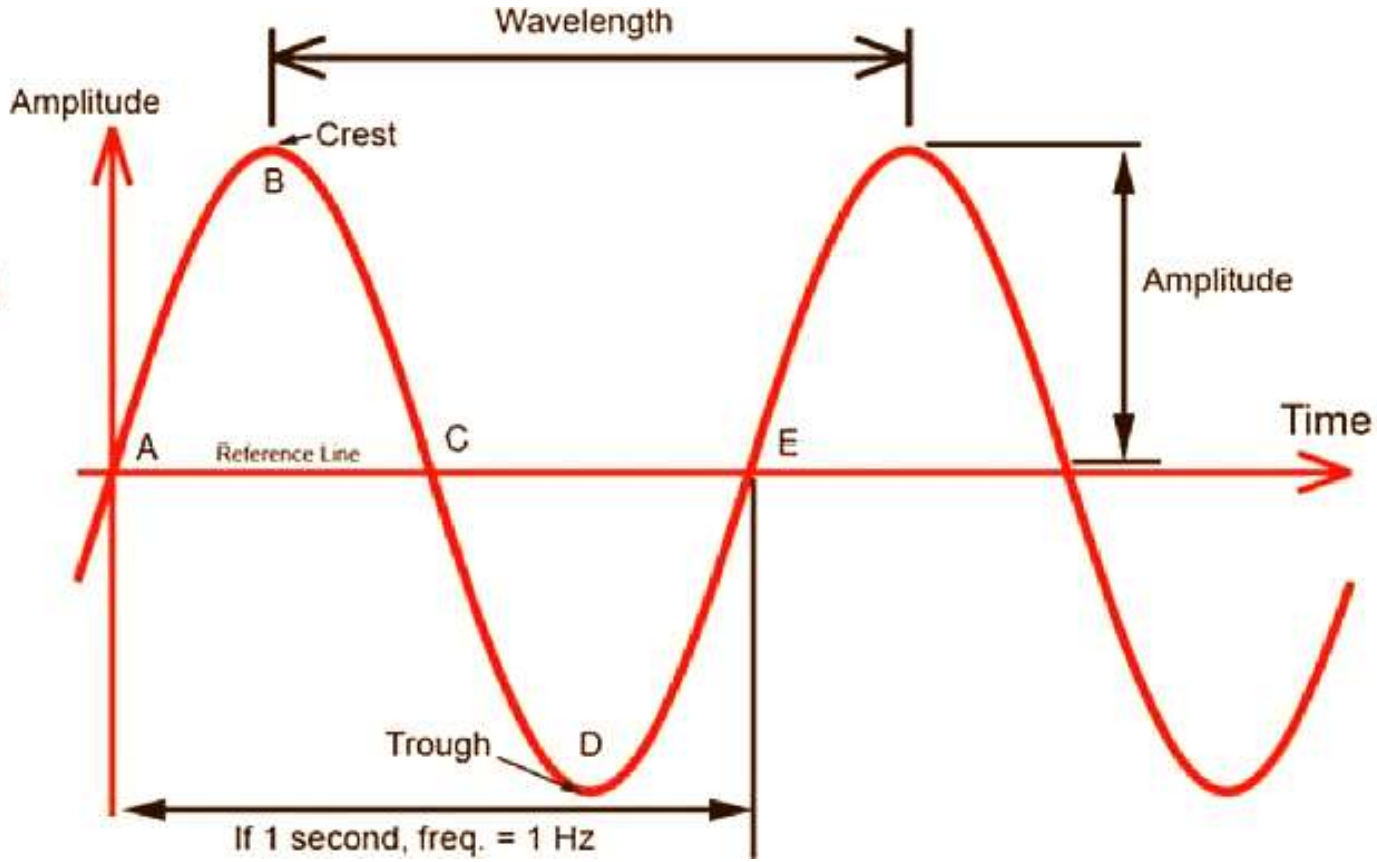
$c = f\lambda$

c = velocity of light in a vacuum = 3×10^8 m/s (constant)

f = frequency (Hz)

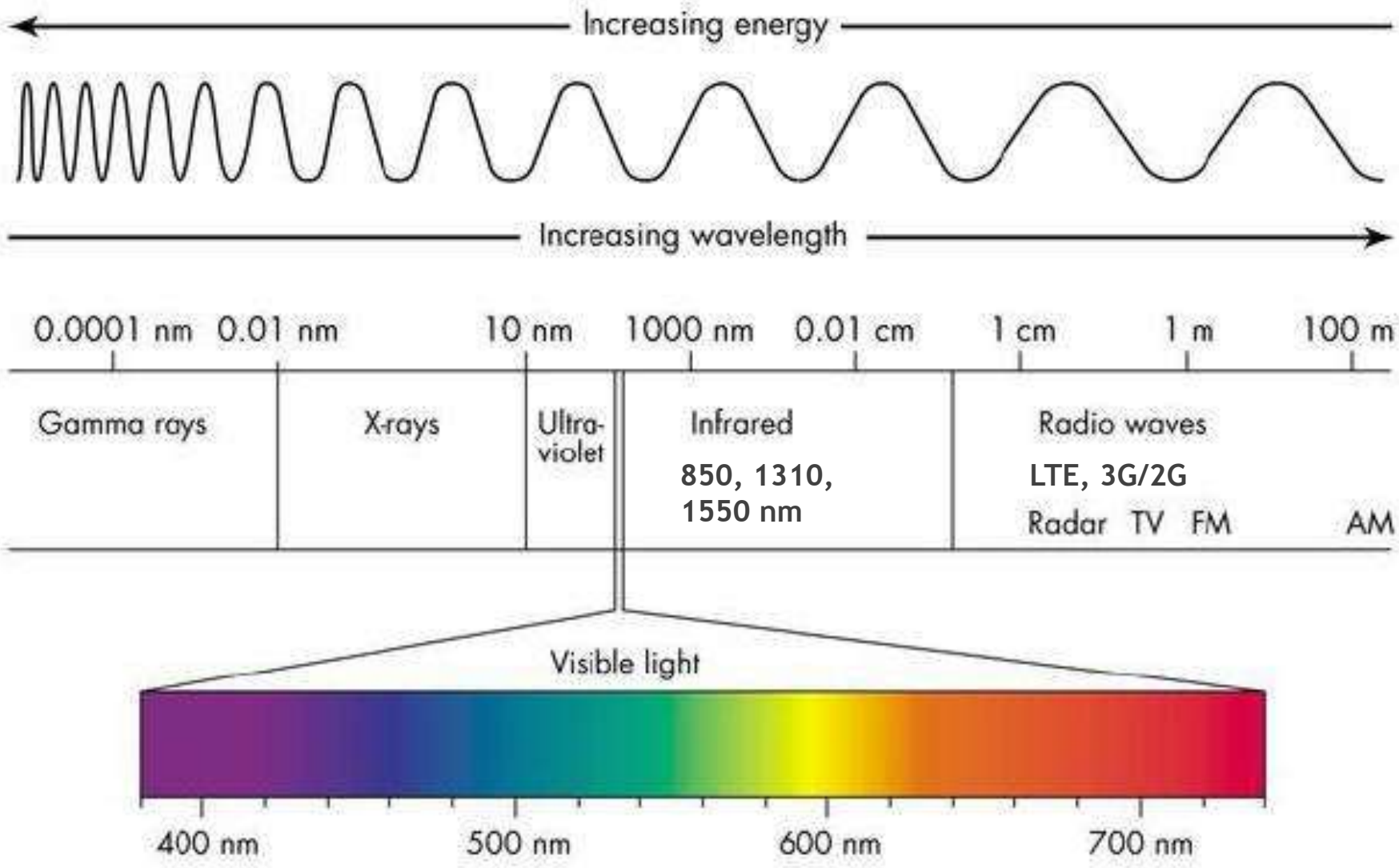
λ = wavelength (m)

$f \propto 1/\lambda$

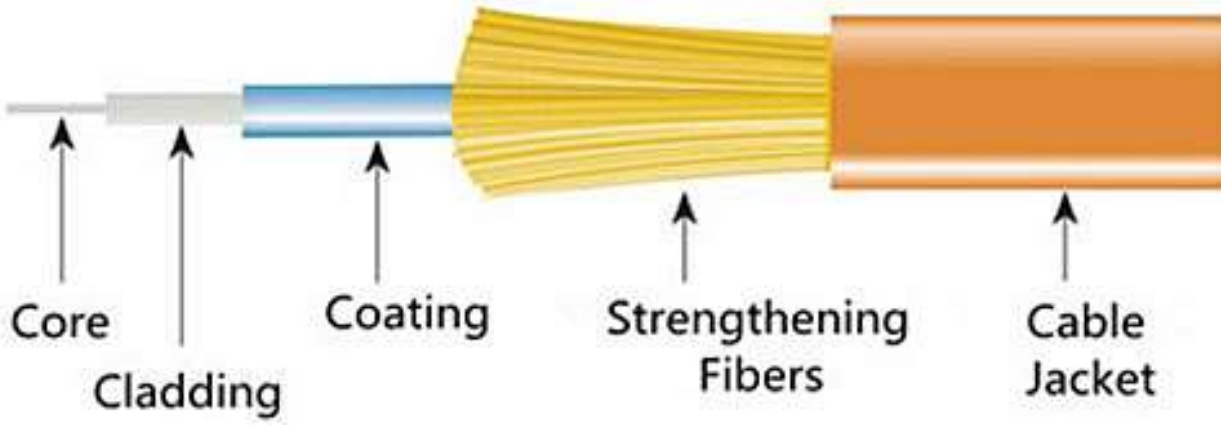


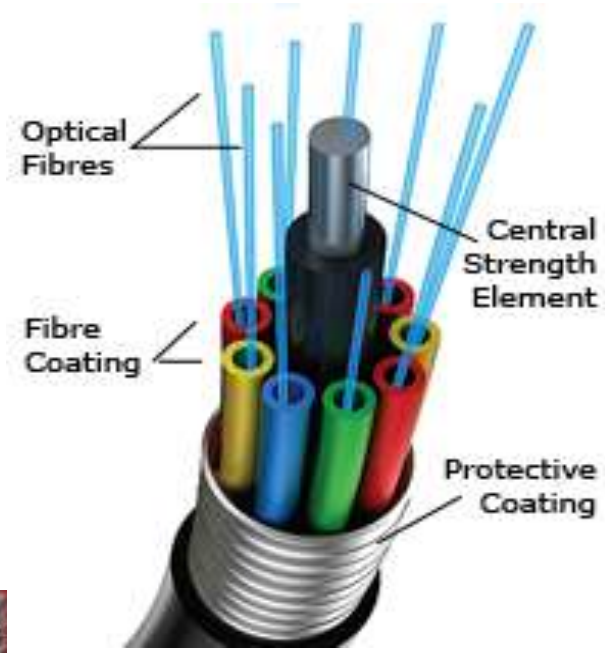
Wavelength is length of wave, commonly designated by the Greek letter lambda (λ), unit is nanometer 10^{-9} m

List the electromagnetic waves

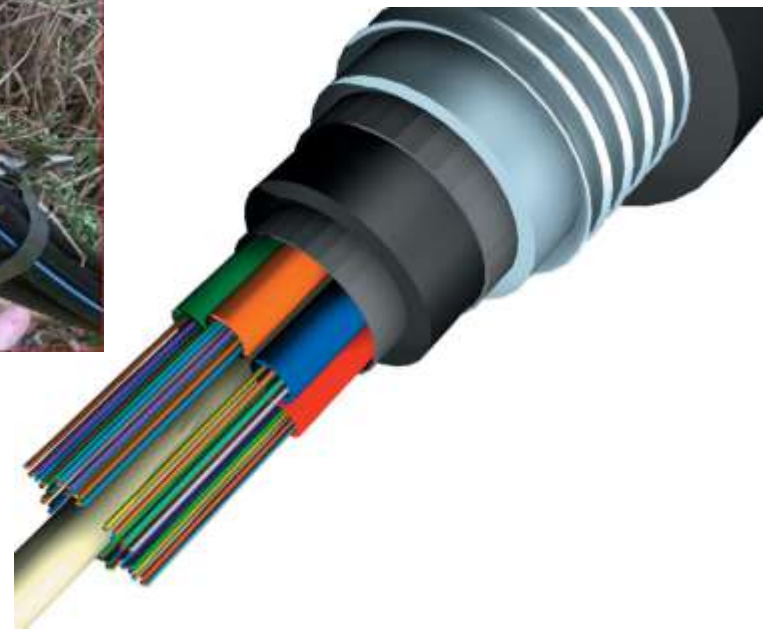


Optical Fiber

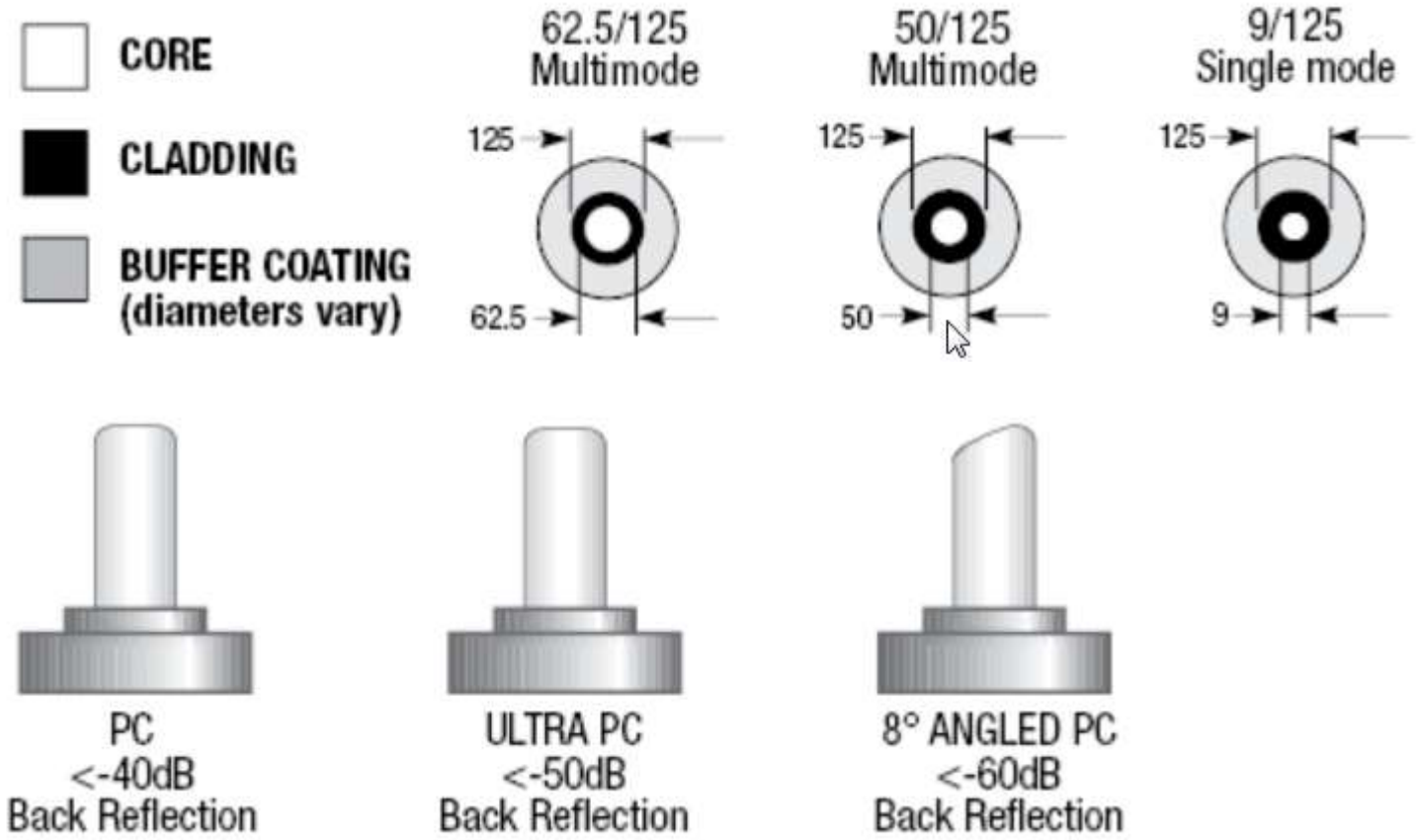


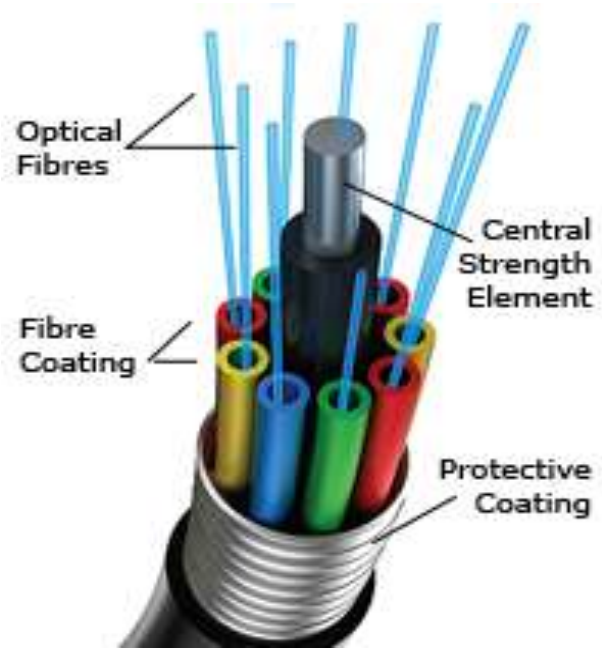


- Core carries the light signal
- Cladding keeps the light in the core, light pulses are reflected back into the core when hitting the cladding
- Coating (inner/outer) protects the glass



Optical Fiber

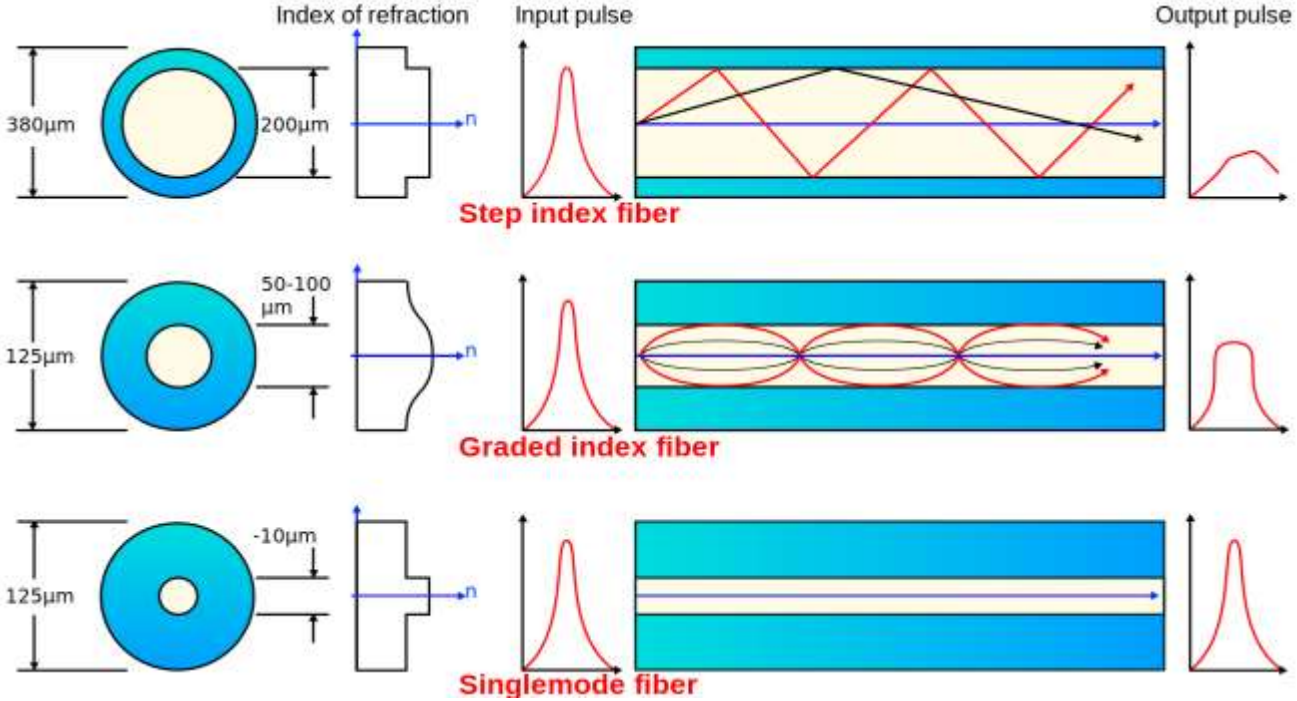


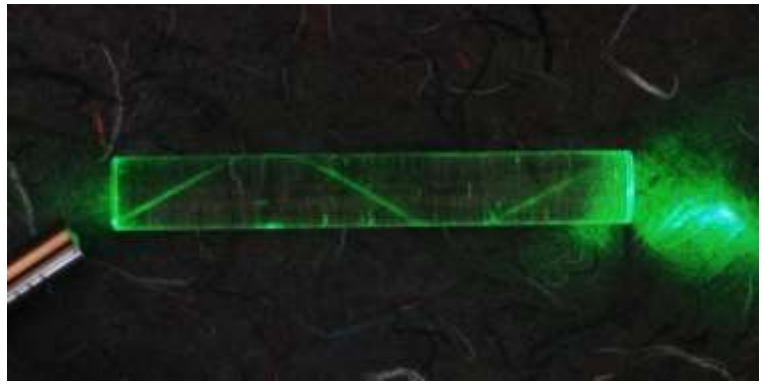


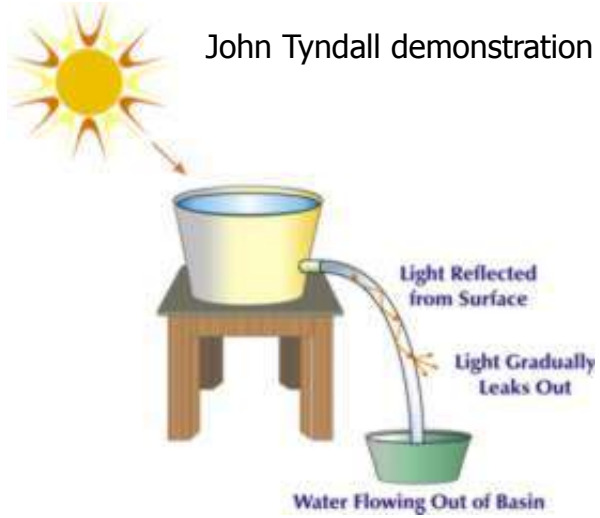
Príklad: „Patchcord singlemode OS1 9/125, FC/PC-LC/PC, 3m, LSOH žltý duplex 2x 2,5mm, Insertion Loos 0,3dB, Return Loss -50dB, alebo MM 50/125 micrometer

Principles of propagation

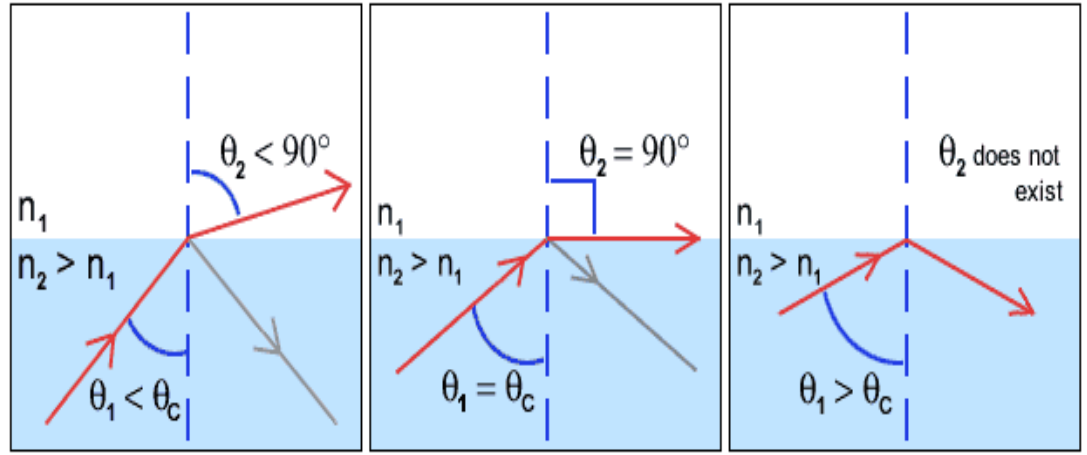
- At the boundary between denser (n2) and rarer (n1) medium (n2>n1, water-air, core-cladding) light signal will be refracted or reflected dependent on the incidence angle





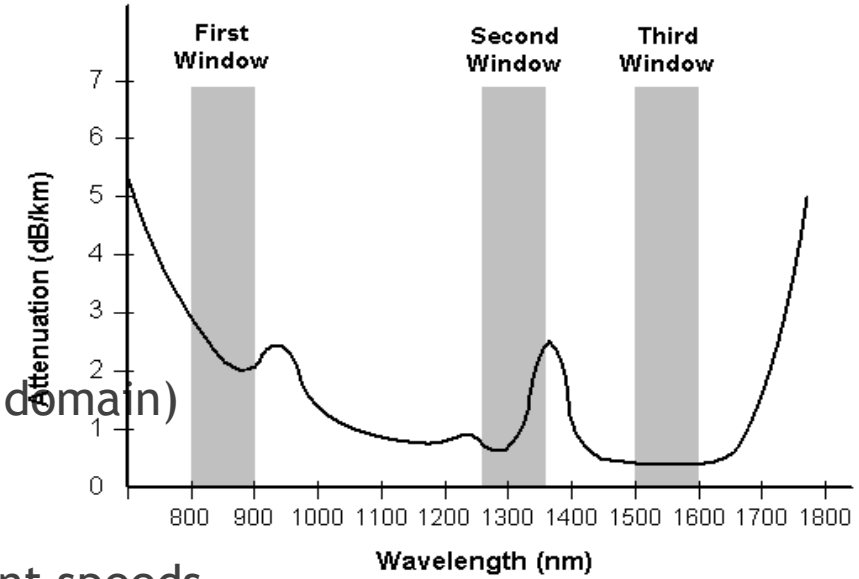


John Tyndall demonstration in 1870

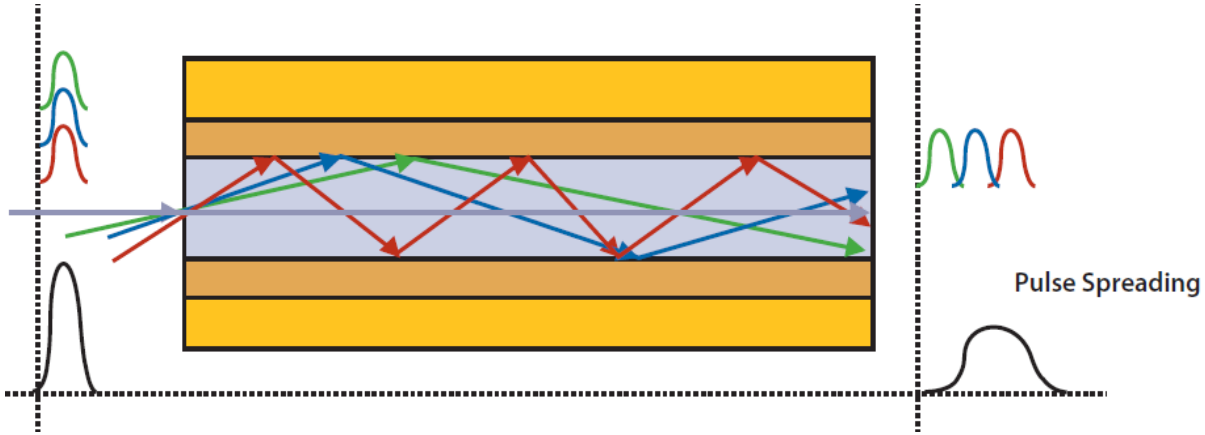


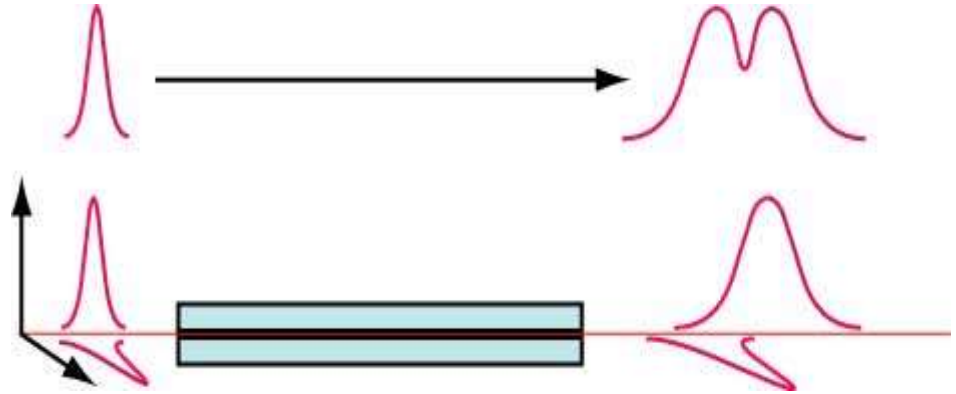
Propagation issues

- Attenuation
  - is the gradual loss in intensity, specified in loss per km [dB/km]
  - Loss mainly due to impurities
  - 1400nm peak due to OH ions
  - Solution for attenuation – Optical Aplification (works fully in optical domain)



- Dispersion
  - **Chromatic Dispersion (CD)** – Different wavelengths travel at different speeds
  - **Polarization Mode Dispersion (PMD)** – SM fiber supports two polarization states, fast and slow axes have different group velocities
  - Solution for dispersion – using dispersion compensating fibers (DCF with negative dispersion parameters), narrow spectral transmitter or signal regeneration (electrical)





dB versus dBm

- dB (Decibel) – relative measure
- Logarithmic unit for the **ration of two quantities**
- *n* dB is $10^{n/10}$ in linear dimension
- In optical fibres, the ration represents typically the power (loss or gain)
- For multimode fiber, the loss is about 3 dB per km for 850 nm sources, 1 dB per km for 1300 nm
- For singlemode fiber, the loss is about 0.5 dB per km for 1310 nm sources, 0.4 dB per km for 1550 nm.

0.1 dB	1.023
1 dB	1.26
10 dB	10
90 dB	1G

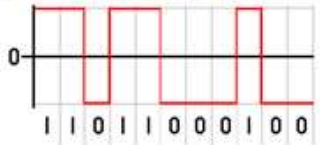
- dBm (Decibel-milliwatt) – absolute value
- Decibel referenced to a milliwatt
- Used for output power and receive sensitivity
- *n* dB is $10^{n/10}$ in [mW]

0 dBm	1 mW
15 dBm	31.6 mW

Modulation overview

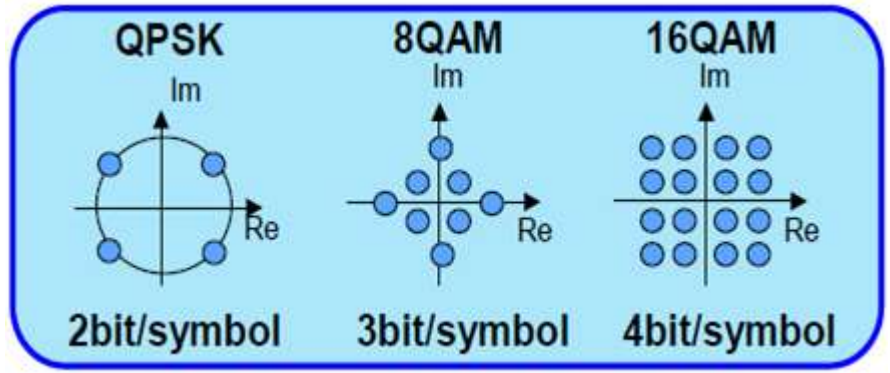
Classic systems use a relatively simple modulation

- Called “Non-Return to Zero” (NRZ).
  - Each symbol encodes 1 bit worth of data.



But there are other more efficient modulations

- If we can’t signal faster, carry more data in each signal.



Number of bits per symbol can be increased

Baud rate per channel can be relaxed

Spectral efficiency can be increased

(Differential) Phase Shift Keying (D)PSK

- changing (modulating) the phase of a reference signal / carrier wave

Quadrature PSK QPSK

- uses four phases

Polarization Multiplexed QPSK PM QPSK

- 2 polarizations on the wavelength

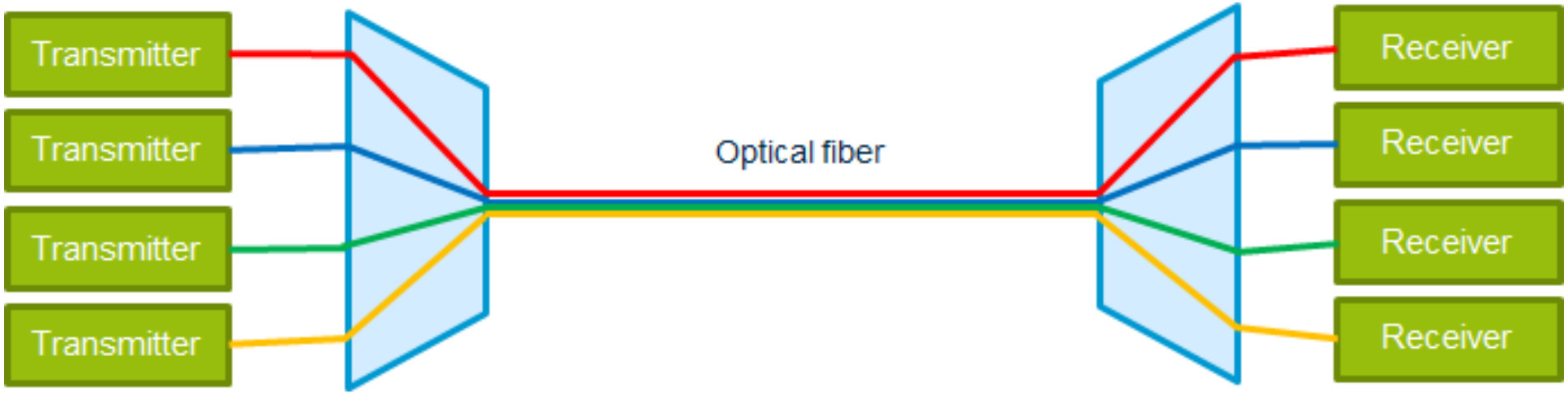
Quadrature amplitude modulation (QAM)

- PSK modulators are often designed using the QAM principle

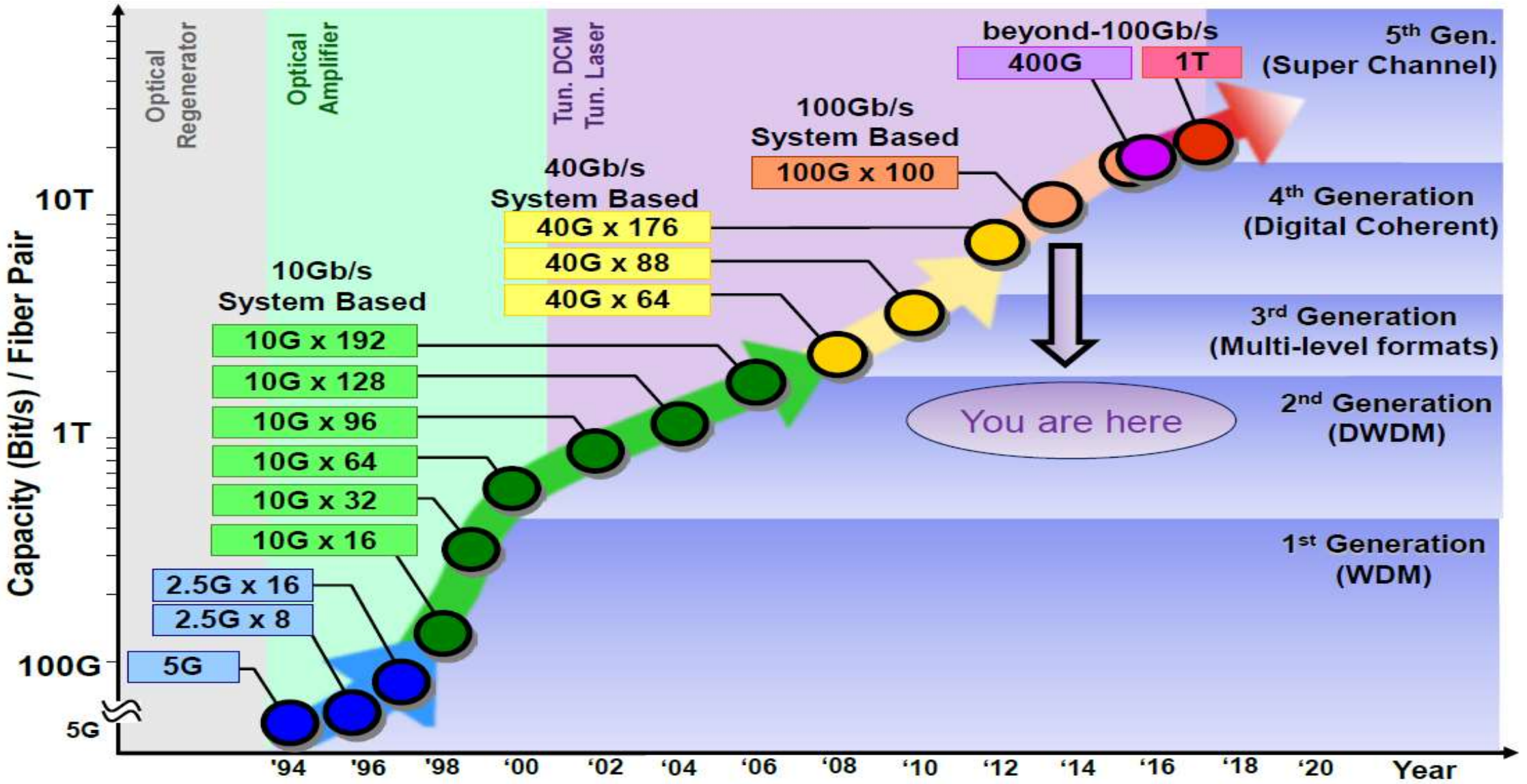
Bit rate	Type of modulation	Minimal OSNR accepted	Optical Reach 1	Optical Reach 2
10 Gbit/s	NRZ	8.5 dB	28 320 km	12 500 km
40 Gbit/s	DPSK	11.5 dB	14 160 km	6 300 km
40 Gbit/s	PM-QPSK	10.2 dB	19 120 km	8 500 km
100 Gbit/s	PM-QPSK	14.2 dB	7 600 km	3 300 km
400 Gbit/s	PM-16QAM	22.4 dB	1 120 km	500 km

What is WDM ?

- Wavelength Division Multiplexing is a technology that utilizes the properties of refracted light to both combined and separate optical signals based on their wavelengths within the optical spectrum
- Different signals with specific wavelength are multiplexed into a fiber for transmission
- The lasers are transmitting the light pulses at different wavelengths that are combined via filters to one single output fiber

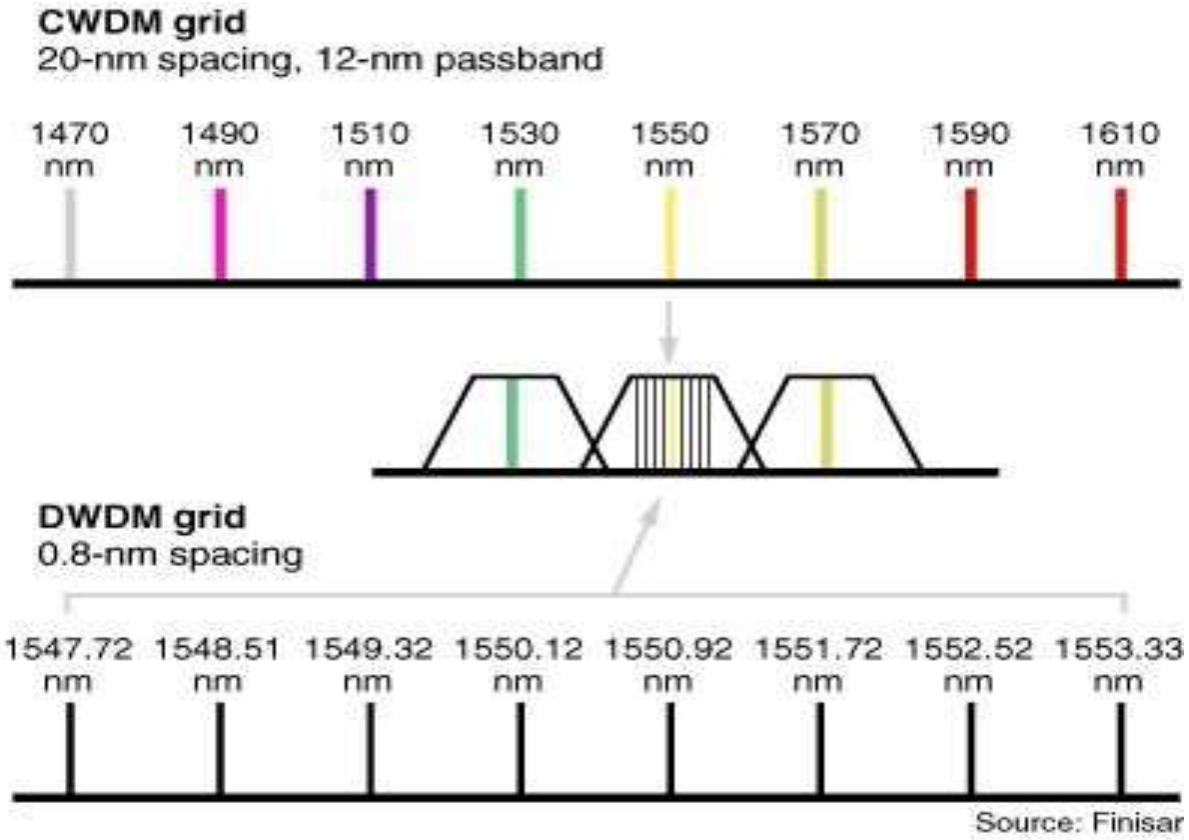


Evolution of capacity and technologies



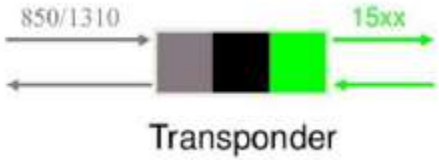
Wavelength Grid

- Set of wavelengths to be used for optical communication
- **Coarse WDM** (CWDM)
  - up to 16 channels across multiple transmission windows, 1270 nm to 1610 nm
  - The bandwidth and spacing of the wavelengths allows for cheaper laser and filter technology compared to DWDM
- Dense WDM (DWDM)
  - uses the C-Band(1530 nm-1560 nm) transmission window but with denser channel spacing. Channel plans vary, but a typical DWDM system would use 40 channels at 100 GHz (0,8 nm) spacing or 80 channels with 50 GHz (0,4 nm) spacing

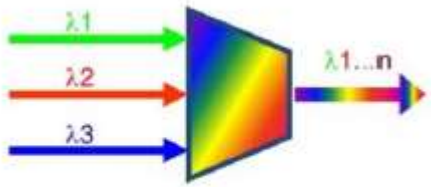


WDM principle elements

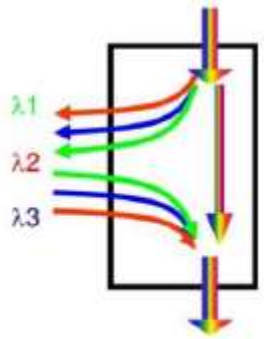
- Traffic to leave and enter the optical network
  - Transponder – signal/wavelength converter
  - Muxponder - combines several client signals into one line signal
- Multiplex wavelengths
  - Optical multiplexer and demultiplexer (MUX)
- Send wavelengths in different directions
  - OADM – Optical Add/Drop Multiplexer
- OA – Optical Amplifier (RAMAN, EDFA, etc)
- Dispersion Compensator Module (DCM)



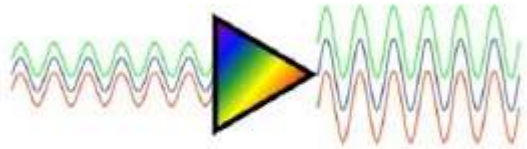
Transponder

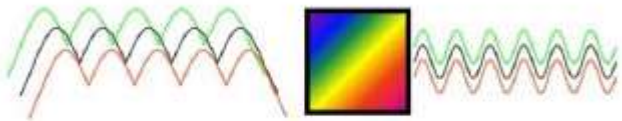


Optical Multiplexer



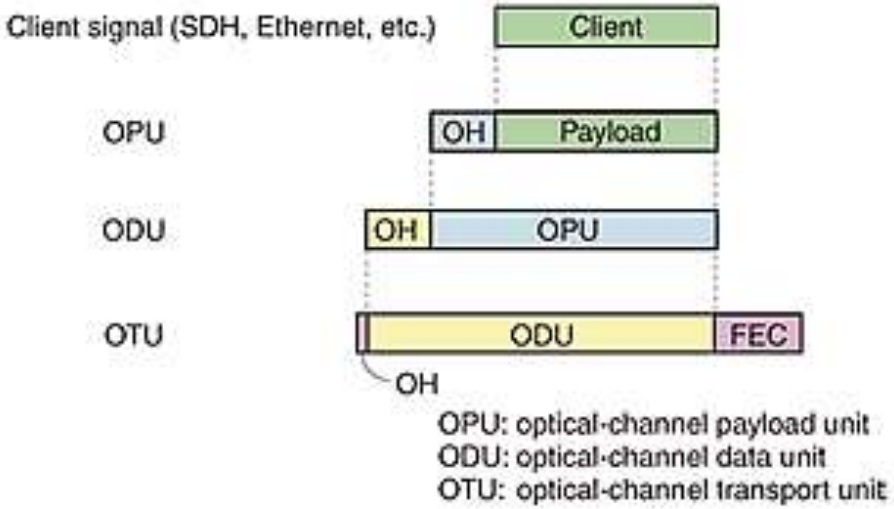
Optical Add/Drop Multiplexer (OADM)

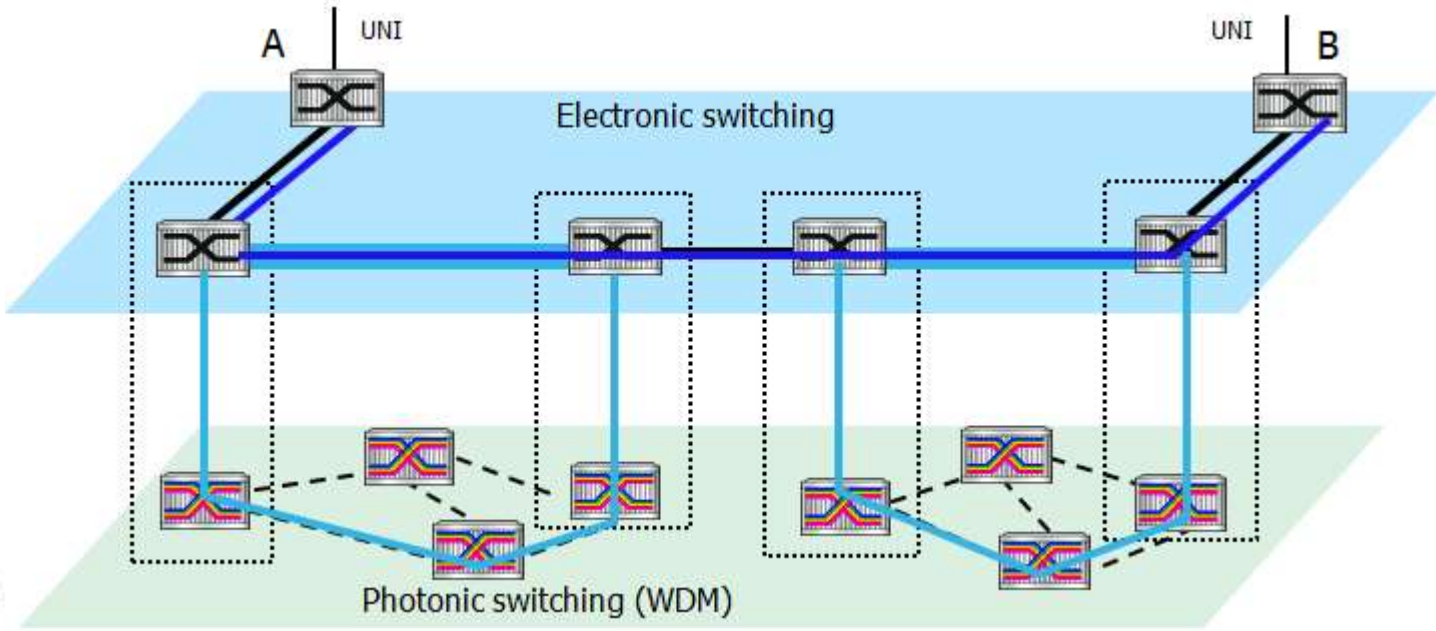

Optical Amplifier


Dispersion Compensator (DCM / DCU)

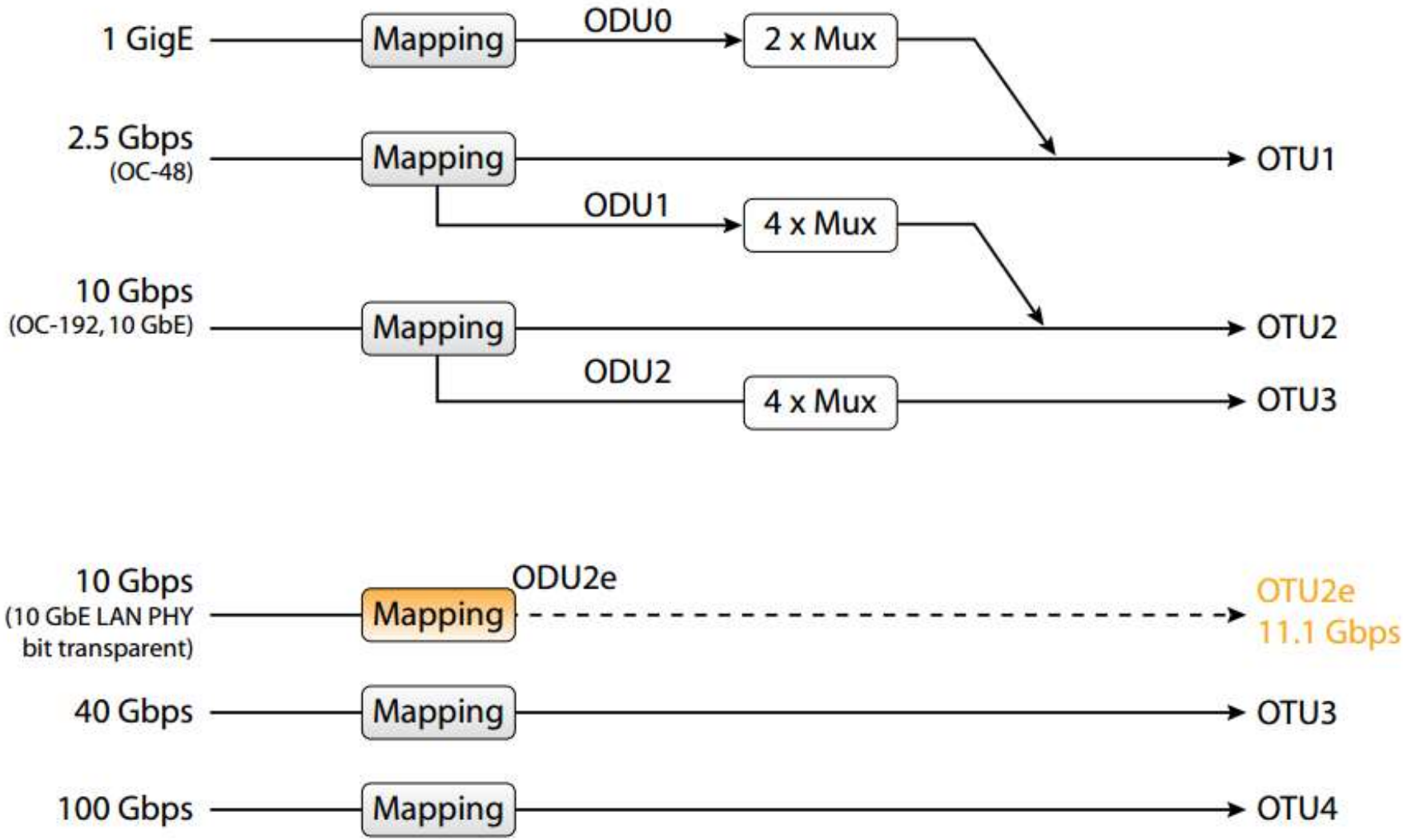
And what about OTN?

- OTN refers to Optical Transport Network
- Any traffic in a modern WDM network is mapped over standard frames defined by OTN standard. This is the minimum must to have requirements to guarantee interoperability between vendors and guarantee homogeneous and agnostic networking over lambdas.
- For example when a network has TDM and Ethernet, both will be mapped over same OTN standard frames and treated equally into the lambdas.
- Optionally it can provide OTN switching – switching on electrical level

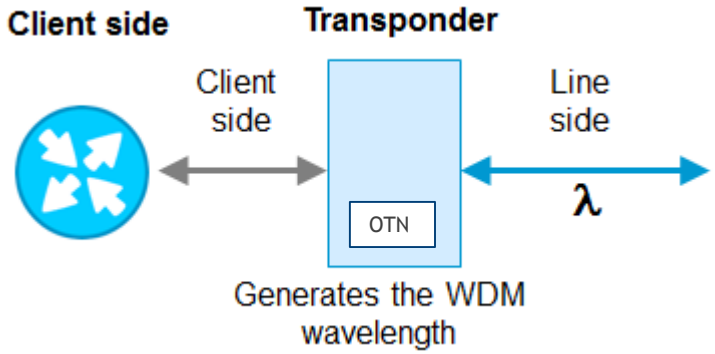


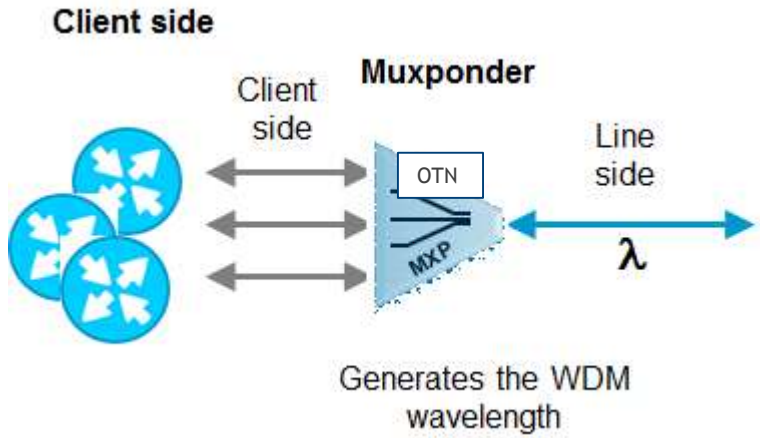


OTN mapping


1 GigE
Mapping
ODU0
2 x Mux
2.5 Gbps
(OC-48)
Mapping
OTU1
ODU1
4 x Mux
10 Gbps
(OC-192, 10 GbE)
Mapping
OTU2
ODU2
4 x Mux
OTU3
10 Gbps
(10 GbE LAN PHY
bit transparent)
Mapping
ODU2e
OTU2e
11.1 Gbps
40 Gbps
Mapping
OTU3
100 Gbps
Mapping
OTU4

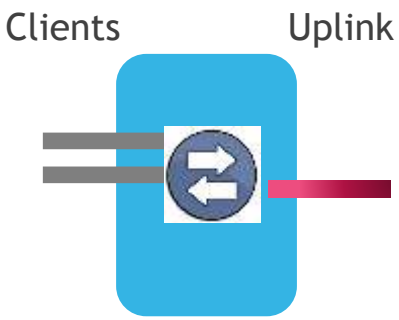
Transponder and Muxponder

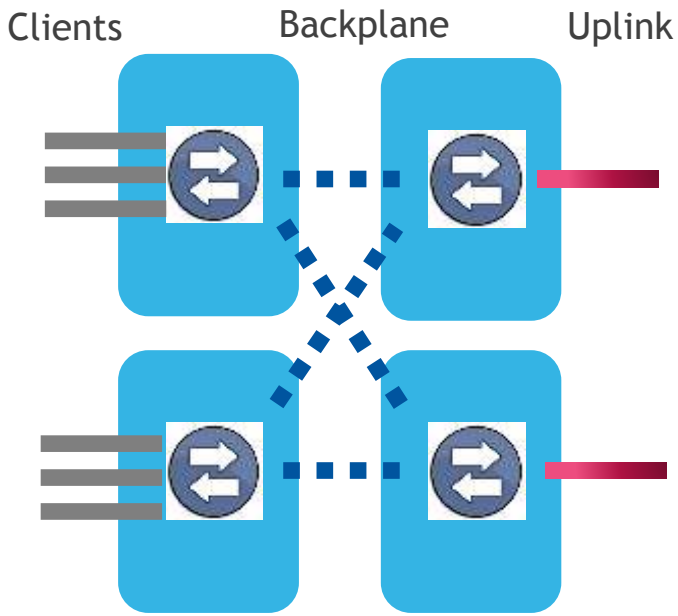


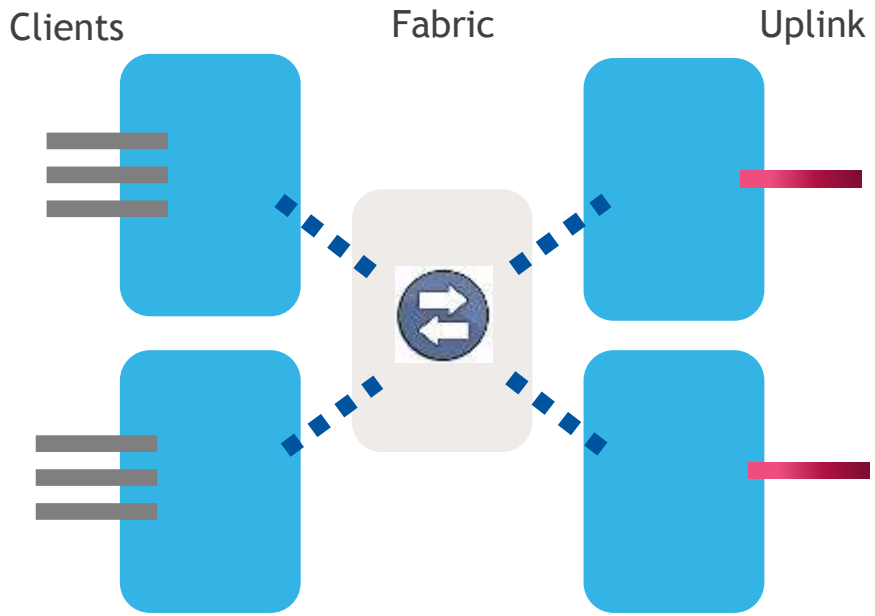


- Transponders and Muxponders provides wavelength conversion from client to WDM signal
- A Transponder maps a single client to a single WDM wavelength
- A Muxponder multiplexes several lower speed client signals to a higher speed WDM wavelength, thus increasing the network capacity
- The digital framing of a line signal from a Transponder or Muxponder provides service monitoring, management connectivity and increased reach

WDM Architectures with OTN Switching options
Transponder & Muxponder split







Blade switching

- ADM, packet sw on blade
- Low cost
- Least scalable

Distributed fabric-less switching

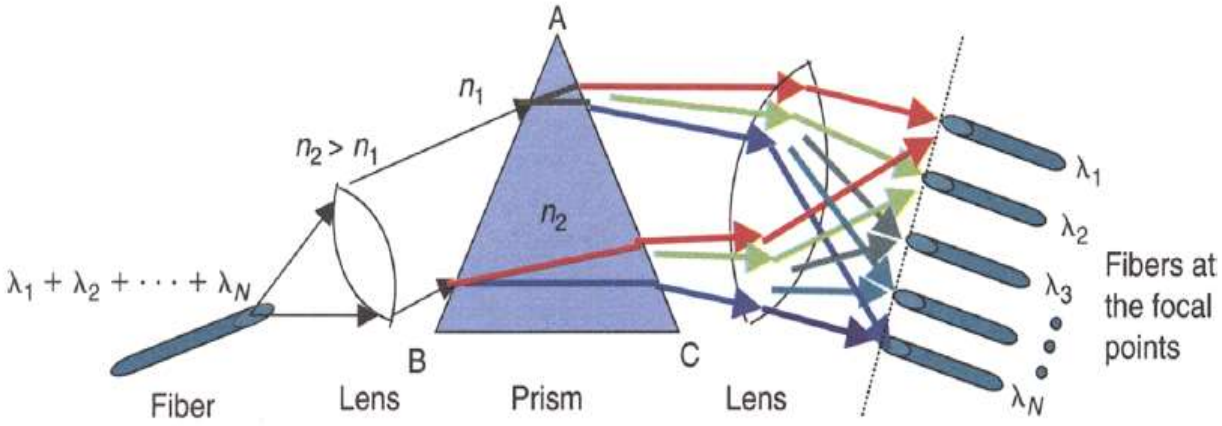
- Small node aggregation
- Pay as you grow

Centralized fabric switching

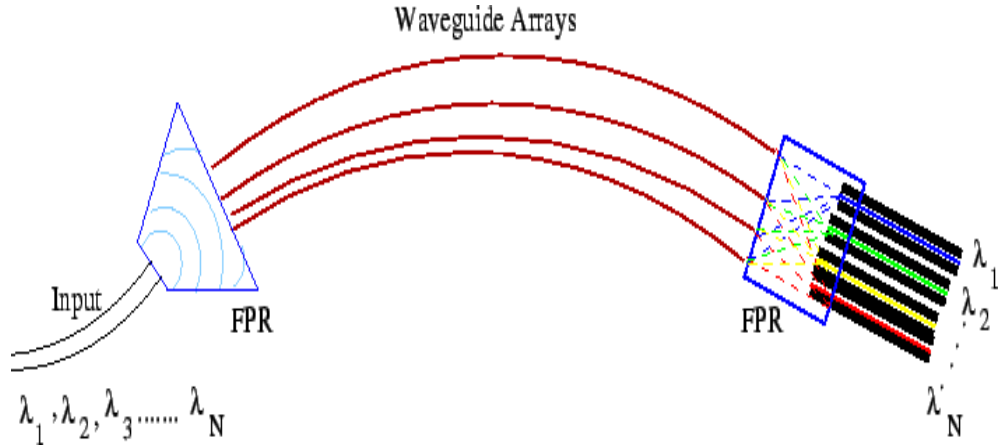
- Large metro and core
- High port density requires fabric switching

Multiplexers & Demultiplexers

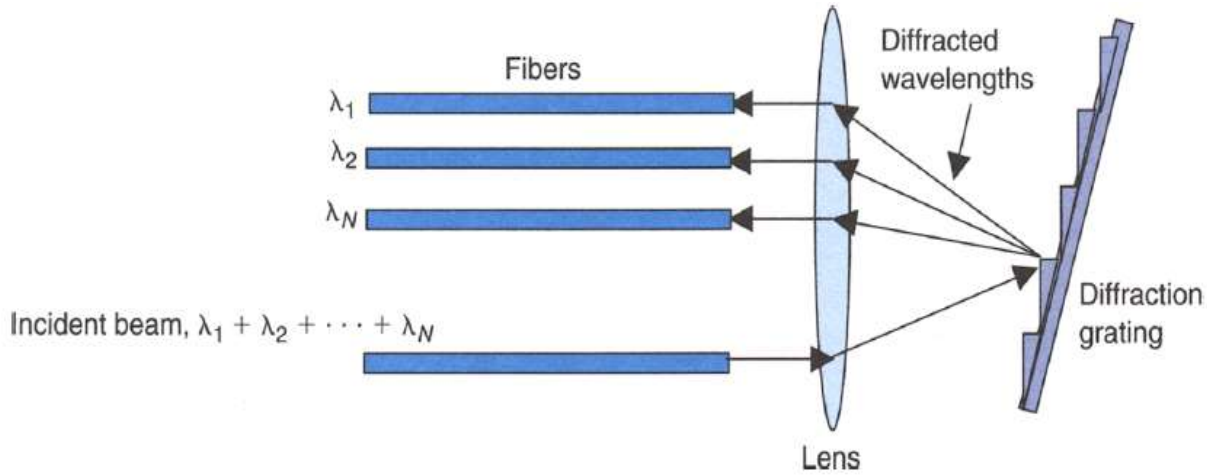
Prism Diffraction Multiplexing



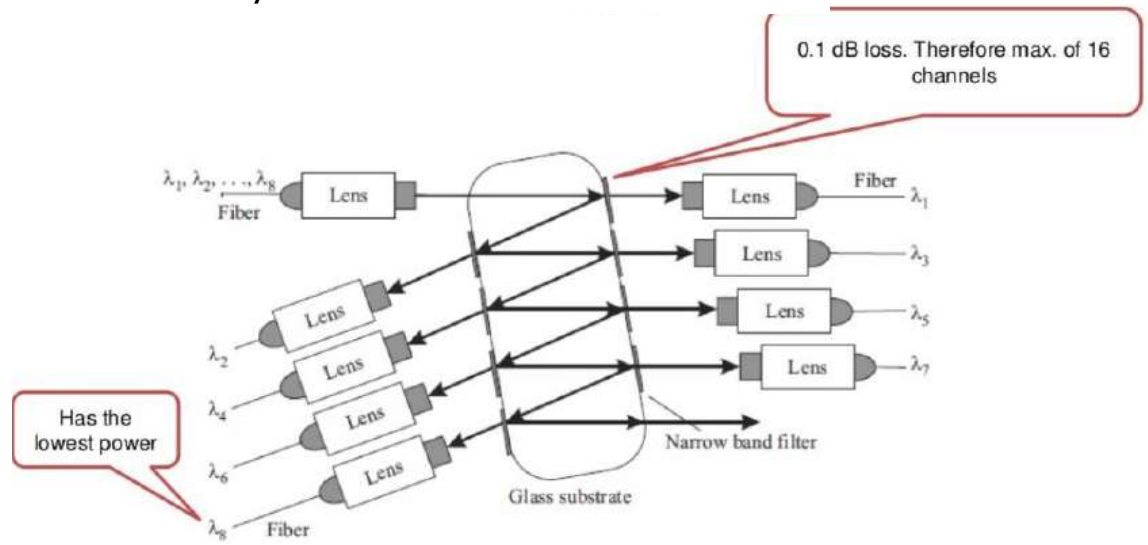
Arrayed Waveguide Grating



Waveguide Grating Diffraction

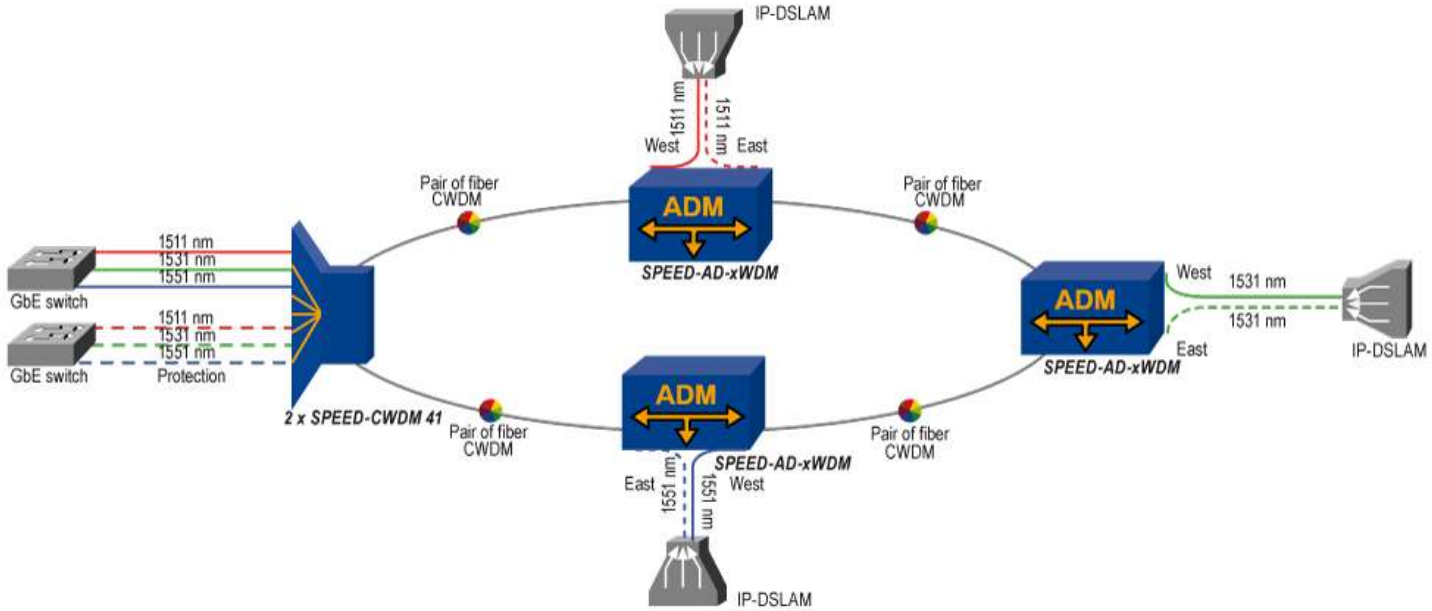


Multi-Layer Interference Thin Film Filters



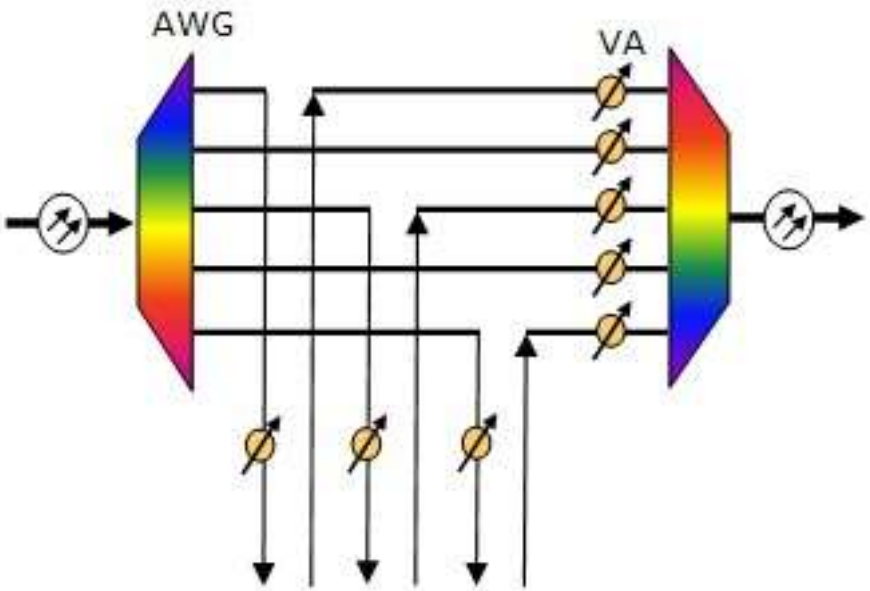
OADM Optical Add Drop Multiplexer

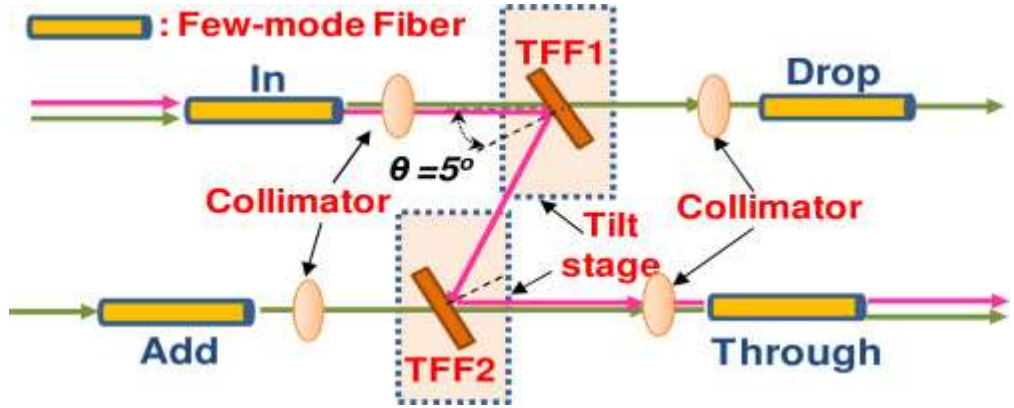
- Optical ADM is used for multiplexing and routing different channels of light into or out of a fiber. "Add" and "drop" here refer to the capability of the device to add/drop one or more wavelength channels to/from an existing multi-wavelength WDM signal
- OADM with remotely reconfigurable optical switches is called a reconfigurable OADM (ROADM). One without this feature are known as fixed OADM (FOADM).
- There are several ways to make an OADM, but typically without demultiplexing of all wavelengths. FOADM is built with thin-film filters (TFFs) fiber bragg grating (FBG) and integrated planar arrayed waveguide gratings (AWG).

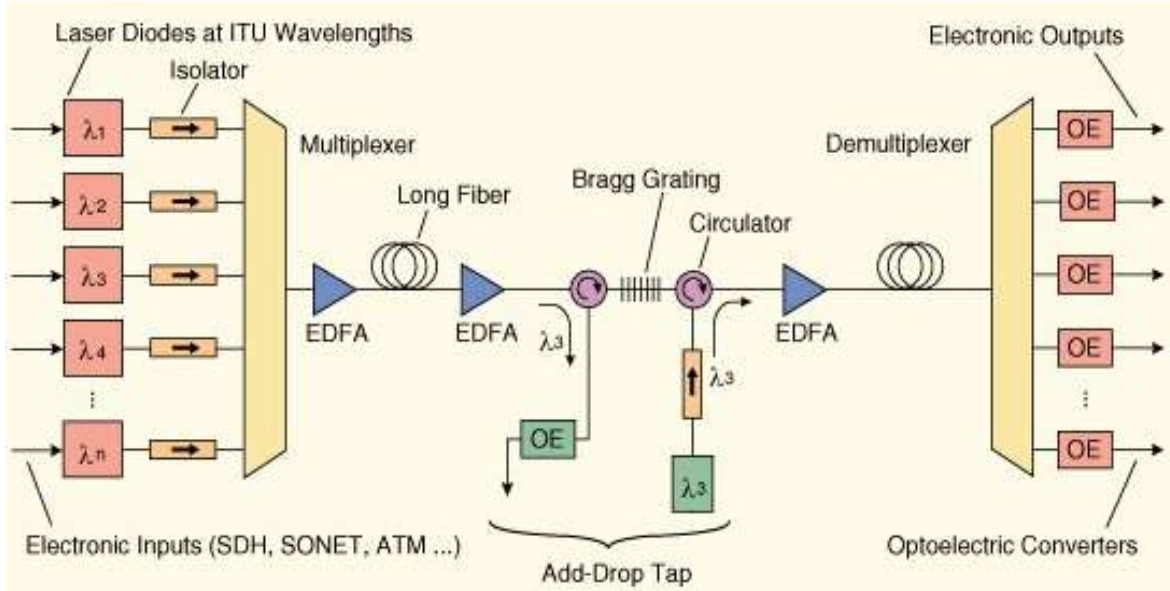


FOADM – different principles

Static – best solution for small optical / aggregation networks

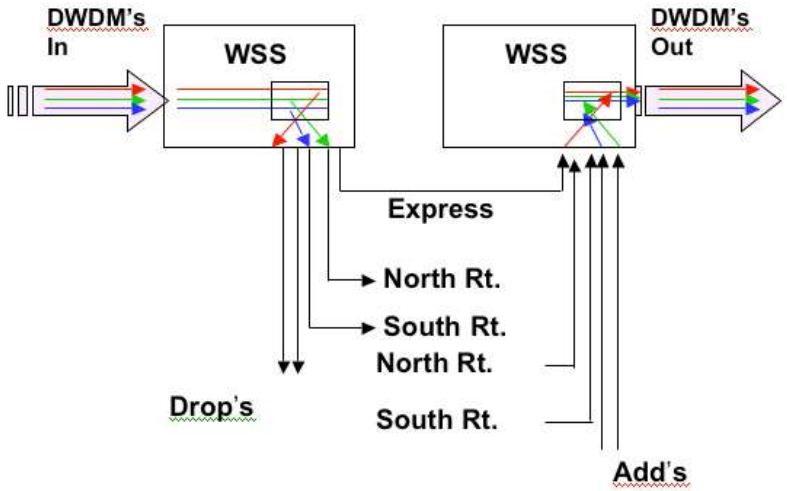


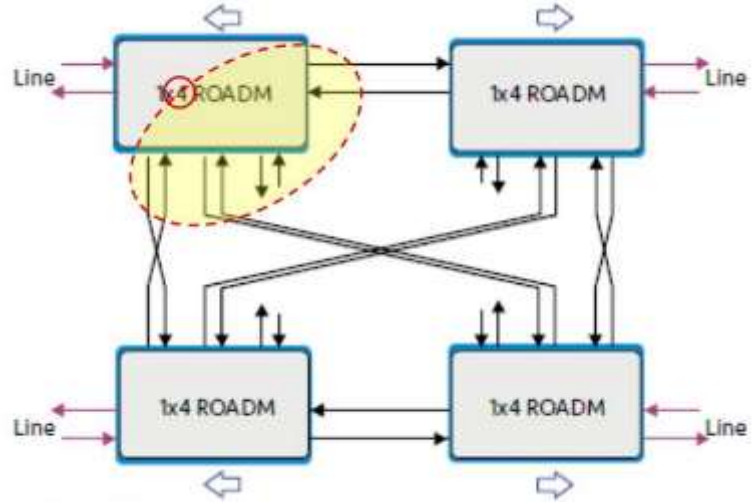


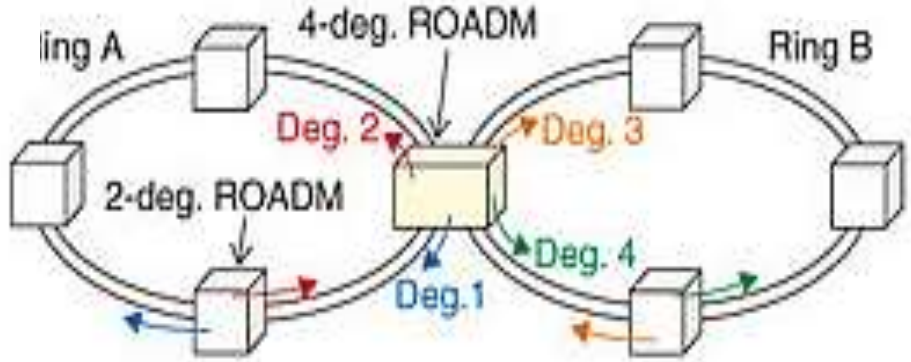


ROADM

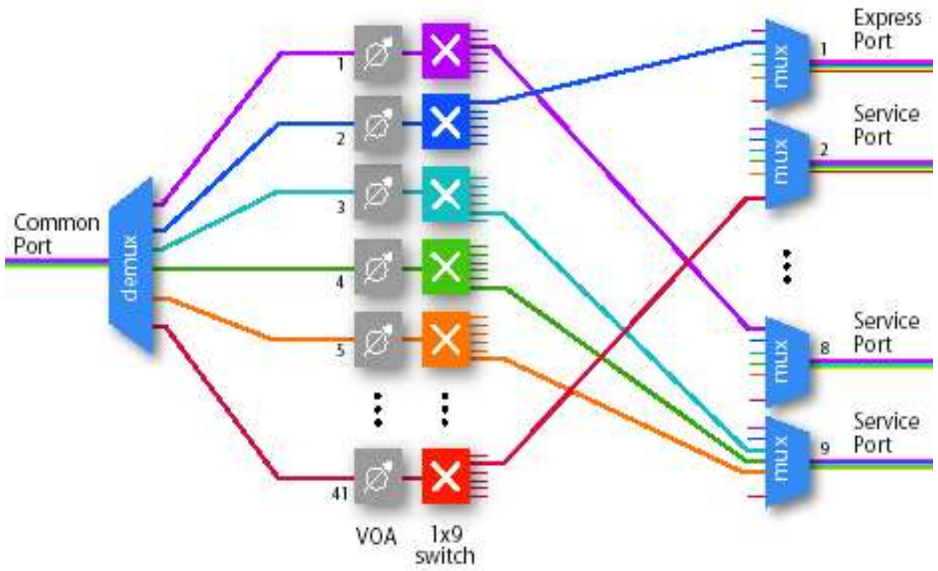
- **ROADM** has ability to remotely switch traffic from a WDM system at the wavelength layer therefore enables automation. This is achieved through the use of a ***wavelength selective switching*** (WSS) module.
- **Multi-degree ROADM -** in order to realize mesh-based network topologies. 4-degree ROADM node configuration connecting two ring networks



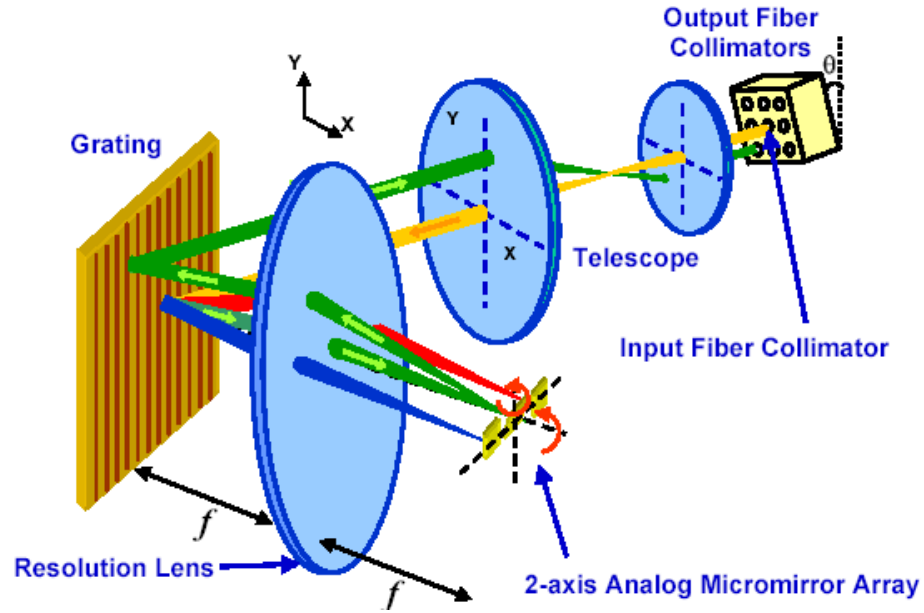




WSS types – key component of ROADM



WSS with hybrid integration of waveguides and MEMS (micro electro mechanical system) switches

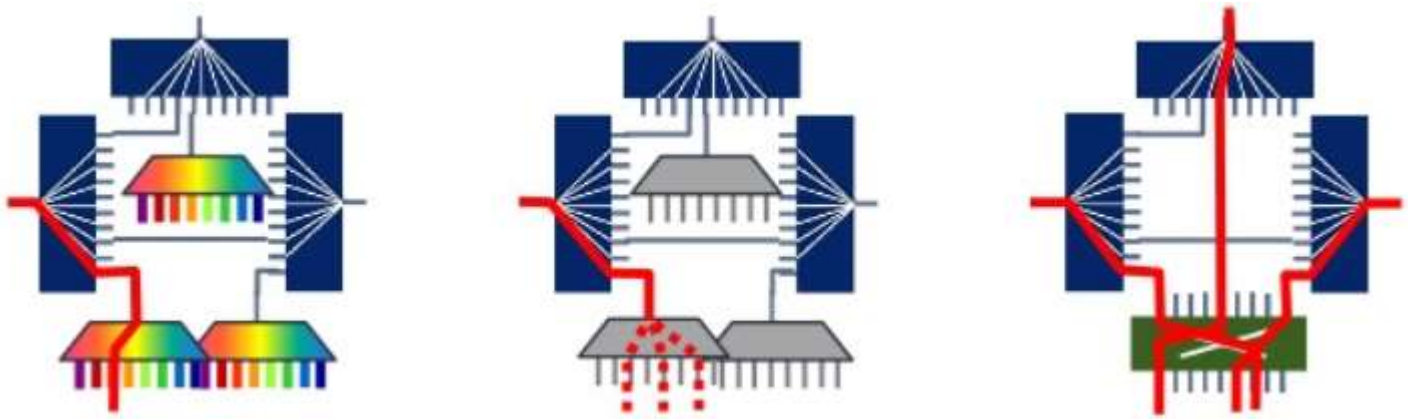


- WSS with Free Space optic and 2-axis micromirror - WDM signal is spatially separated by the diffraction grating and focused onto its corresponding micromirror. Then the 2-axis mirrors direct individual wavelengths to any arbitrary output port in the 2D collimator array

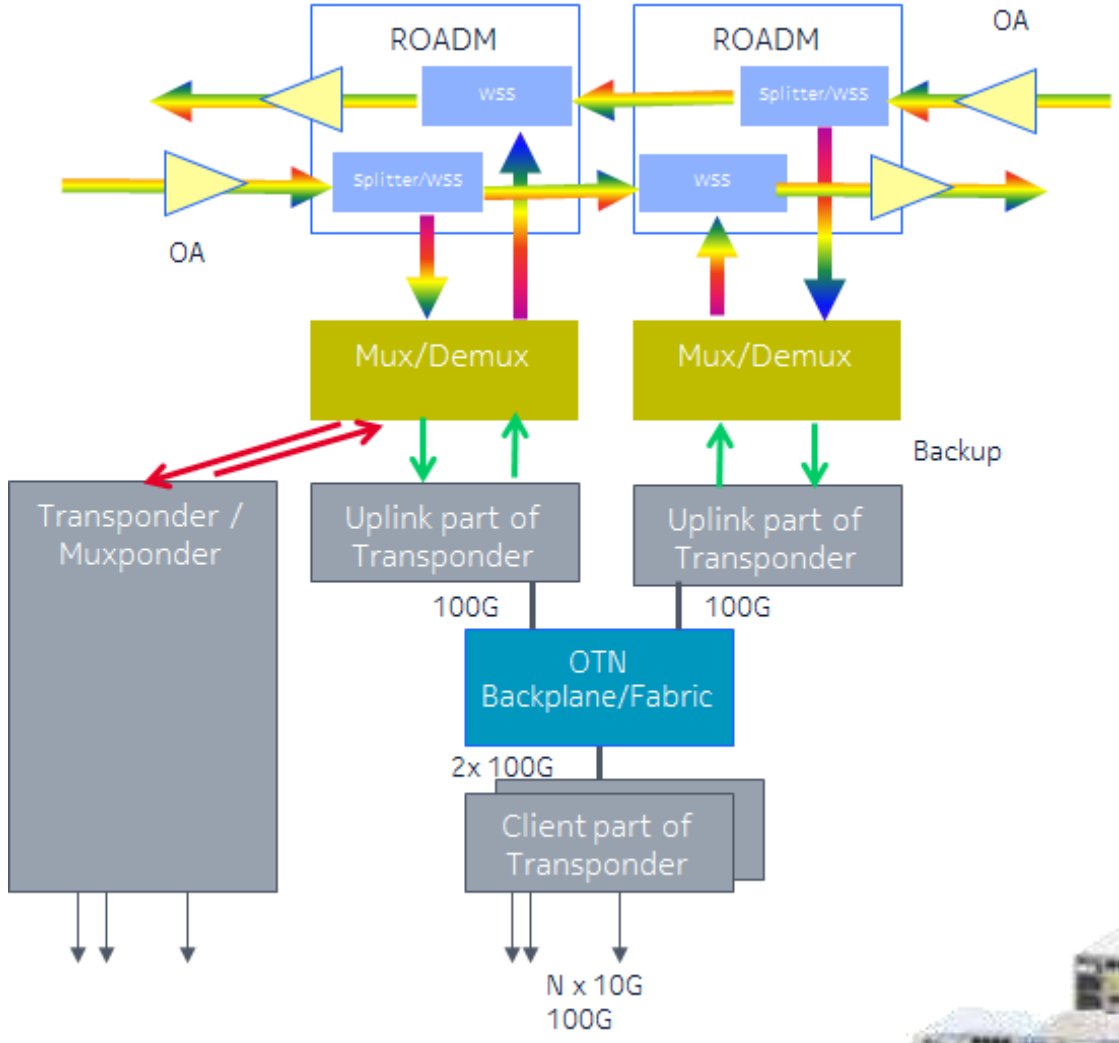
ROADM generations

- 1st generation – wavelength blocker based, 2-degree only, add/Drop only
- 2nd generation – limited multidegree functionality
- 3rd generation – WSS based, multidegree, colorless, directionless mode (CD)
- 4th generation – WSS based, multidegree, CD and contentionless (CDC), flexible channel spacing

- Color independent or "**colorless**“ – the transceiver does not to be manually connected to the correct mux/demux port at the add/drop site
- Direction independent or "**directionless**“ - allow any wavelength to be routed to any direction or degree, do not need 1 MUX per direction, can share one MUX for all directions
- Wavelength contention-free or "**contentionless**“ – solves the situation when two wavelengths of the same color converge at the same WSS structure at the same time
- Flexible ITU grid or "**gridless**"



WDM chassis overview



OOB management - Optical Supervisory Channel (OSC)

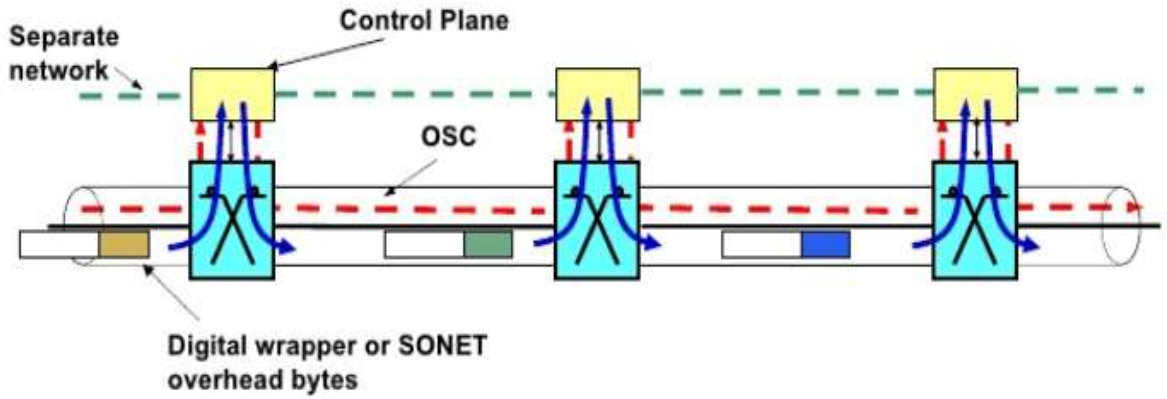
- OSC is a separate channel, which carries overhead information for network management purposes
- Typically used for remote configurations, SW upgrades and other management purposes
- Always terminated at intermediate amplifier sites (EDFA OA) where collects mgmt. information
- 1310, 1510, 1620 nm (outside EDFA)
- Uses OTN framing

Out-of-band

- Via an optical supervisory channel (OSC)
- Via a separate IP network

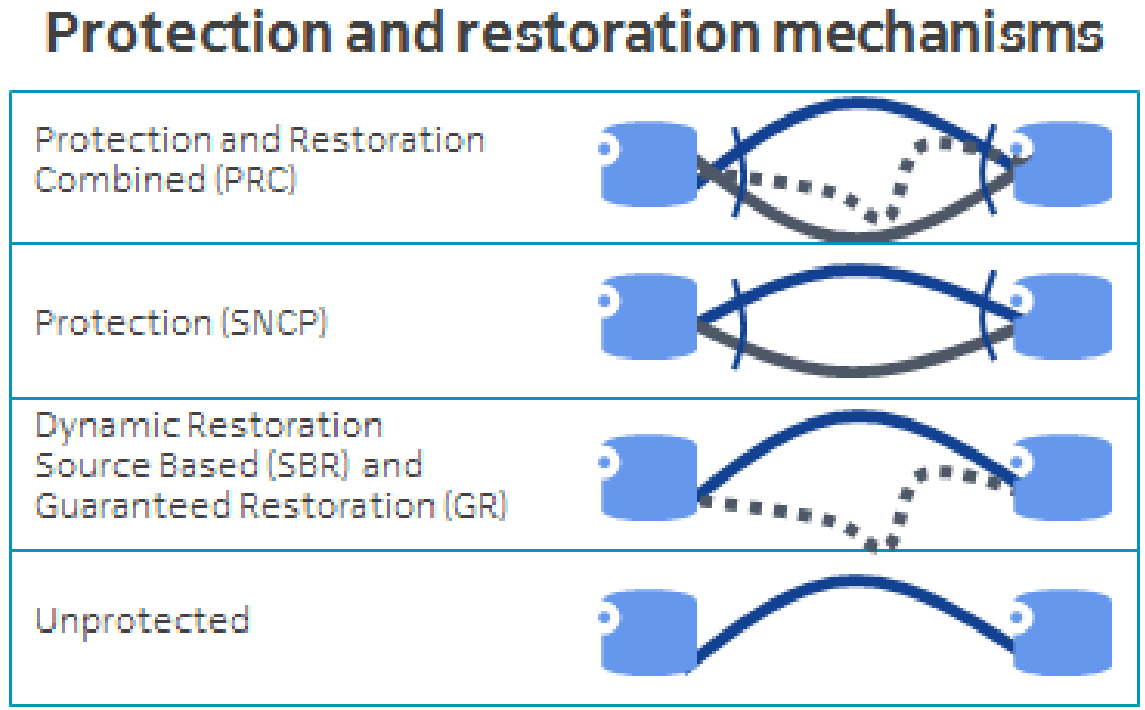
In-band

- Via overhead in "digital wrapper" or SONET overhead bytes
- Via sub-carrier modulation (SCM) on the optical channel



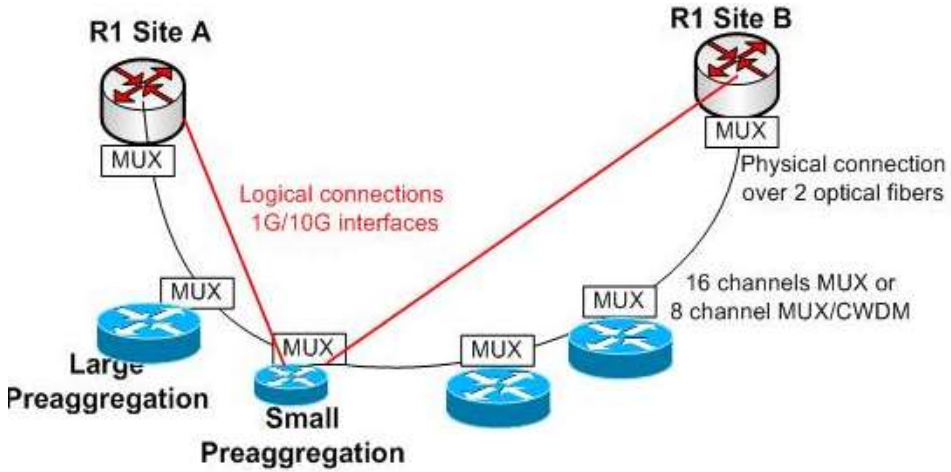
Protection and Restoration

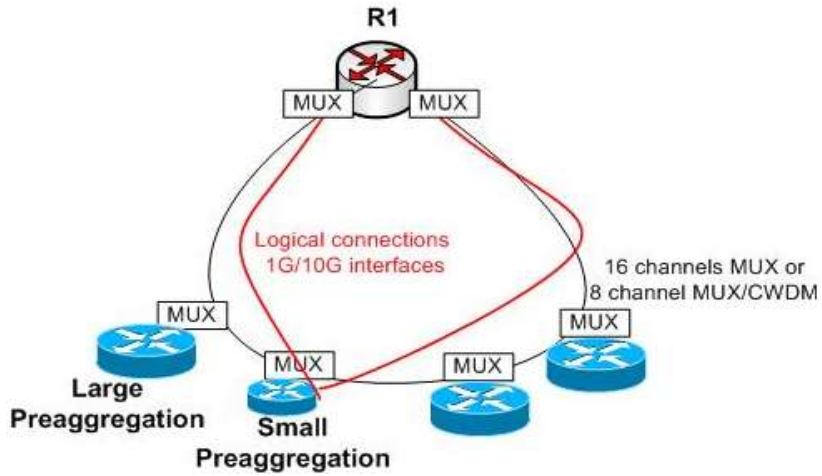
- **Unprotected**: path will not be protected against failures
- **SNCP (Subnetwork Connection Protection)** (1+1) protection shared protection rings mechanism
- **PRC (Protection and Restoration Combined):** 50ms restoration even in case of multiple failures
- **SBR (Source Based Restoration):** path will be restored after a failure, restoration route is evaluated on-the-fly by the source node
- **GR (Guaranteed Restoration):** a shared backup is assigned to the path, resources for recovery are only signaled, not really allocated



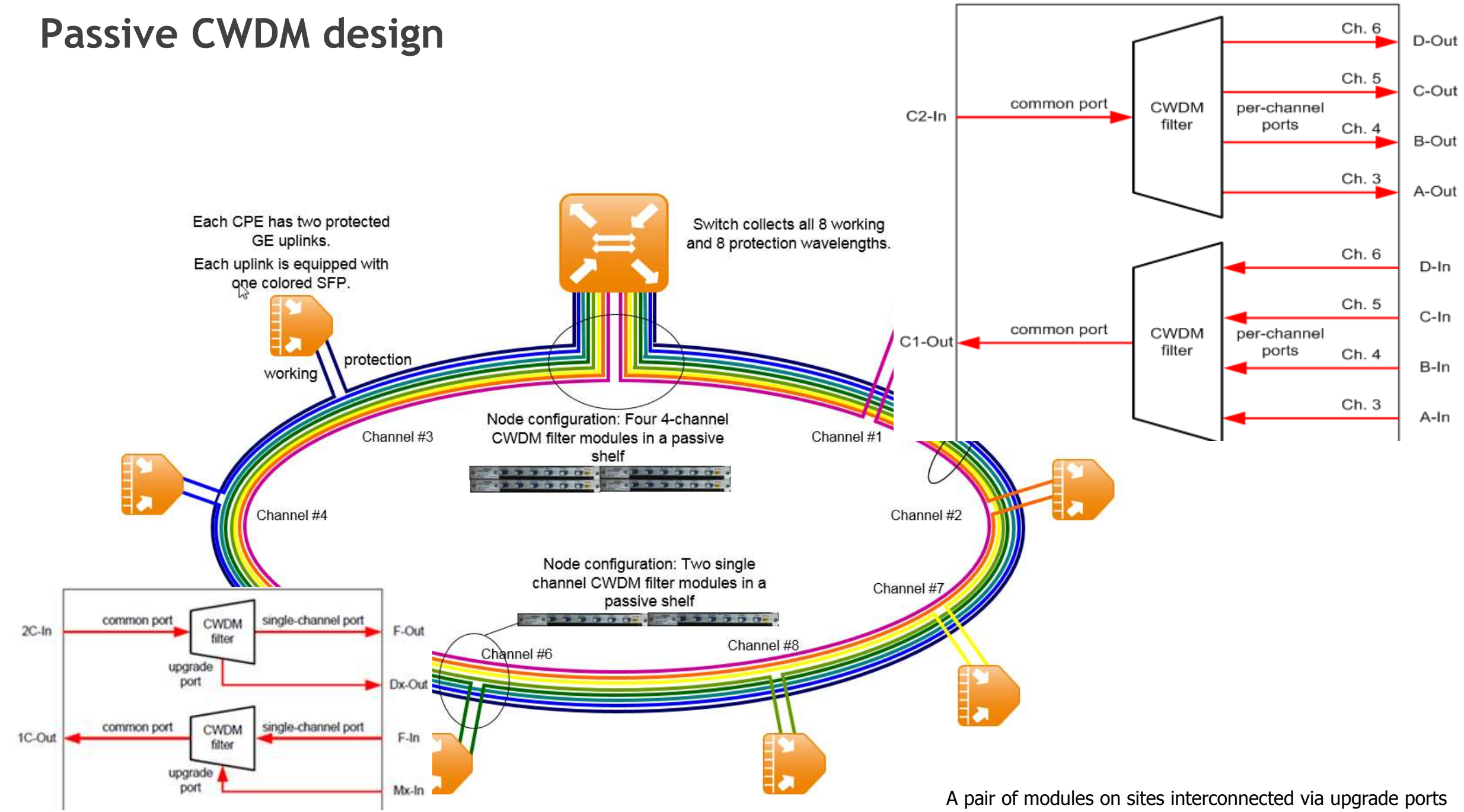
CWDM overview

- Coarse wavelength division multiplexing (CWDM) is a method of combining multiple signals on laser beams at various wavelengths for transmission along fiber optic cables
- Passive CWDM equipment is implemented on dark fiber connecting the aggregation devices in a ring or a horseshoe. Underlying CWDM devices are fully passive ones
- Passive Optical Network can be seen to be an immediate solution for solving the increasing throughput connectivity need which is relatively simple
- The distance is up to 80 km only
- 1GbE and 10GbE can run on the same CWDM link without any restrictions.



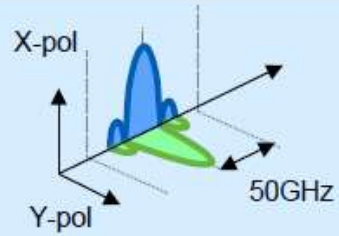
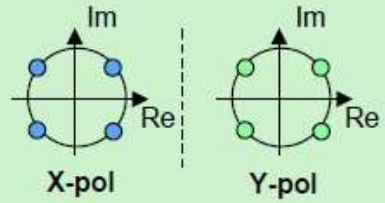


Passive CWDM design



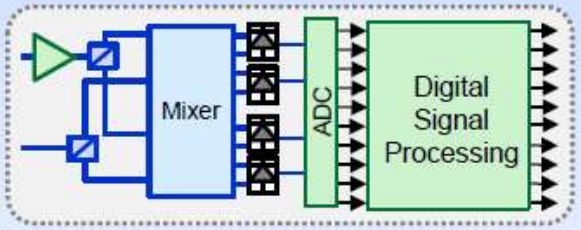
A pair of modules on sites interconnected via upgrade ports

Coherent DWDM

Modulation Format	Channel Spacing	SE [b/s/Hz]	Carriers	Optical Spectrum	Constellation Map
100G DP-QPSK	50GHz	2	1		

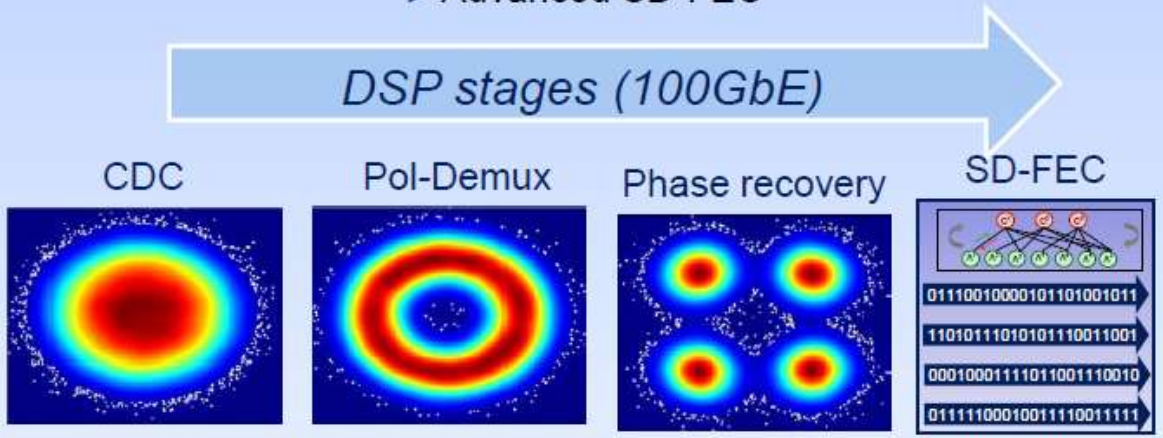
Coherent Receiver

- ▶Unmatched sensitivity
- ▶Hybrid Mixer Chip by PLC
- ▶Tunable lasers
- ▶Narrow linewidth



LSI *digital signal processing*

- ▶Digital Adaptive Impairment Compensation
- ▶ Polarization-mode dispersion
- ▶ Ultra-large Chromatic dispersion compensation
- ▶Digital polarization demultiplexing (increased SE)
- ▶Advanced SD-FEC



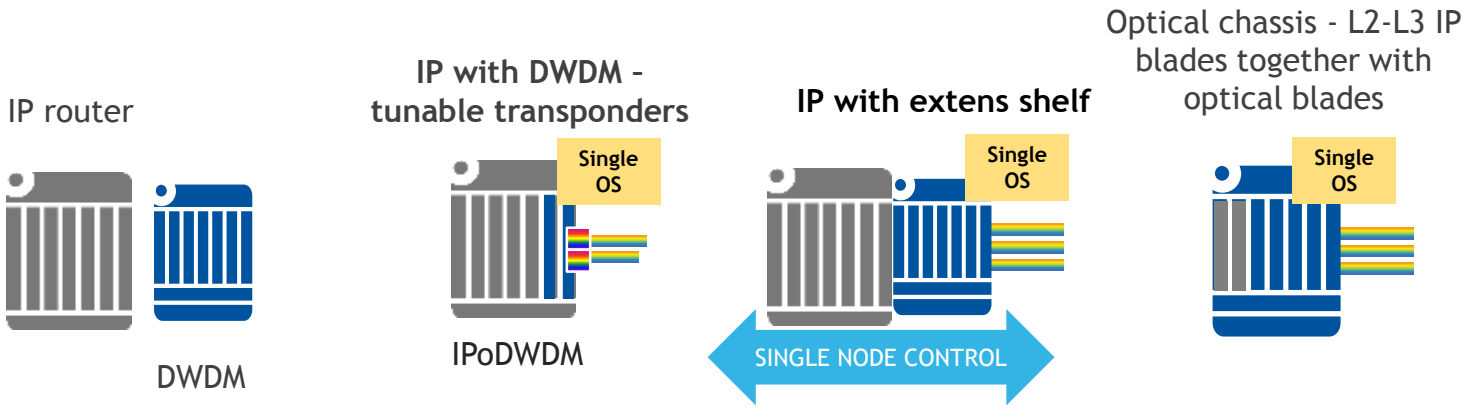
- High-order amplitude/phase modulation
- Polarization multiplexing

Mixture of optical, digital and radio modem experience, coupled with a very demanding optical transmitter and receiver circuit design

IP and Optical Convergence Alternatives

1. **Two layer standard approaches**
   - Packet over DWDM networks where OTN is exclusively used for framing purposes
   - Packet/OTN/DWDM networks where transit traffic is mainly groomed/switched by OTN multiplexing/switching network elements
     - simple and easy to implement, a little or no interaction needed between IP and Transmission
     - more CAPEX and OPEX spending, operators need to consistently build up two layers in parallel
2. **Converged approach**
   - IP over P-to-P DWDM , transponders into routers
     - 100G is expensive, power-hungry and temperature-sensitive, IP and fiber-optics hardware may not develop in a synchronized manner, and so a combined card may not be able to take advantage of the most up-to-date technology
     - IP is the only layer that can aggregate, protect or route the traffic
   - Router Offload
     - *Peer model – Single IP & Optics domain*
     - *Overlay model – GMPLS UNI*
     - any transit traffic/service at any intermediate core router should be offloaded to lower layer
     - core routers do not need to grow as fast as lower layers need to, thus bringing significant cost savings for operators
     - BUT it doesn’t mean complete offload of IP core routers

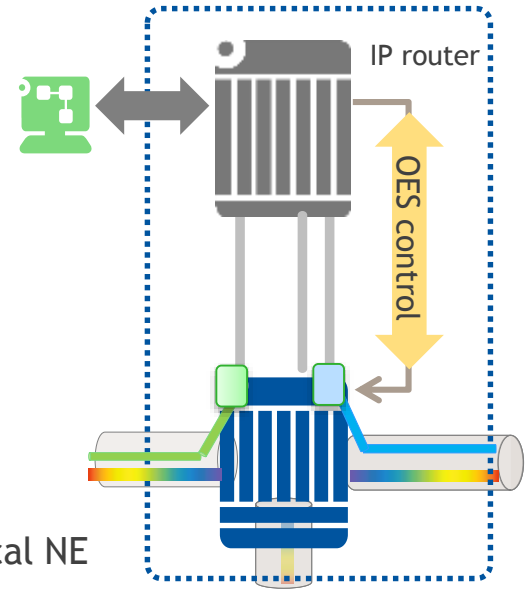
IP Optical Data Plane Integration



Saves on optical transponders and DWDM transport.
Integrated routing & transport OAM

Optical extension shelves connects using standard gray router optics

- Low cost interface solution without impacting port density
- Transport OAM visibility via OES control port
- Configured with single OS



OES offers better scalability in high density IPoDWDM scenarios

IP and Optical Control Plane Integration

GMPLS CONTROL PLANE GENERALIZED MULTI PROTOCOL LABEL SWITCHING

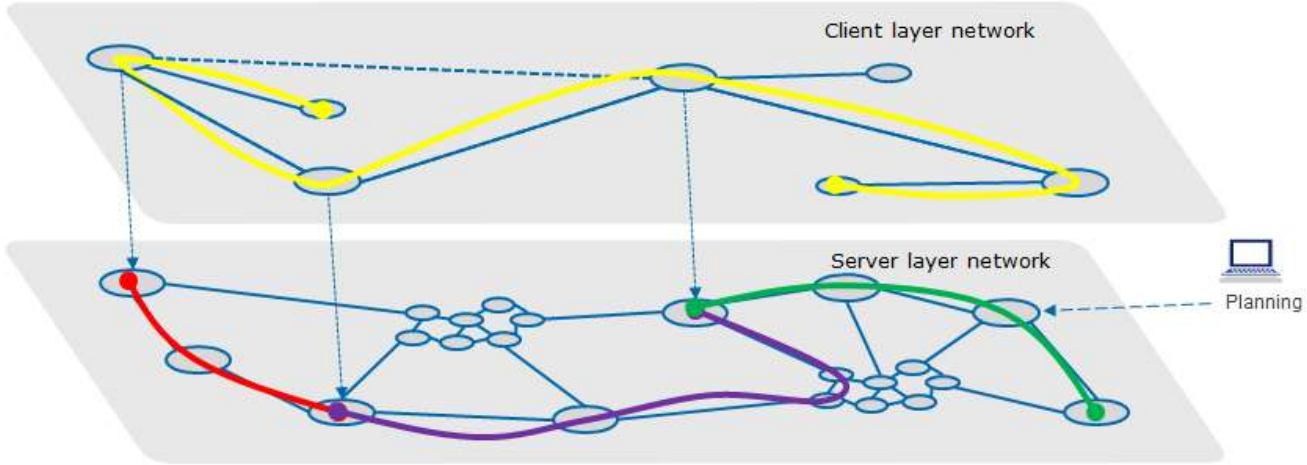
- Natural evolution of MPLS towards circuit-oriented transport networks (SDH, DWDM, OTN…)
- Can be considered as a protocol suite to dynamically dial and protect/restore connections (path/circuit) in an optical transport network
- Can work in a multi-vendor and cross-technology (IP, Ethernet, SDH, DWDM, OTN) environment
- Combines the benefits of well-proven carrier-class optical transport and IP packet-based technologies

BENEFITS

- Auto discovery of network resources: eases installation and commissioning
- Automated provisioning and operations: less site visits
- Another dynamic automated restoration option
- Provides not only transport but also service level protection

ASON, WSON and GMPL

- ASON – Automatic Switched Optical Networks – is a concept based on SDH ideas how to provide e2e services and providing in WDM, defined by ITU G.805/G.8080
- GMPLS and ASON started originally from different positions but are addressing the same problem
- WSON - Wavelength Switched Optical Network – is based on static WDM transmission technology and a generalized multiprotocol label switching (GMPLS) control plane, defined by IETF
  - Besides points mentioned before it includes also **Impairment control** at the optical level – In a WDM network, wavelength connection signal quality can be affected by linear and nonlinear optical impairments. While calculating a path, WSON can intelligently consider and manage wavelength switch restrictions, tunable lasers, physical impairments, and other optical layer restrictions. It also conducts on-line impairment control through the control plane.

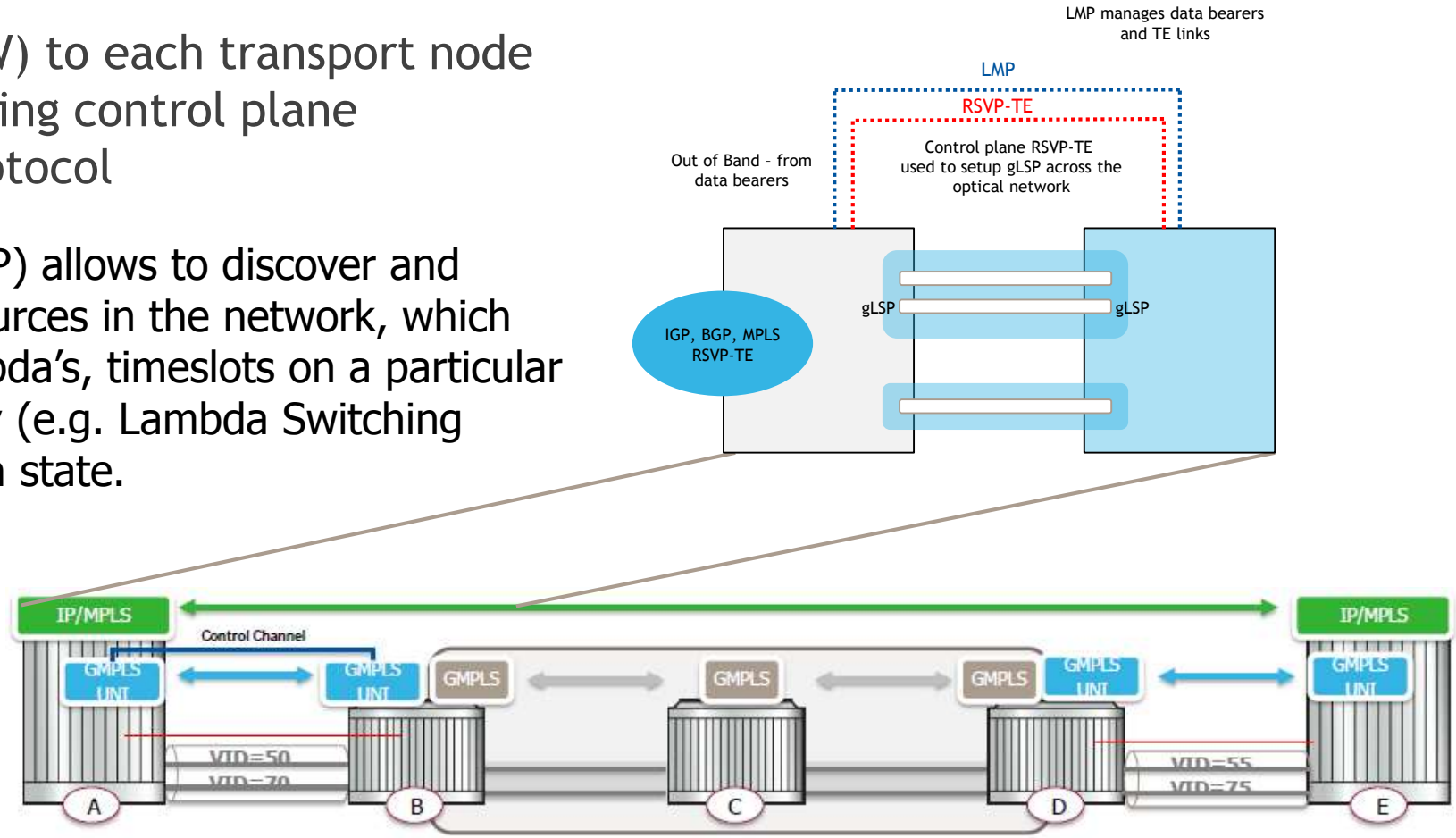


GMPL and GMPLS UNI

- GMPLS UNI interface creates a circuit connection by signaling exchanges between UNI Client (UNI-C) and UNI Network (UNI-N) nodes without manual intervention. UNI-C nodes are router nodes and UNI-N nodes are optical nodes.
- Create an IP control plane overlay with an IGP
- Add a small routing engine (SW) to each transport node and add the capability of running control plane protocols next to a routing protocol

Link Management Protocol (LMP) allows to discover and exchange the consumable resources in the network, which are links but also available lambda's, timeslots on a particular link. A link will have a capability (e.g. Lambda Switching Capable (LSC) and an allocation state.

RSVP-TE with GMPLS extensions - allows to signal requests for resource reservation using the well-known RSVP-TE protocol



Thank you