INTEGRATING OPTICAL NETWORKING INTO THE PACKET CORE

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OPTICAL INTEGRATION IN CORE ROUTING

For years, the optical portion of the network has been separate to – and managed separately from – the IP core

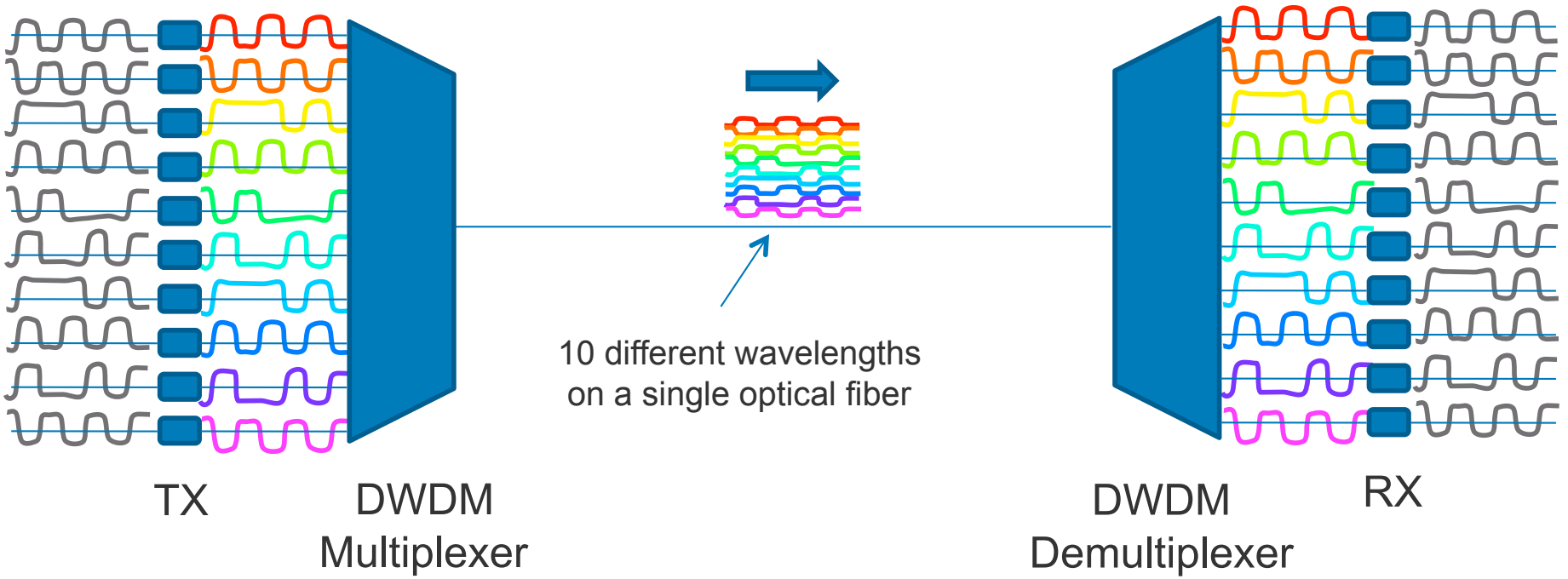
New standards and advancing technology is changing that status quo now

- Miniaturization of components
- G.698.2 standard – “black link”
- Management hooks into optical/router elements
- Integration between transmission failure and IP/MPLS reroute

We will examine how this landscape is changing – but first, a quick overview of optical networking terms and functionality

OPTICAL DEVICES/TERMINOLOGY

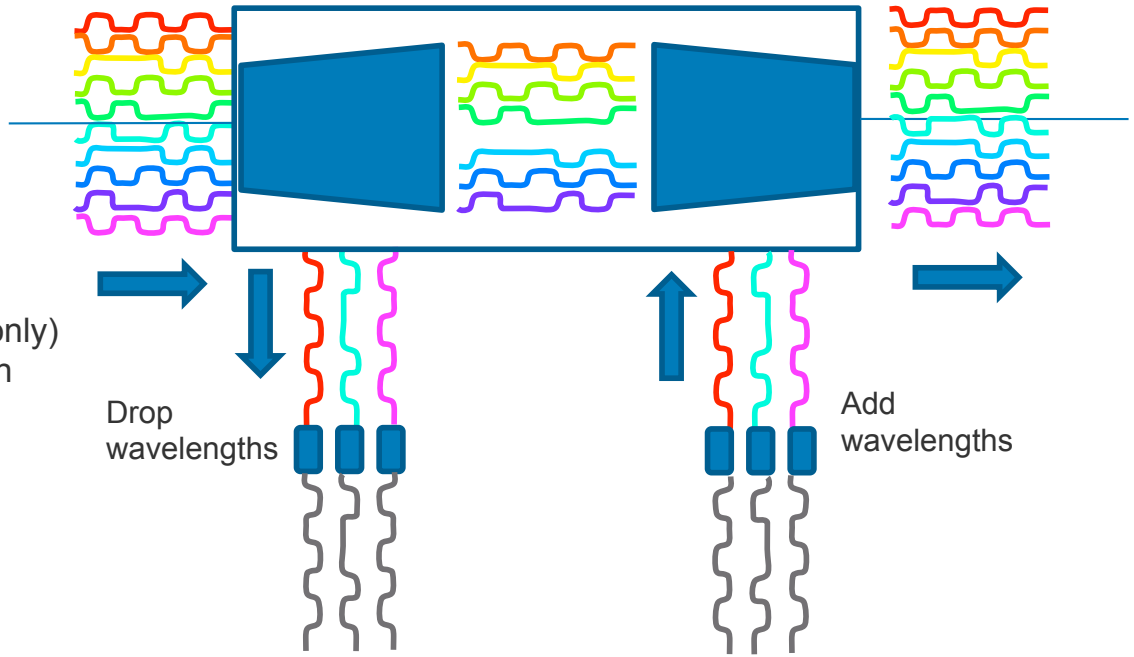
SIMPLE DWDM TRANSMISSION SYSTEM



- Ten individual gray signals converted to colored signals via wavelength-specific transmitters.
- Ten wavelengths combined onto single fiber using DWDM multiplexer
- Ten wavelengths separated at end of single fiber transmission link using DWDM demultiplexer.
- Commercial DWDM transmission systems today transmit more than 80 wavelengths per fiber.

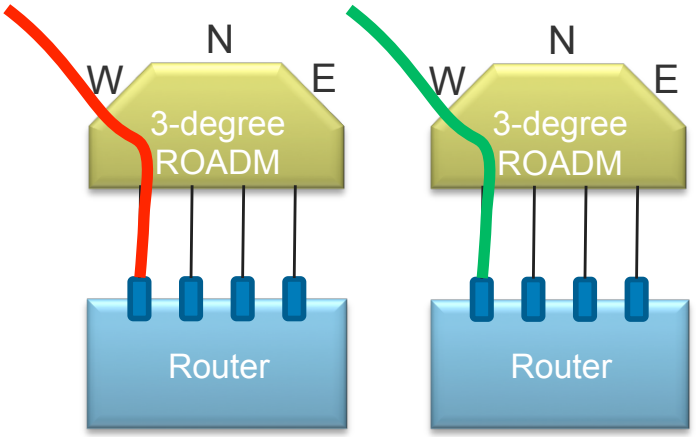
OPTICAL ADD-DROP MULTIPLEXER (OADM)

OADM
(schematic representation only)
(only one direction shown
for simplicity)

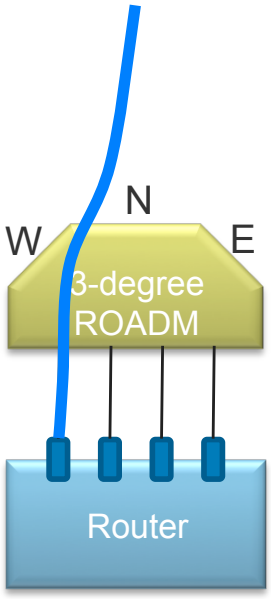


- OADM keeps pass-through wavelengths in optical domain
- Only wavelengths being added or dropped get converted to electrical domain
- OADMs for building optical ring networks
  - Higher degree OADMs useful for building optical mesh networks
- Reconfigurable OADMs (ROADMs) allow rapid, remote reconfiguration of add-drop wavelengths
- Latest generation are multi-degree ROADMs

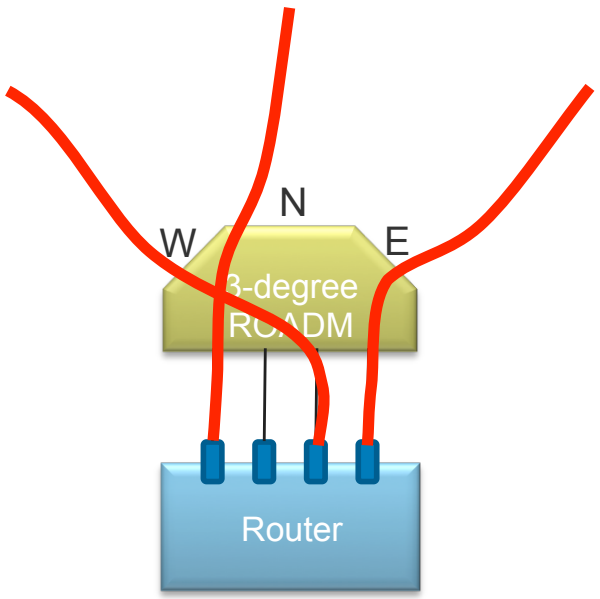
COLORLESS, DIRECTIONLESS, CONTENTIONLESS ROADM



Colorless – use any wavelength on a given add-drop port.

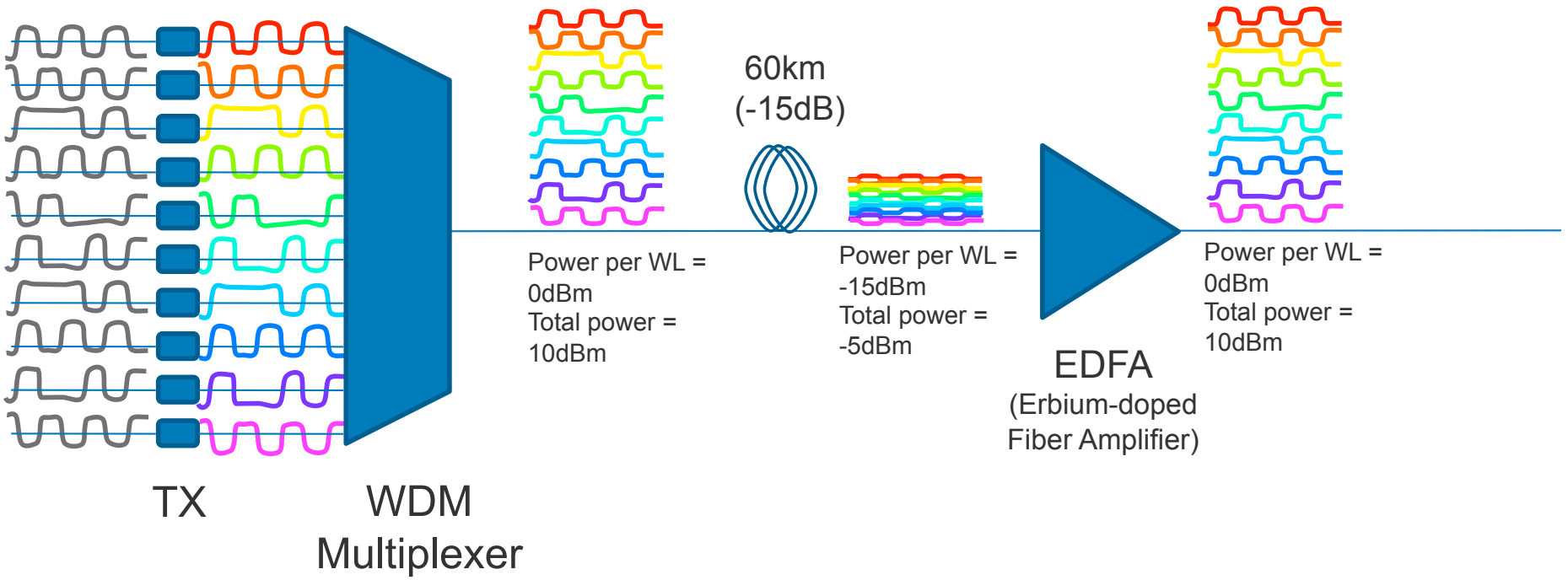


Directionless– use any add-drop port can connect to any direction (degree)



Contentionless– use any wavelength independent of all others in use

OPTICAL AMPLIFIERS AND DWDM

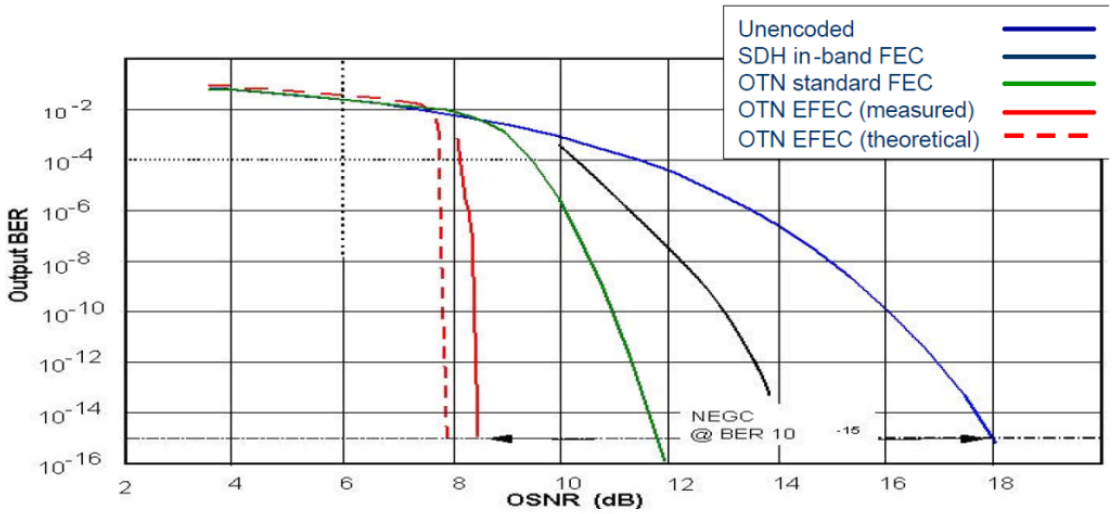


- Optical amplifiers amplify ALL of the wavelengths at the same time.
- Without optical amplifiers, alternative would be to demultiplex all of the wavelengths every 60-80km, regenerate the individual component signals (most likely electrically), then multiplex the different wavelengths back onto a single fiber.
- DWDM would not be a very successful technology without optical amplifiers that amplify across a broad spectrum of wavelengths.

FORWARD ERROR CORRECTION

- Adds redundant information to data which is used to correct for errors.
  - Implemented in digital electronics.
- Real FEC implementations use 6% to 25% FEC overhead to correct pre-FEC BER of ~10^{-3} to post-FEC BER of 10^{-15}
- Allows lower OSNR at receiver since higher pre-FEC BER will be corrected with redundant data.
  - Characterized by net coding gain.
  - Translates into more optically amplified spans and/or greater distance between EDFAs.

- FEC is mainly useful for reducing the impact of ASE noise in optically amplified systems.
- Not really useful in extending the reach of unamplified systems.



THE DIFFERENT MEANINGS OF OTN

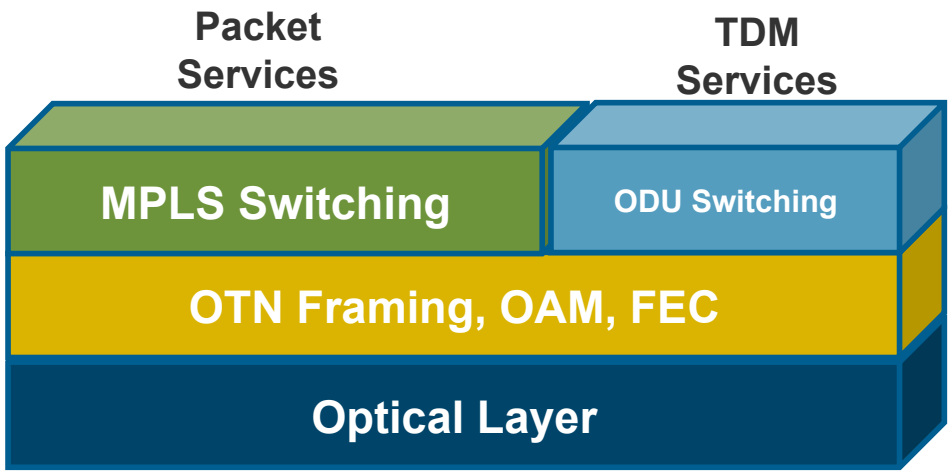
- OTN (Optical Transport Network) standardized in ITU G.709.
- OTN as generic term for optical networking and DWDM
  - Not very helpful use of term in this context
- OTN encapsulation
  - Provides FEC and OAM
  - Referred to as OTN termination when used on router or MPLS switch interfaces for packet traffic.
- OTN Switching
  - Next generation of TDM / circuit switching technology
  - Covering higher speeds than SONET/SDH
  - Defines mapping of lower speed circuits into higher speed circuits.

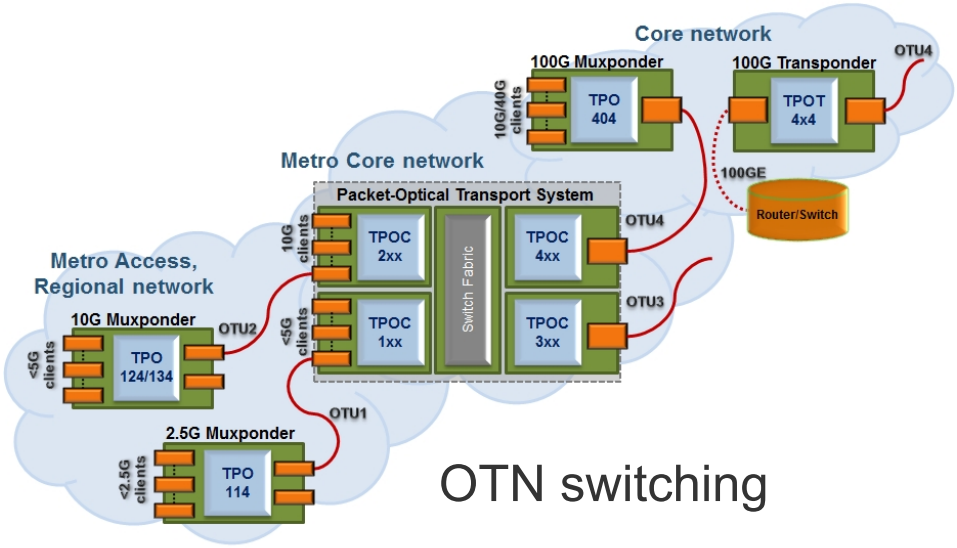
OTN encapsulation	Approximate bitrate*
ODU0	1.25 Gbps
OTU1/ODU1	2.5 Gbps
OTU2/ODU2	10 Gbps
OTU3/ODU3	40Gbps
OTU4/ODU4	100Gbps

* See G.709 for exact values. OTUk rate > ODUk rate > OPUk rate due to FEC and other overhead.

HANDLING PACKET AND TDM TRAFFIC

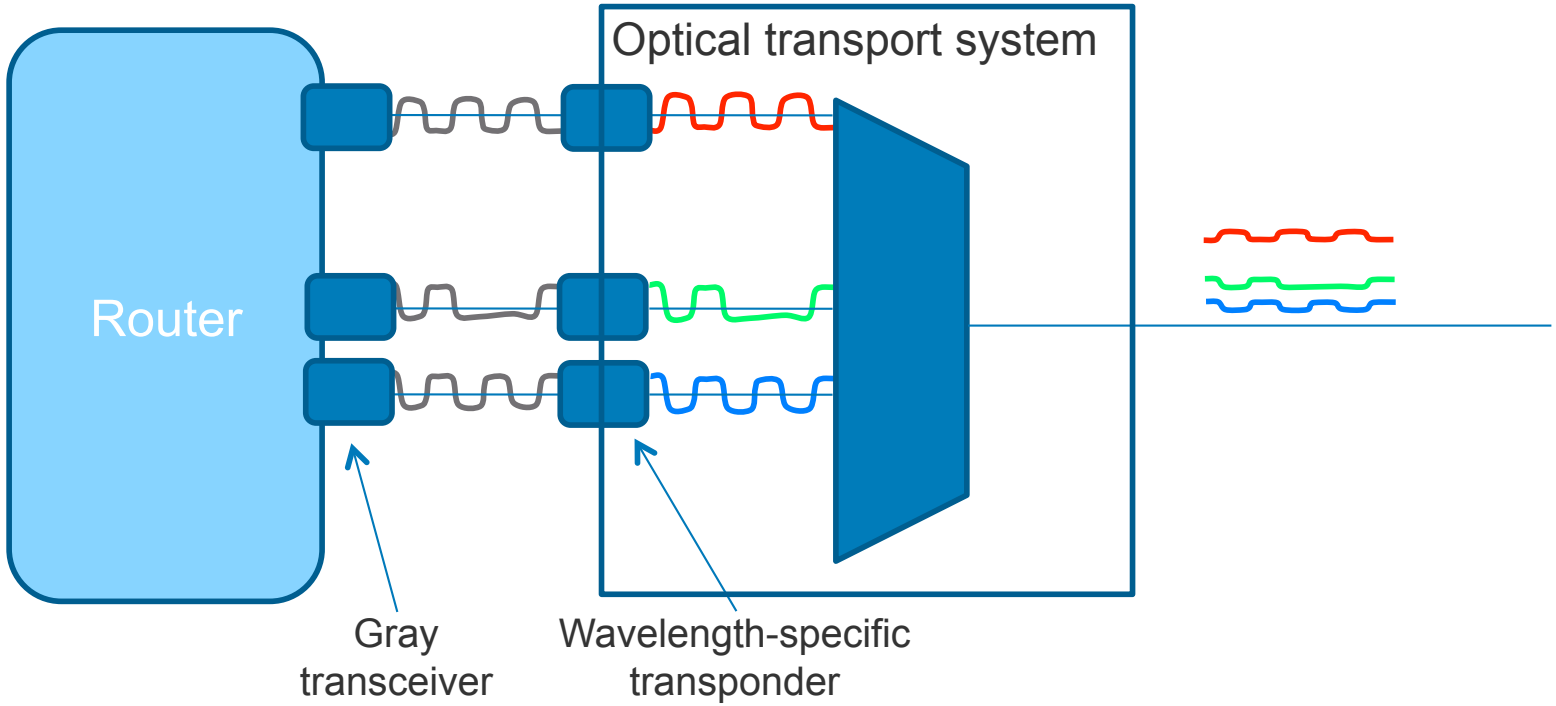
- Packet traffic most efficiently handled by packet switches (Routers)
  - Dynamic bandwidth allocation
  - Statistical multiplexing
  - Local Repair
- OTN switches are fixed-cell based technologies that are best used for TDM legacy traffic





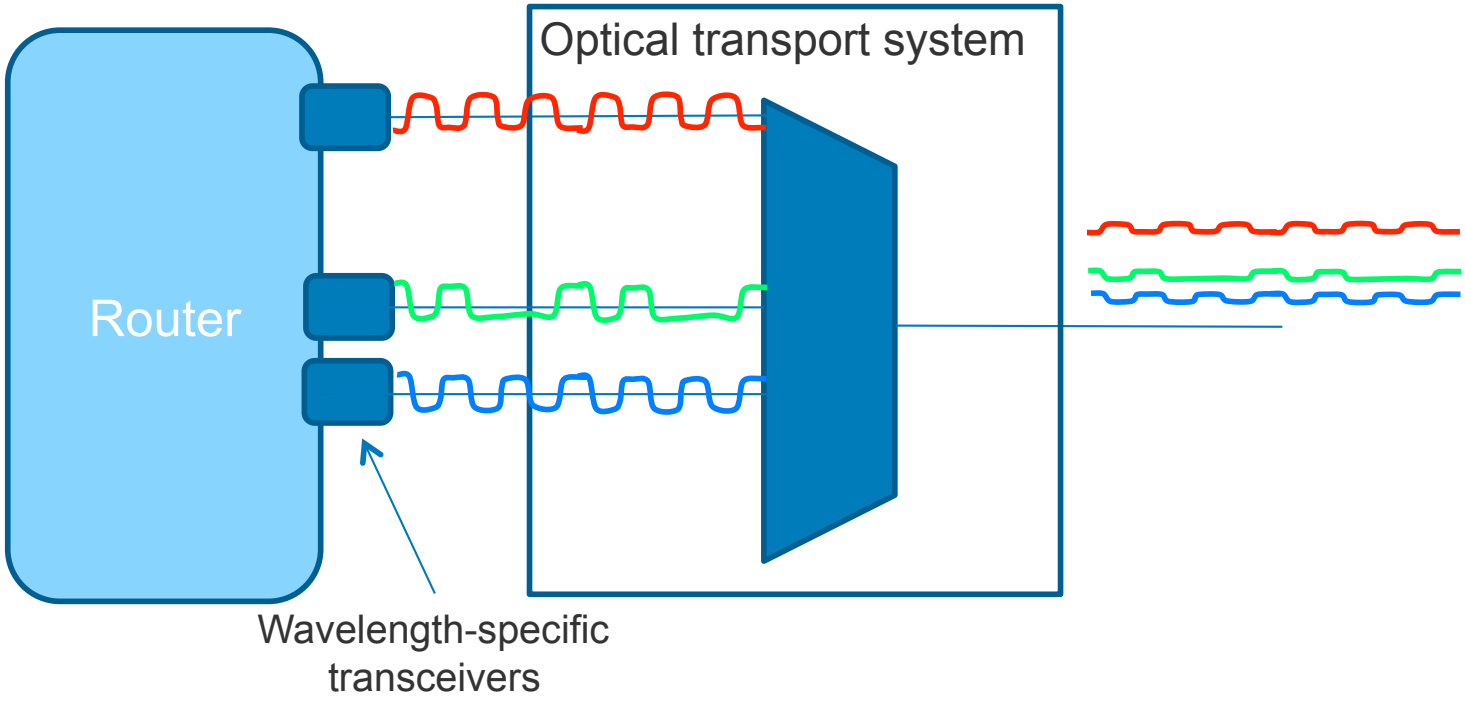
INTEGRATING OPTICAL NETWORKING INTO THE IP/MPLS CORE

FROM TRANSPONDER-BASED CONNECTION TO OPTICAL TRANSPORT SYSTEM…



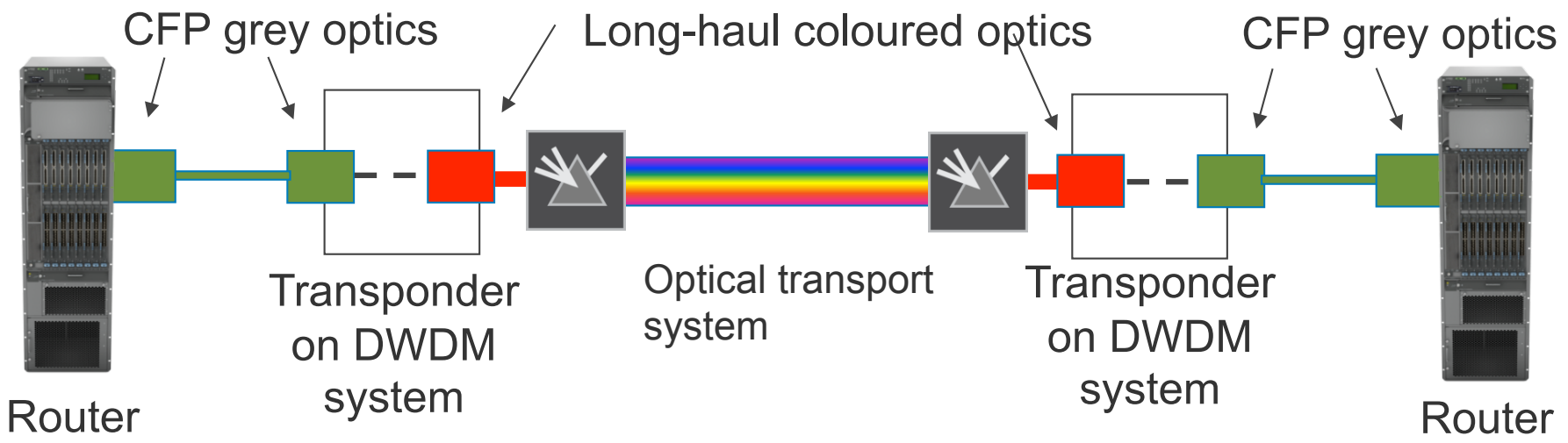
- Gray transceiver on router
  - "Gray" refers to an optical signal that does not have the optical characteristics to go transparently into the optical transport system. Also referred to as client-side optics.
  - For example, gray transceiver could be 1310nm (1260-1355nm range) on SMF.
- Wavelength-specific transponder on optical system
  - Transponder takes short-reach gray optical signal and converts it to a wavelength-specific optical signal with the right optical characteristics for the optical transport system.
  - Also referred to as "line-side" optics (wavelength specific long-reach interface)
  - For example, wavelength-specific line-side optics could be 1552.52nm.

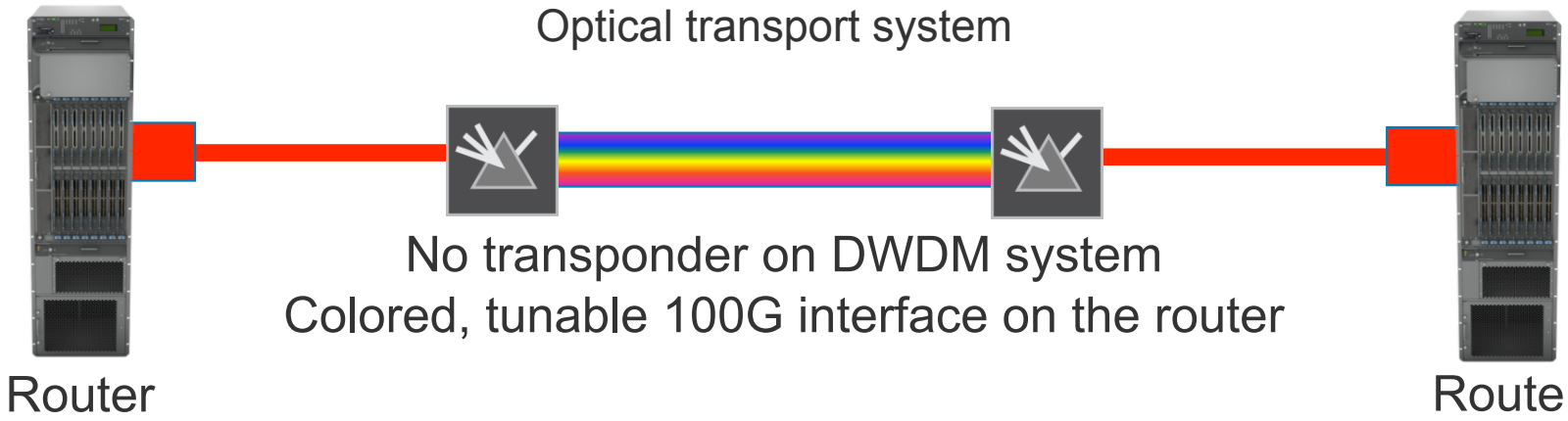
… TO TRANSPONDER-LESS CONNECTION TO OPTICAL TRANSPORT SYSTEM



- Wavelength-specific transceiver on router
  - Optical signal with wavelength (for example,1552.52nm) and longer reach optical characteristics
  - Allows it to go directly onto optical system without a transponder (no O/E/O conversion)
  - Sometimes referred to as “alien wavelengths” from point of view of optical transport system.
- Less expensive due to fewer O/E/O conversions.

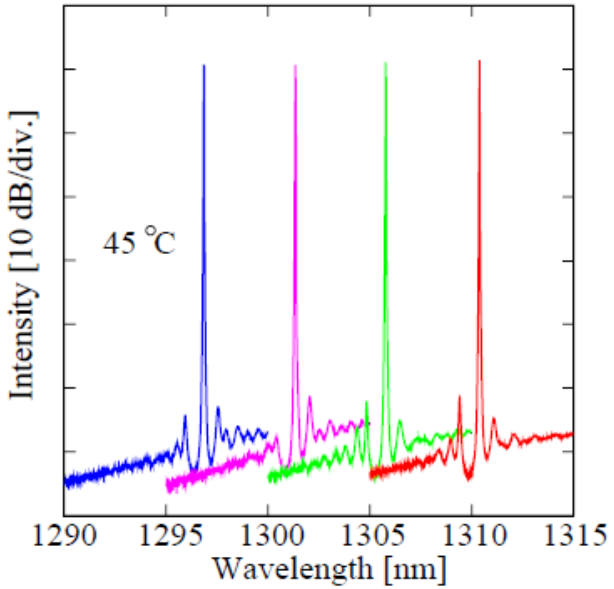
Grey interfaces versus Colored interfaces



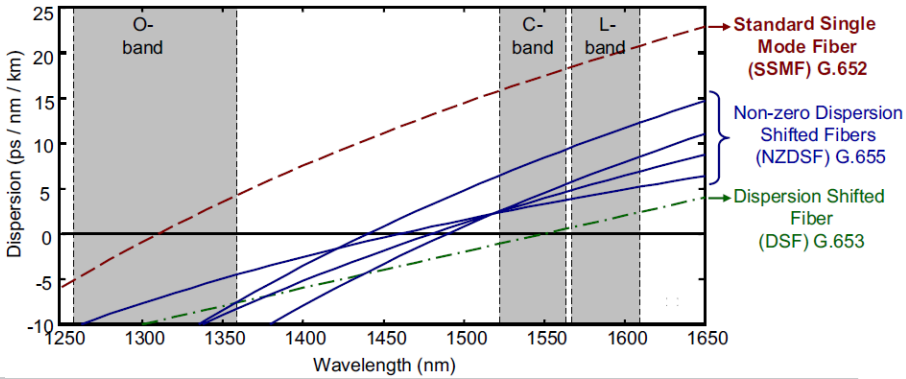


FROM 100GBASE-LR4…

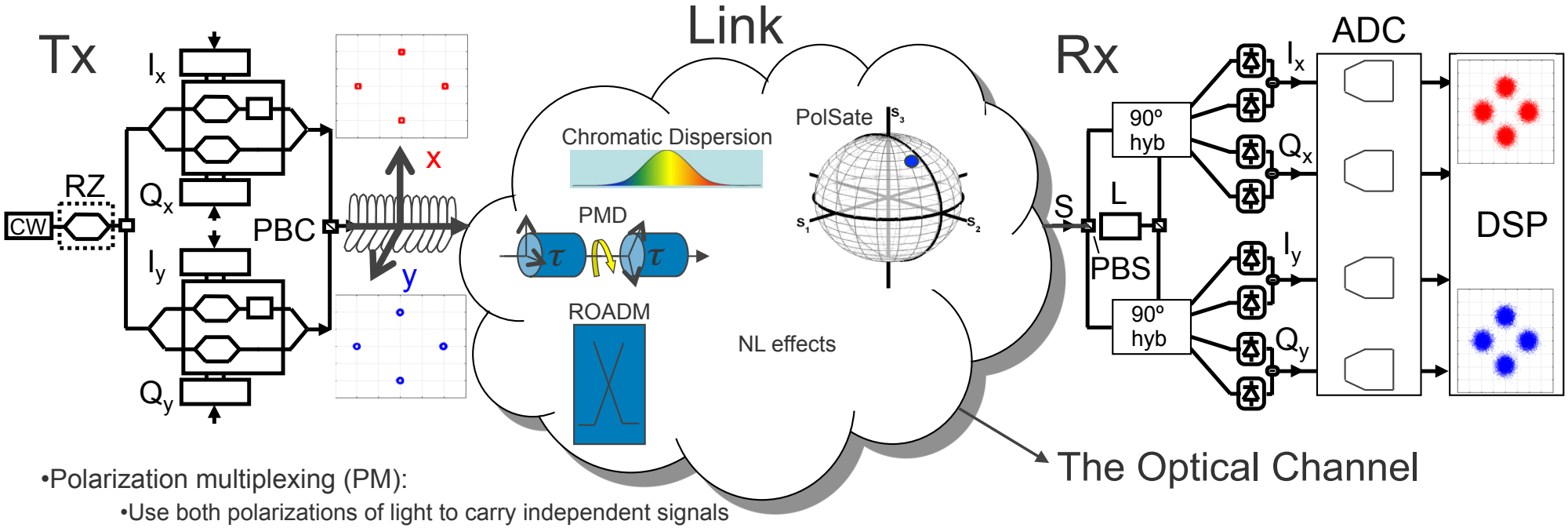
- Standardized in 802.3ba-2010 for 10km reach on SMF.
- Uses four parallel wavelengths running at 25.8 Gbps each
  - 4x25Gbps transmitters easier than 1x100Gbps
  - Lower bit rate also reduces effect of chromatic dispersion
- Lasers in 1300nm range with 800 GHz channel separation (LAN-WDM)
  - 1300nm range chosen for low dispersion for single-mode fiber
- "Grey" client interface



Lane	Center frequency	Center wavelength	Wavelength range
L_0	231.4 THz	1295.56 nm	1294.53 to 1296.59 nm
L_1	230.6 THz	1300.05 nm	1299.02 to 1301.09 nm
L_2	229.8 THz	1304.58 nm	1303.54 to 1305.63 nm
L_3	229 THz	1309.14 nm	1308.09 to 1310.19 nm



… TO 100G COHERENT PM-QPSK DWDM



- Polarization multiplexing (PM):
  - Use both polarizations of light to carry independent signals
  - Lowers symbol rate by a factor of 2
  - Allows for electronic compensation of PMD
- Quadrature-phase shift keying (QPSK):
  - Uses a constellation with 4 symbols
  - Lowers symbol rate by another factor of 2
  - Captures phase information allowing digital signal processing (DSP) to compensate for chromatic dispersion electronically.
- Coherent detection:
  - Laser at receiver tuned to wavelength of received light selects detected wavelength in DWDM system
- DWDM:
  - Optical signal still fits in 50GHz channel spacing for DWDM
- Benefit:
  - 2500 km transmission at 100Gbps with no external dispersion compensation and high PMD tolerance.

CONTROL PLANE: GMPLS (GENERALIZED MPLS)

- Set of protocols to dynamically provision optical layer resources
  - Within optical layer
  - From routers to optical layer
- Generalized MPLS (GMPLS) reuses and extends protocols used by MPLS (ISIS or OSPF and RSVP) and adds LMP (link management protocol)
- GMPLS has been around since 2004 but not widely deployed on routers to signal wavelength setup
- Optical layer is becoming more flexible
  - More able to respond to arbitrary wavelength set up demands from packet layer
  - Flexible ROADM technology (directionless, colorless, contentionless)
  - 100G coherent detection with digital signal processing automates dispersion compensation.
- Packet layer requirements increasing

CURRENT STANDARDS WORK

Black Link in ITU-T:

- **Recommendation ITU-T G.698.2: Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces**

1 Black Link Framework:
http://tools.ietf.org/html/draft-kunze-g-698-2-management-control-framework-01

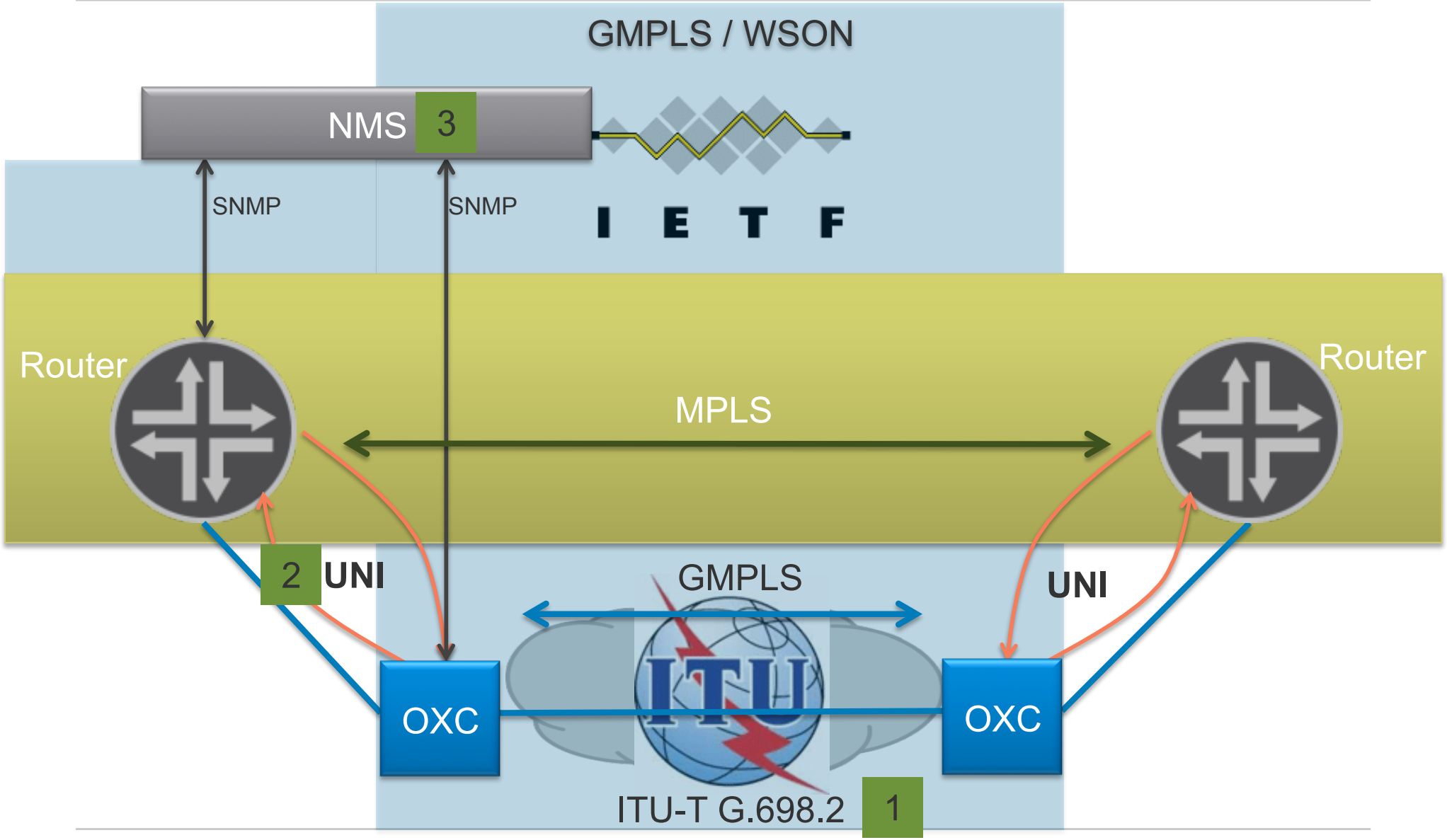
3

Black Link Management:

2 http://tools.ietf.org/html/draft-galimbe-kunze-g-698-2-snmp-mib-01

GMPLS-UNI+:
http://tools.ietf.org/html/draft-beeram-ccamp-gmpls-uni-bcp-00

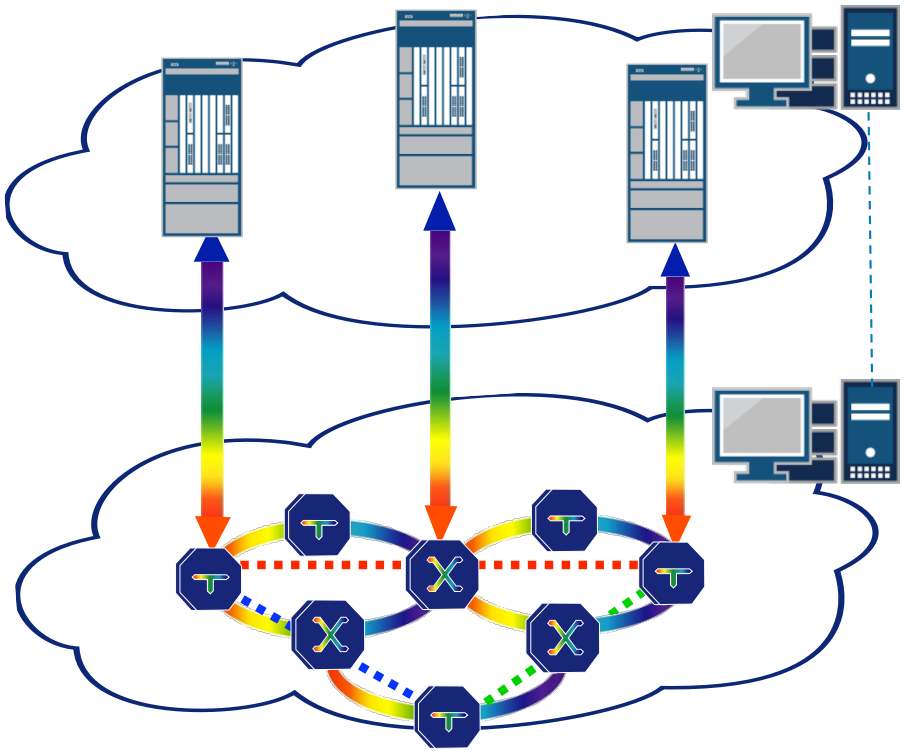
PACKET/OPTICAL NETWORKING: AN OPEN PACKET OPTICAL TRANSPORT ECO-SYSTEM



OPEN THE LOOP
- PACKET OPTICAL NETWORKING

Management plane integration

- NMS displays, monitors and manages native router DWDM ports and services
- NMS partitions DWDM network bandwidth “reservation rules” per customer requirements



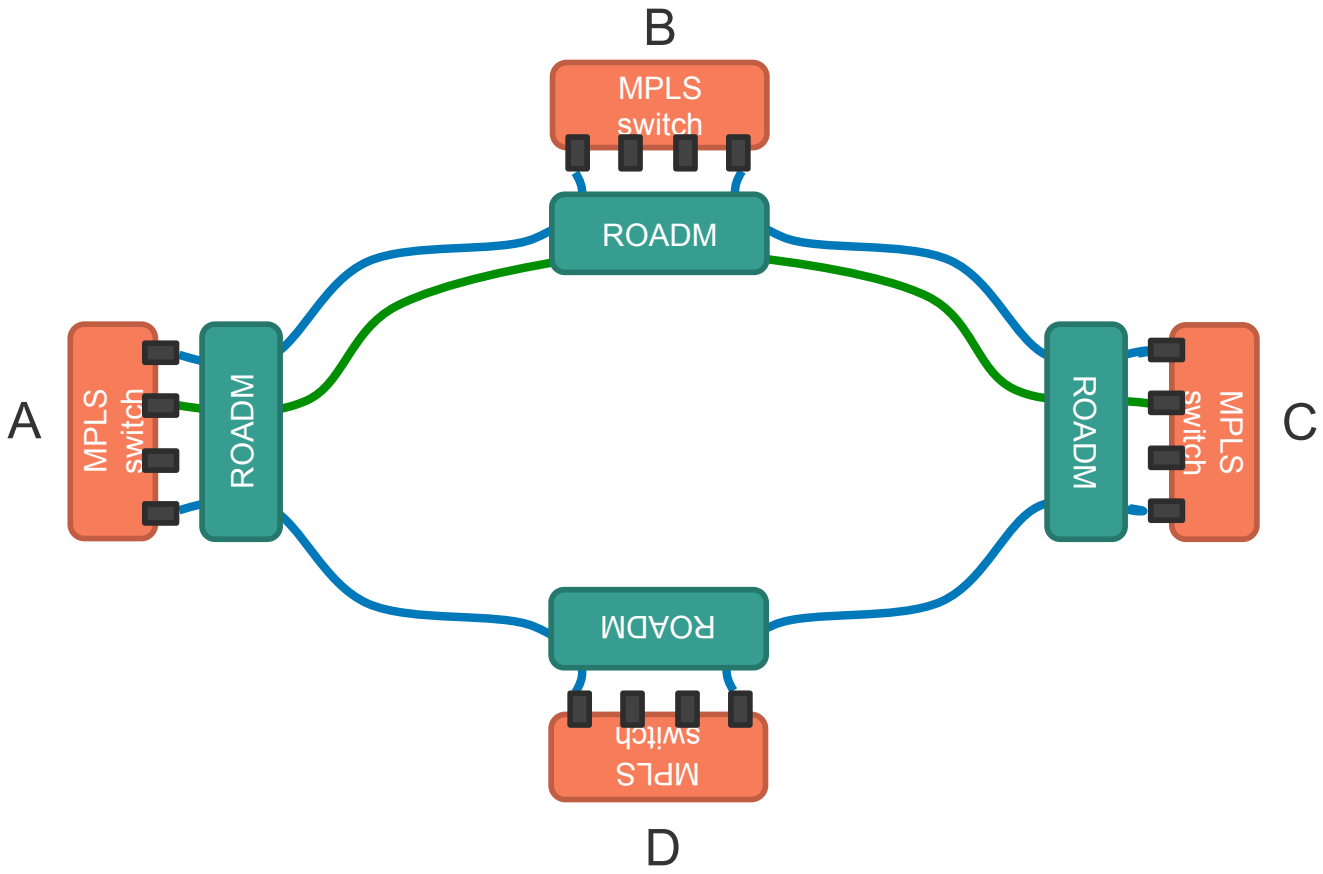
Data plane integration

- OTN and non-OTN DWDM router ports connected directly to DWDM platform without the need for transponders
- More than 2000km transmission distance demonstrated at 10Gb/s

Control plane integration

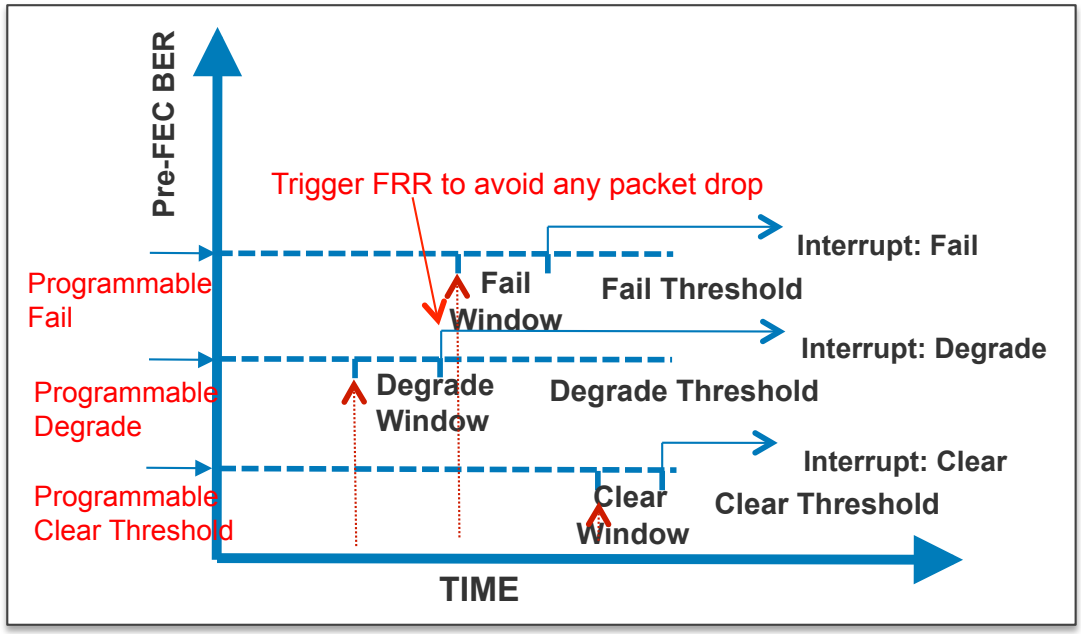
- MPLS/GMPLS interop enables router user (via CLI) or automated script to create end to end loose paths across DWDM network without needing to manually configure the DWDM equipment

RESPONDING TO UNPREDICTABLE GROWTH WITH AUTO-WAVELENGTH (ANIMATED)

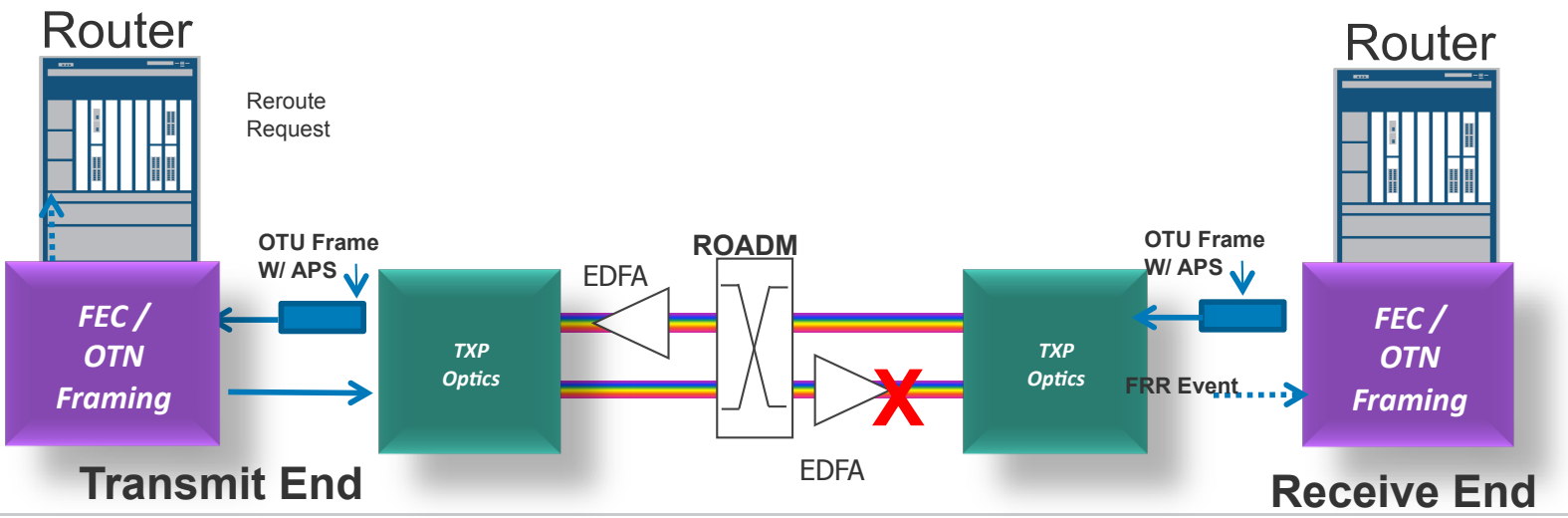


- Auto-wavelength responds quickly to the actual demand growth.
- If only A to C demand grows, only A to C wavelength is added.
- Avoids over-provisioning and saves capex.

PROACTIVE PROTECTION



- FRR: Hitless switch over based pre-FEC BER
- Packet layer protection based on visibility of transport layer performance degradation




everywhere