DWDM & Packet Optical Fundamentals:

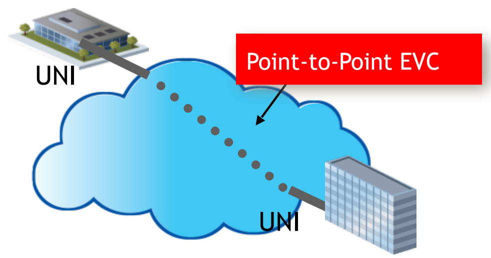
How to Troubleshoot the Transmission Layer.

Nanog 64
Peter Landon, Director Product Architecture
BTI Systems

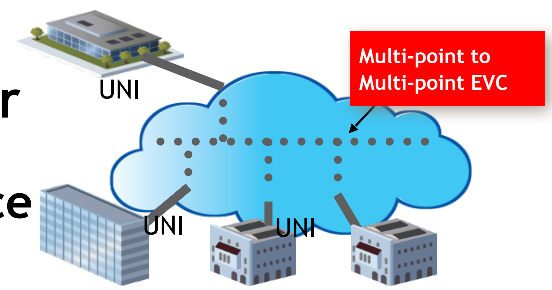
Packet Optical Fundamentals

Standardized Services and Flexibility

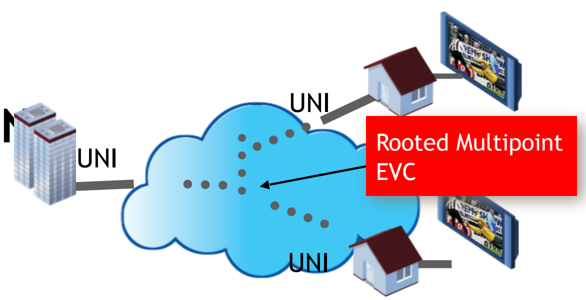
E-Line Service Type for
- Virtual Private Lines (EVPL)
- Ethernet Private Lines (EPL)
- Ethernet Internet Access



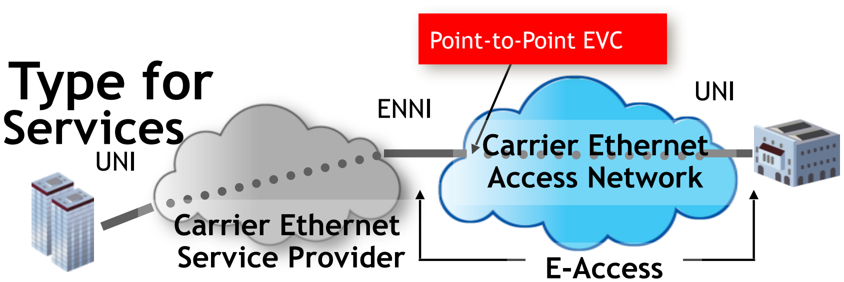
E-LAN Service Type for
- Multipoint L2 VPNs
- Transparent LAN Service
- Multicast networks



E-Tree Service Type for
- Rooted multi-point L2 VPN
- Broadcast networks
- Telemetry networks



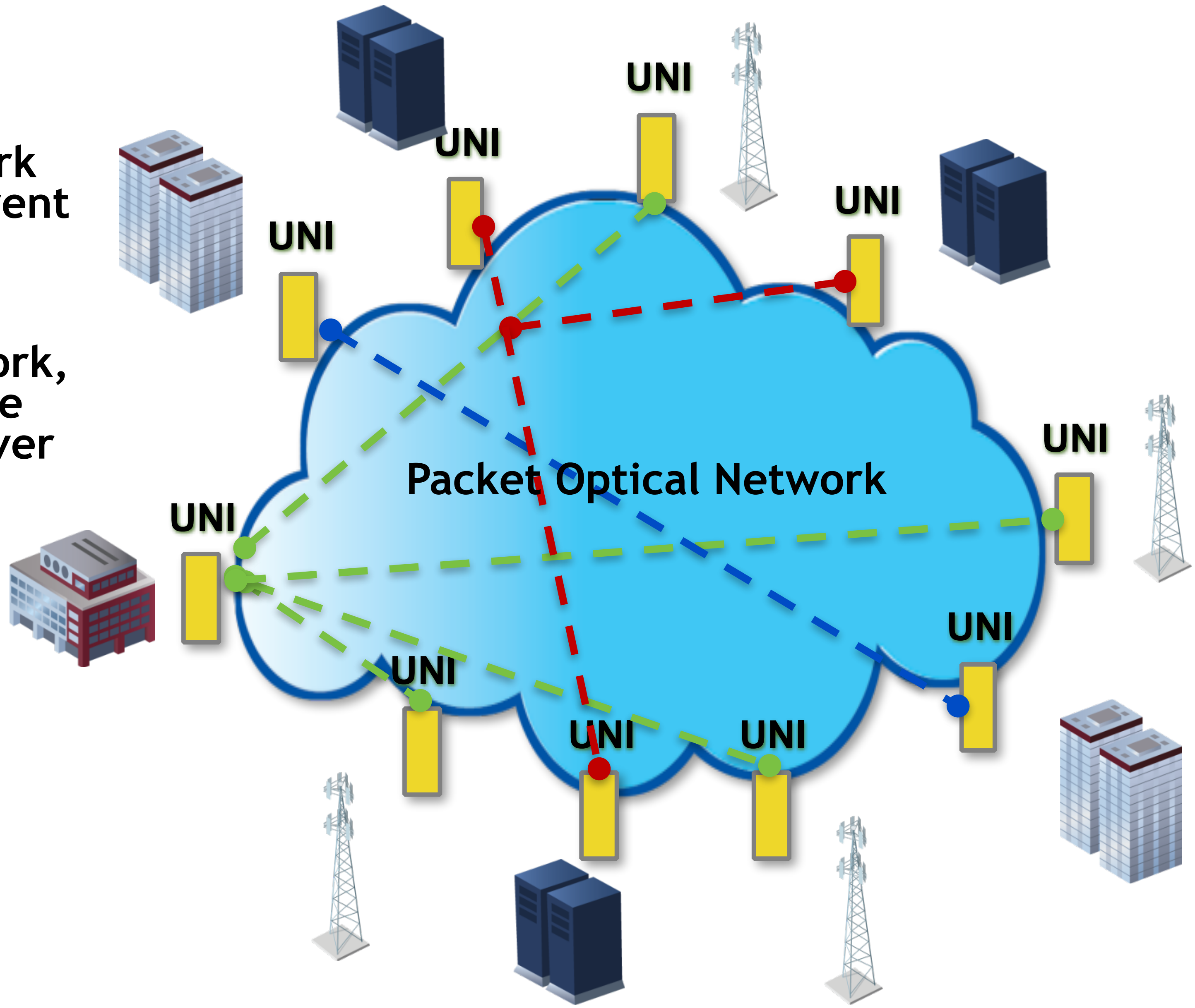
E- Access Service Type for
- Wholesale Access Services
- Access EPL
- Access EVPL



Source: MEF

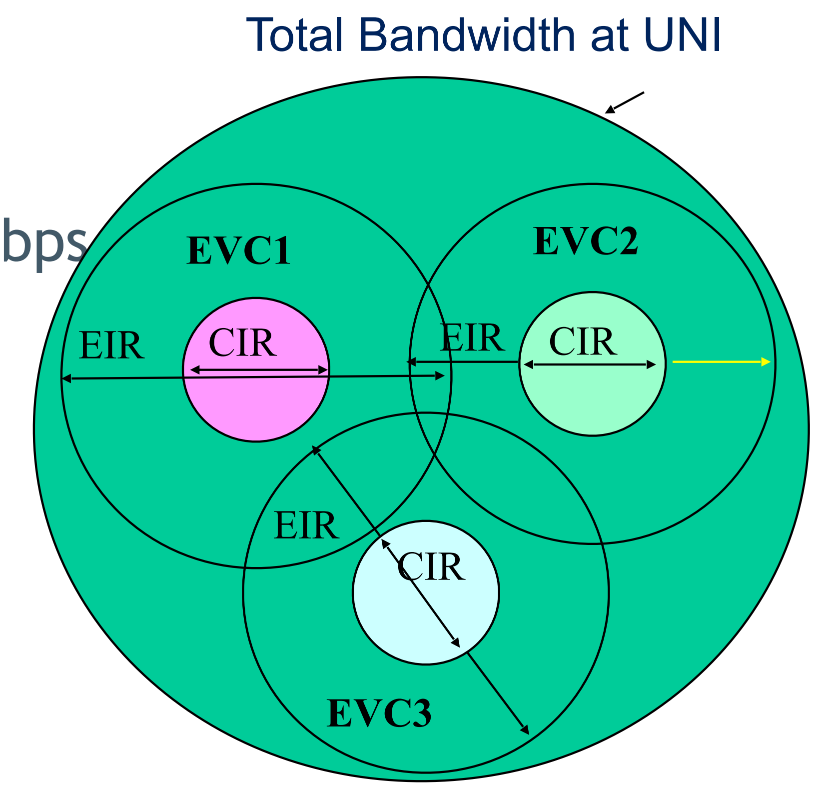
Standardized Services and Flexibility

- Use the same network for delivery of different Ethernet services
- With an integrated packet optical network, one can use the same network to also deliver 10G managed wavelength services



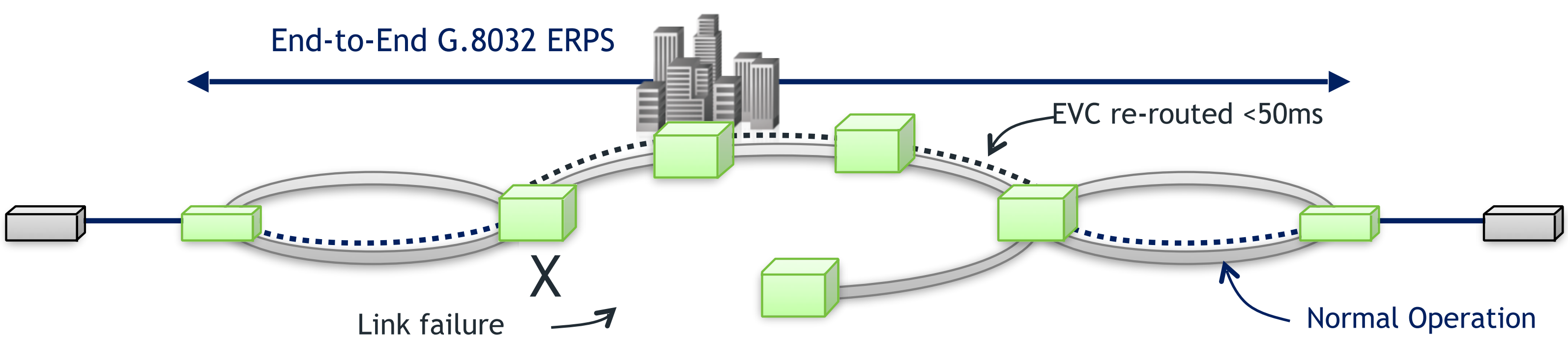
Service Bandwidth Scalability: 1Mbps to 10Gbps

- User Network Interface - UNI
- Ethernet Interface Speeds
  - 10Mbps, 100Mbps, 1Gbps and 10Gbps
- Ethernet Virtual Circuit - EVC
- Common Bandwidth Offerings
  - 1M to 100M in 1M steps
  - 1M to 1G in 10M steps
  - 1G to 10G in 100M steps
- Bandwidth Profiles
  - Committed Information Rate - CIR
  - Excess Information Rate - EIR



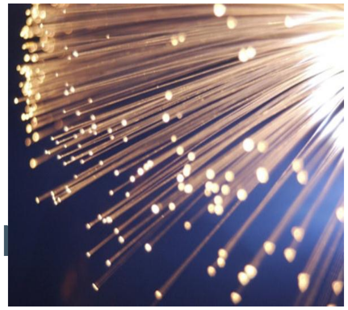
G.8032 v2 Ethernet Ring Protection Switching

- Portfolio-wide ITU Standard G.8032 v2 Support for Sub-50ms Protection Switching Performance
- Flexible and Resilient Ladder Rings Capabilities

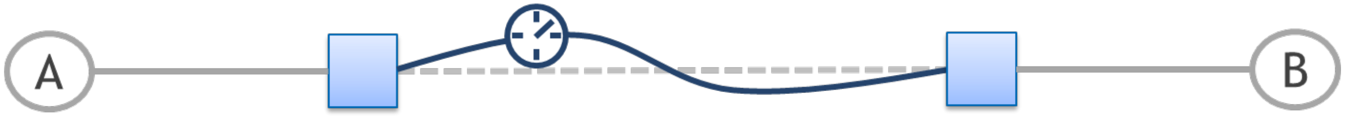


Mirrors SONET capabilities

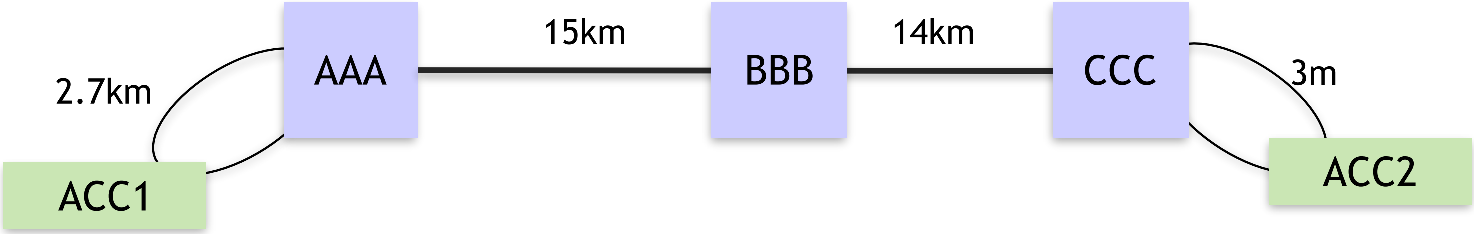
Latency Basics



- Propagation Latency
  - the delay in moving the packet across the fiber mediu
  - Propagation thru fiber is approx. 5 usec per km



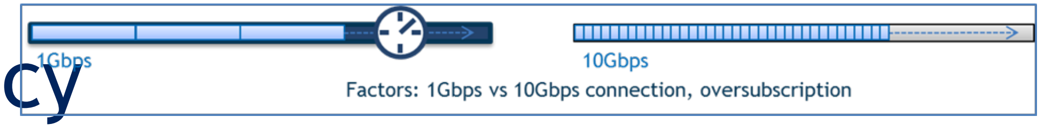
  - Example



  - Total Distance = 2.7km + 15km + 14km = 31.7km
  - Propagation Latency = 31.7km * 5 usec/km = 158 usec = 0.158 msec

Latency Basics

- Serialization Latency

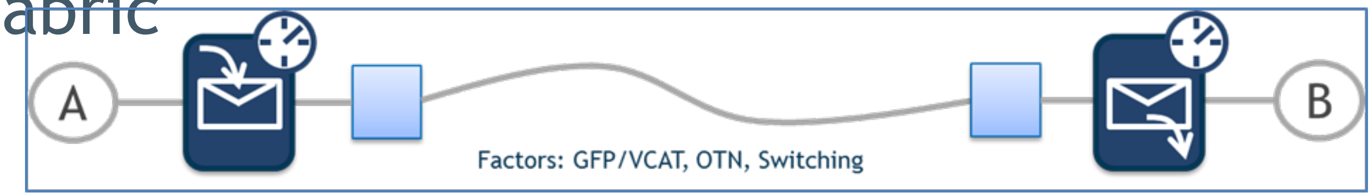


  - the delay in moving packets from the Network Interface Controller's (NIC) transmit buffer to the wire
  - Function on the speed of the interface and the frame size
  - Higher the speed, lower the serialization latency

Interface	Serialization Delay Formula	1518 byte	64 byte	9600 byte
10BASET	*(Frame Size x 8 bits/byte) / 10 Mbps*	*1214.4 usec*	*51.2 usec*	*7680 usec*
100BASET	*(Frame Size x 8 bits/byte) / 100 Mbps*	*121.44 usec*	*5.12 usec*	*768.0 usec*
1000BASET	*(Frame Size x 8 bits/byte) / 1000 Mbps*	*12.14 usec*	*0.512 usec*	*76.80 usec*
10GE	*(Frame Size x 8 bits/byte) / 10000 Mbps*	*1.21 usec*	*0.0512 usec*	*7.68 usec*

Latency Basics

- Switching Latency
  - the delay in moving packets across the switching fabric



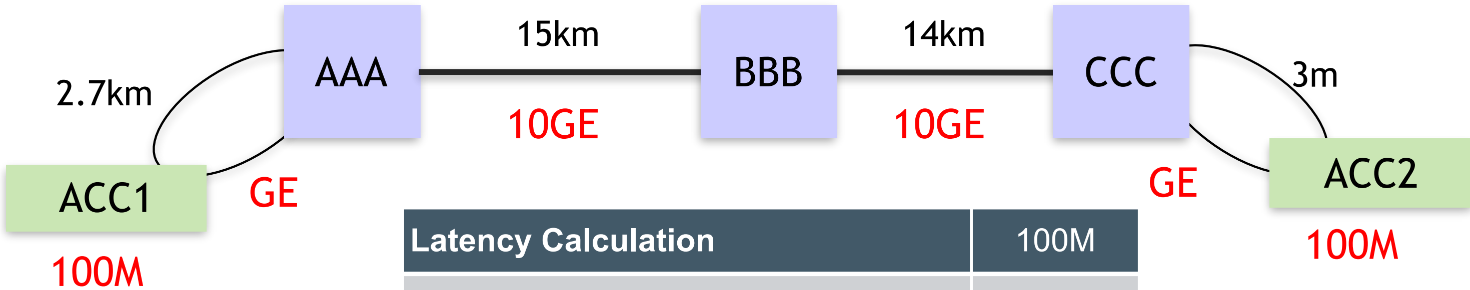
**Source: Popescu & Constantinescu, Blekinge Institute of Technology Karlskrona, Sweden*

*** Source: ITU-T Rec. G.707 and G.803*

  - Typical Switching Latency

SDH	IP/MPLS	Carrier Ethernet
*~125-150 usec**	*~50-200 usec***	*~10-20 usec*

Latency Result

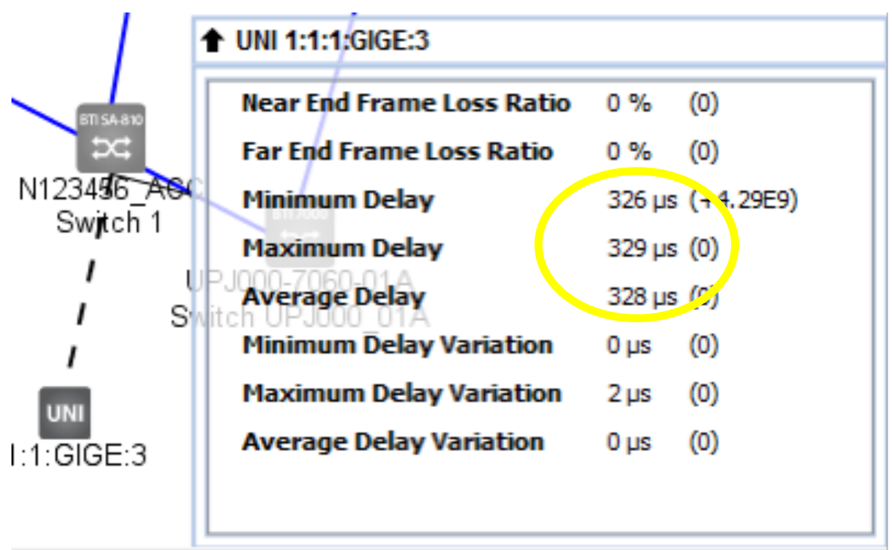


Latency Calculation	100M
Propagation	0.159
Serialization	0.006
Switching	0.035
Total Round-Trip Latency	0.400

Test Set

Frame Length (Bytes)	Copper		Fiber	
	10M	90M	100M	1000M
64	342	342	327	329
128	356	356	332	334
256	381	381	339	1178
512	431	431	352	1682
1024	531	531	378	380
1280	581	581	391	591
1518	626	626	401	403
1522	627	627	402	403
9600	2185	2185	812	1889

Y.1731



Carrier Ethernet Latency Notes

- Fiber route is usually major contributor to the overall latency of the network
  - Work with the planners for the shortest distance
- Interface rate, frame size and traffic influence the Serialization and Queuing Latency
  - Network traffic and QoS engineering
- Switching technology is the key differentiator
  - Optical will yield the best latency but does not maximize the use of fiber or wavelengths
  - Carrier Ethernet has superior switching latency
  - Carrier Ethernet + WDM yields the lowest cost per bit
- Able to remotely monitor, measure and report on the performance of the network using Y.1731 and management products key differentiator

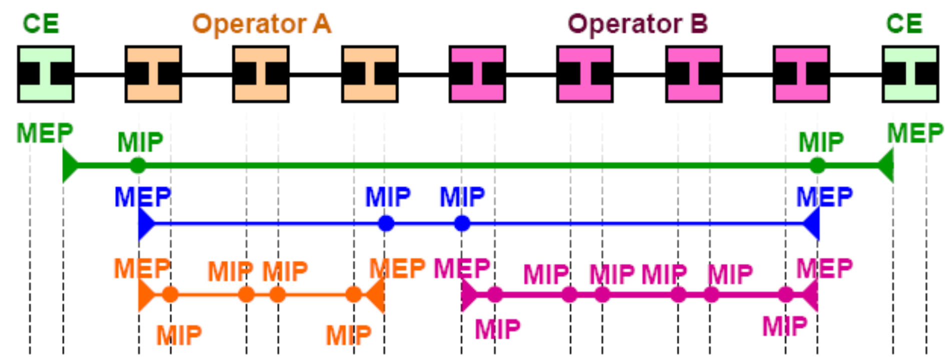
Service Management & Service Level Agreements

- Rich standards based Ethernet Services OAM for trouble shooting (connectivity fault management, loopbacks, linktrace, built in RFC 2544, Y.1564 test functionality)
- Highly accurate hardware based Y.1731 performance measurement and monitoring (latency, jitter, loss)
- Historical data collection for SLA compliance and reporting

Service Management & Service Level Agreements

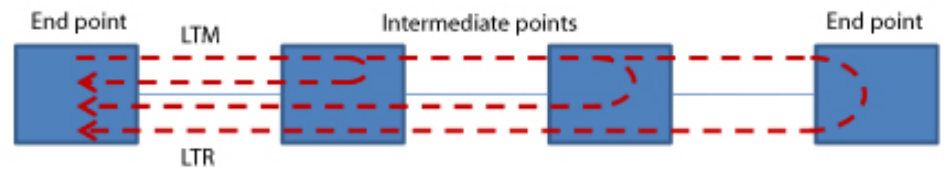
Connectivity Fault Management (CFM)

- End-to-end fault detection and isolation on a per-Service-VLAN (or per-EVC) basis
- Per service visibility and fault isolation
- Continuity Check Messages
- Connectivity failures and unintended connectivity detection



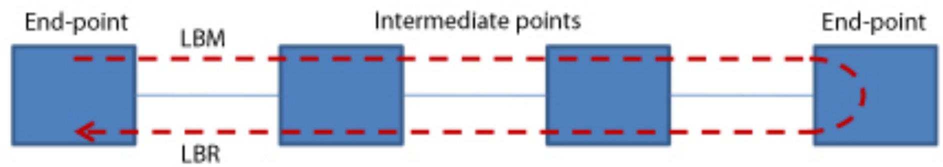
Link Trace

- Administrative service path analysis; Layer 2 traceroute equivalent
- Link Trace Message (LTM) & Link Trace Reply (LTR) between maintenance points
- Reports MEPs and MIPs on the service path



Loopback

- Fault isolation and verification; Layer 2 ping equivalent
- Loopback Message (LBM) & Loopback Reply (LBR) unicast between maintenance end points



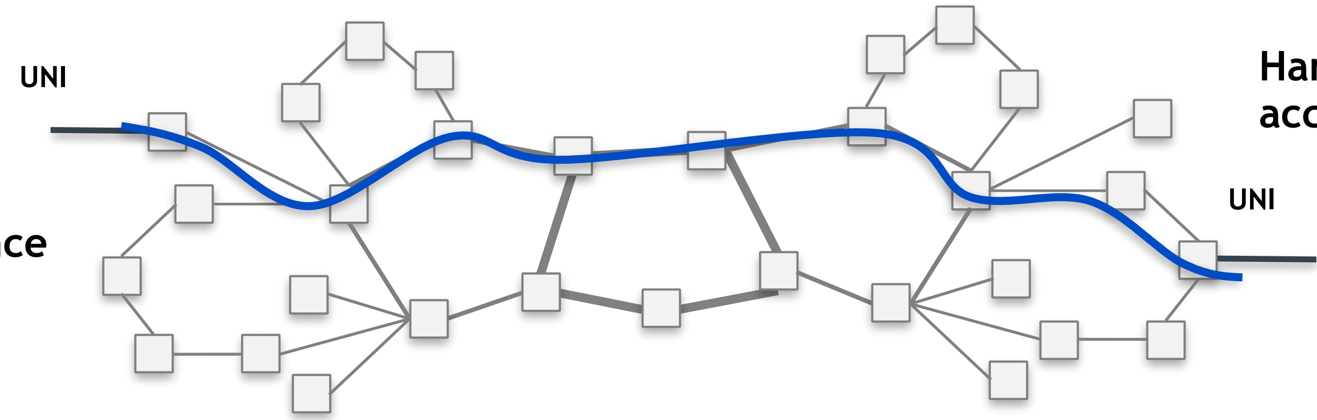
SLA Performance Monitoring

- Performance
  - ➢ Delay (latency)
  - ➢ Delay variation (jitter)
  - ➢ Frame loss

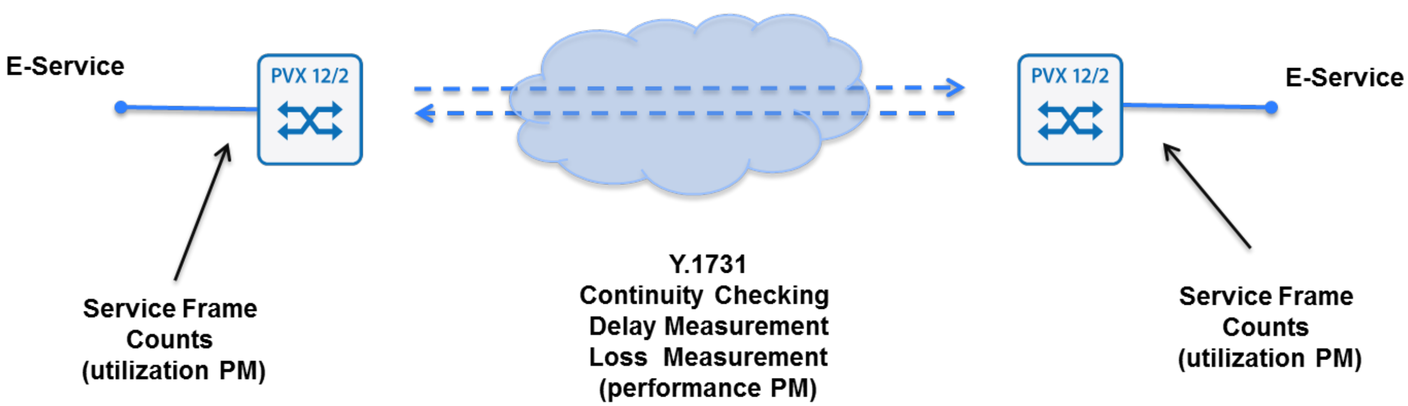
- Utilization
  - ➢ Received frames
  - ➢ Accepted frames
  - ➢ Dropped frames

- Availability
  - ➢ Network Availability
  - ➢ SLA Availability

Y.1731 Performance Monitoring

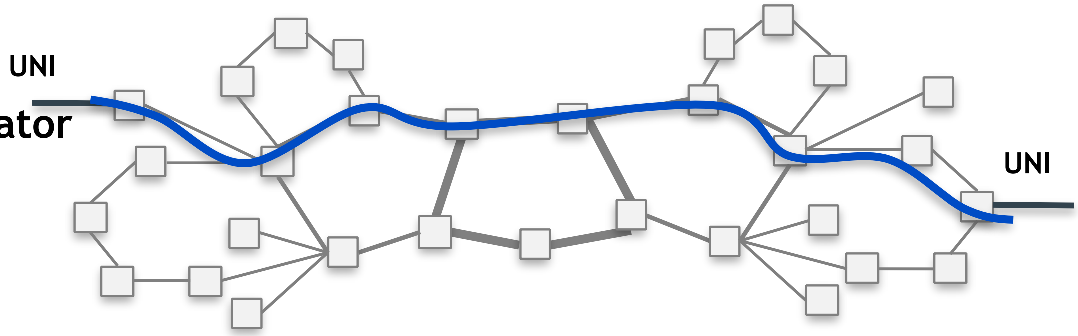


Hardware based, very accurate



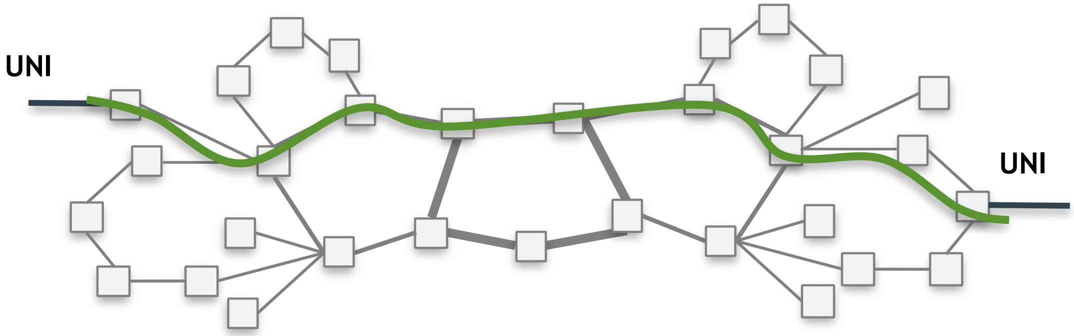
Test Methods: RFC2544, Y.1564, Station Loopback

RFC2544 Test Generator and Analyzer



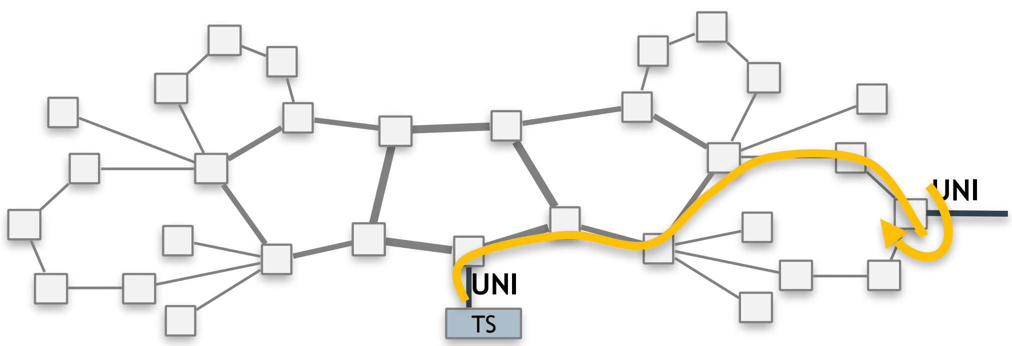
Embedded Test Generator and Analyzer (Throughput , Latency, Frame Loss and Back-to-Back) with automatic report generation

Y.1564 Service Activation Testing



Based on Y.1731 LBM / LBR

Station Loopback



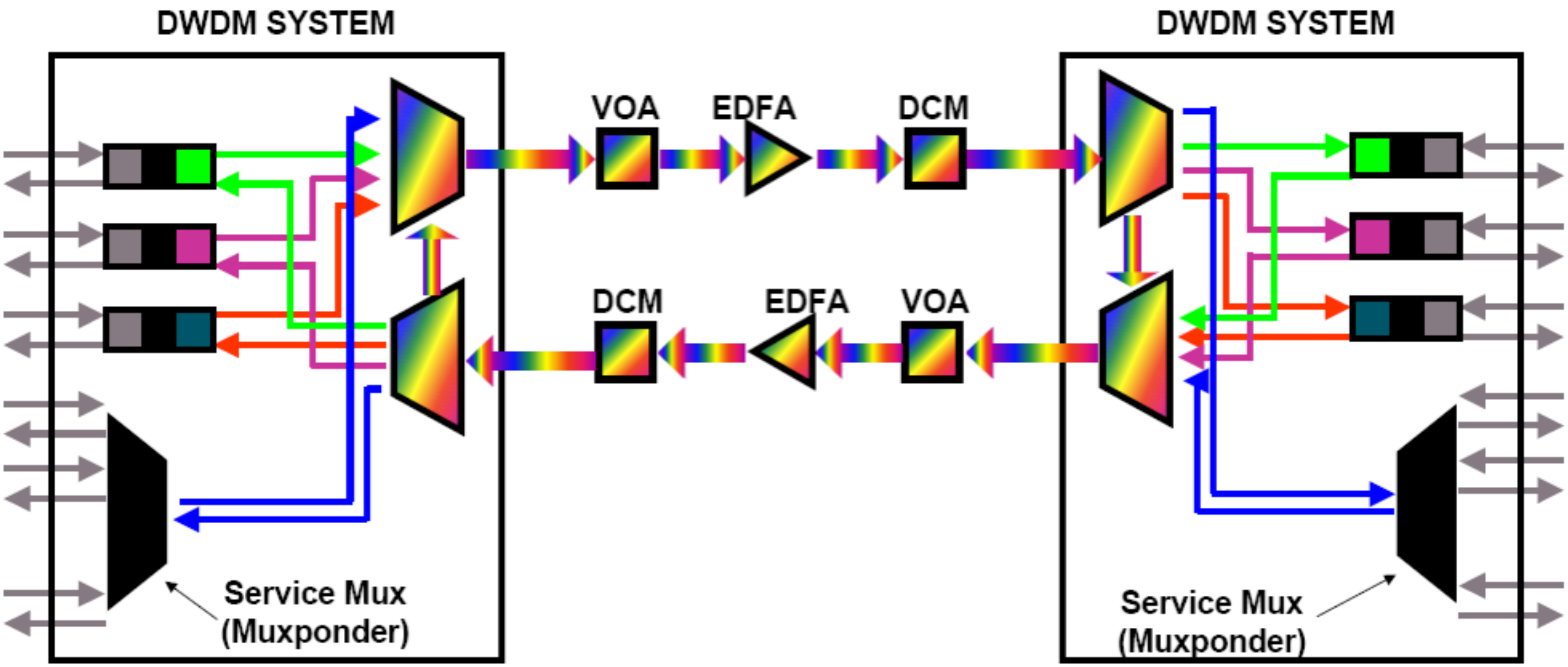
Station Loopback reacts to in-band loopback requests sent from test-sets (e.g. EXFO)

Advantages of Packet Optical Carrier Ethernet Network

Claim	Solution Features
Service Flexibility	*EPL, EVPL, ELAN, ETREE, EACCESS* *Ability to offer 10G wavelength services on same network* *Simple Service Activation with proNX Services Manager*
Capacity	*FE/GE/10G access, 1Mbps->10Gbps service, Nx 10G core* *Easily expand service bandwidth and network capacity* *DWDM Optics*
Reliability	*Ethernet Ring Protection Switching (G.8032) < 50msec switching* *Traffic re-routed around multiple failures*
Low Latency	*Carrier Ethernet based, lowest switching latency*
Service Level Agreements	*OAM Functions and Mechanism based on Y.1731* *SLA Portal for performance guarantee*
Synchronization	*Multiple packet and line synchronization capabilities* *E1/STM1 services over Ethernet*
Profitability	*Ethernet, minimum overhead, no stranded bandwidth* *DWDM based so able to maximize use of fiber* *Lowest cost per bit with CE+WDM*

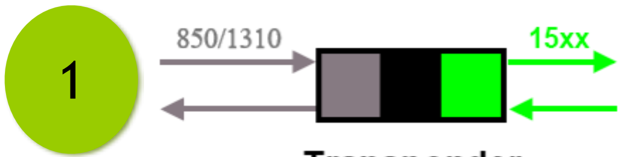
DWDM Fundamentals

Standard DWDM Point to Point System

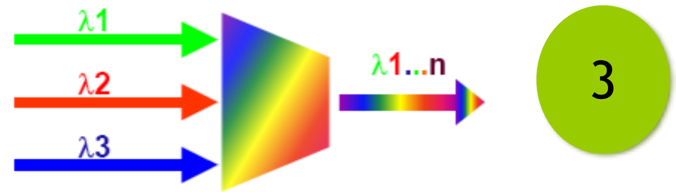


Basic Building Blocks of a DWDM system

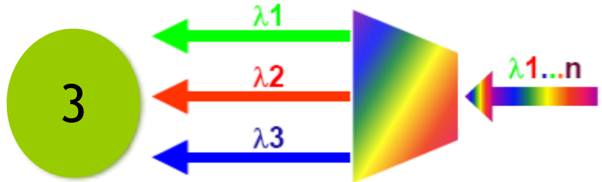
- Transponders
  - Client Side
  - Line Side
- Amplifiers
  - Erbium doped
  - Raman
- Add/Drop Filter
  - Static Optical Mux/Demux
- Dispersion Compensation
  - Chromatic Dispersion



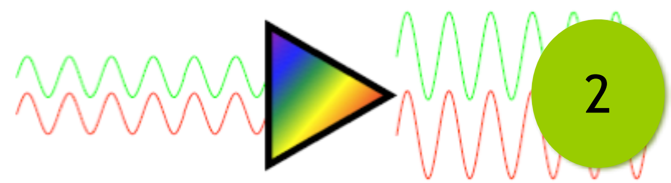
Transponder



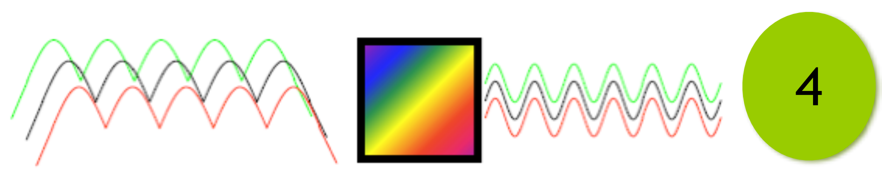
Optical Multiplexer



Optical De-multiplexer

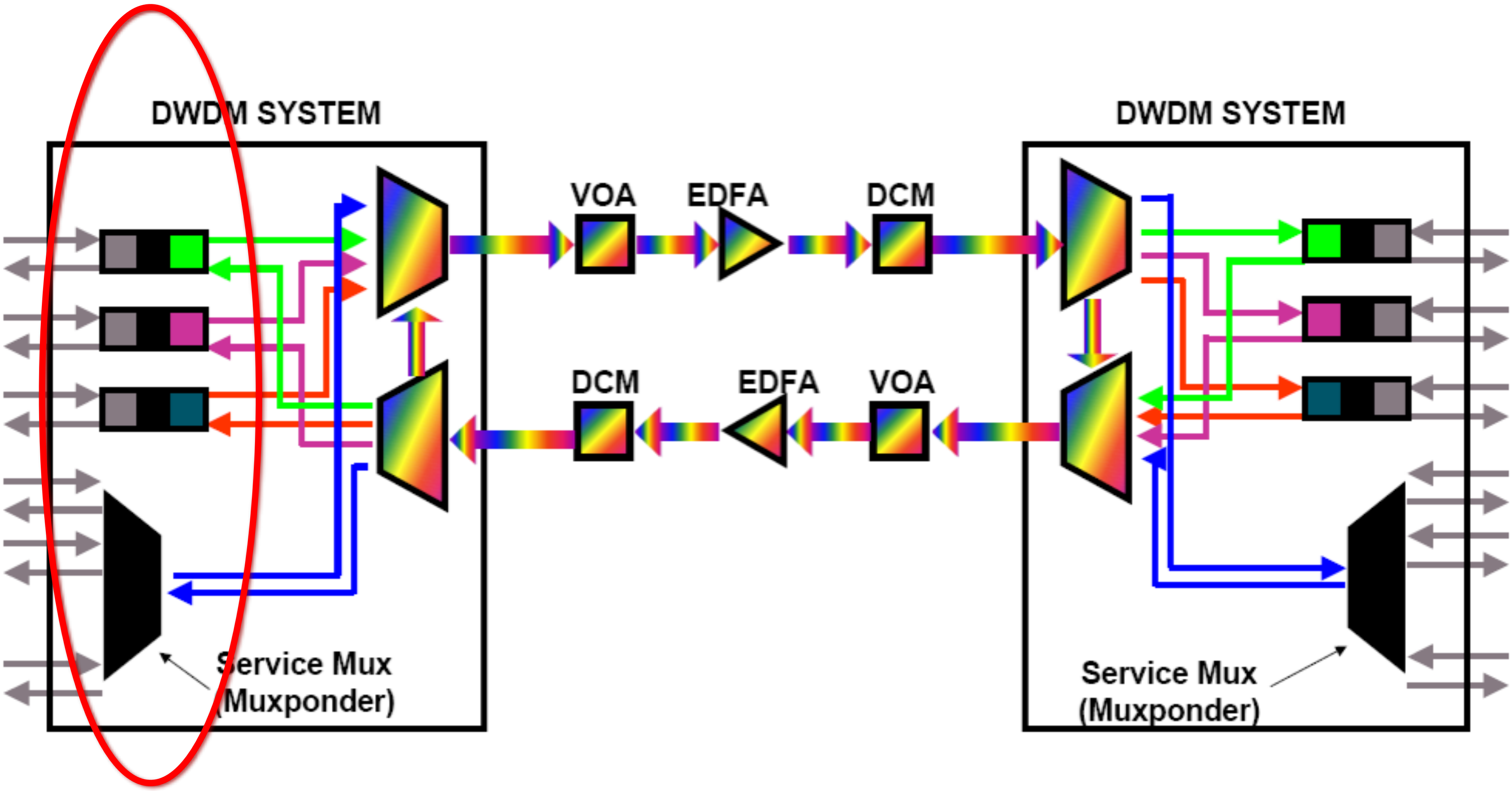


Optical Amplifier (EDFA)



Dispersion Compensator (DCM / DCU)

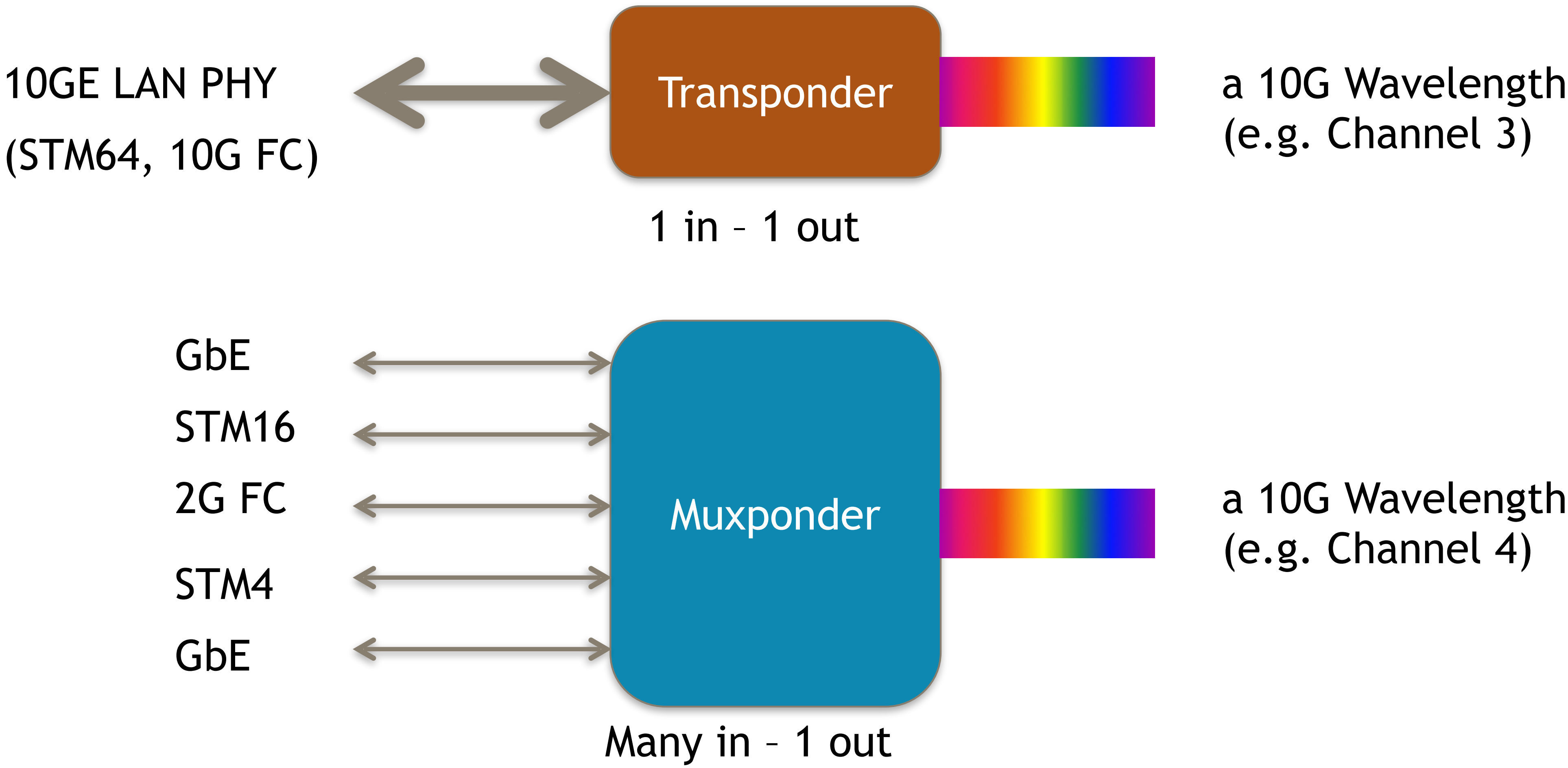
Basic DWDM Network View



Transponder and Muxponder Selection

Client Signal (Grey optics)
(e.g. from L2 switch, router)

Line Signal (Color optics)
(to DWDM mux / outside plant)



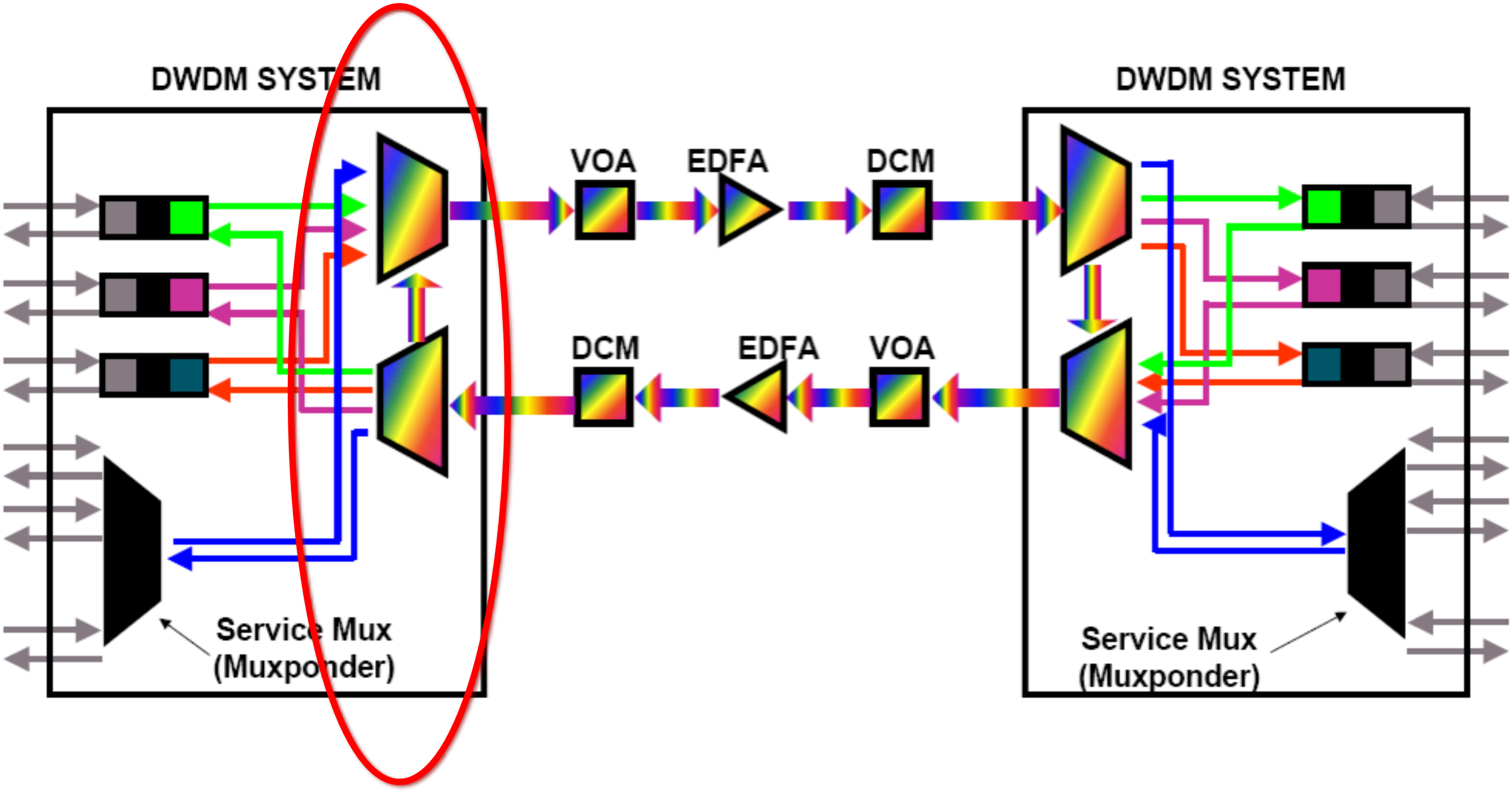
Transceivers Selection

Transceivers

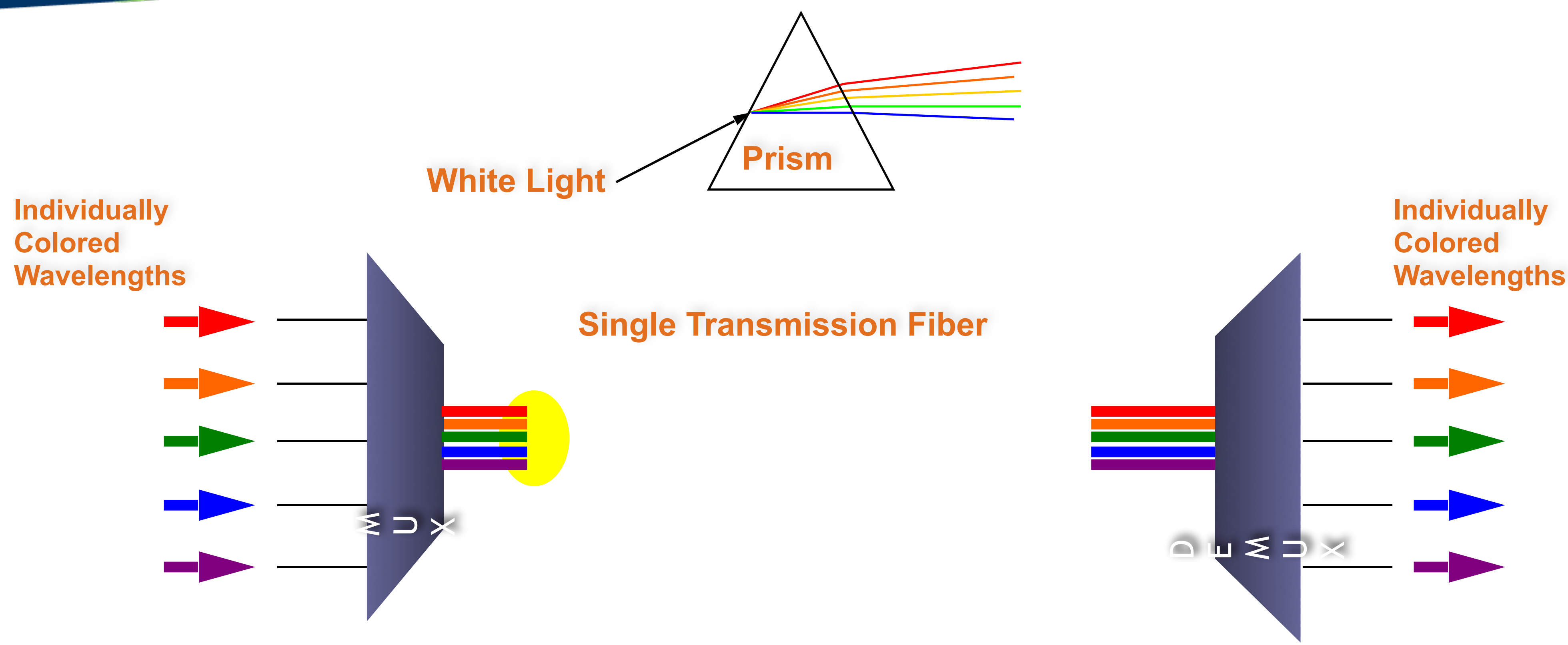
- **Typical Line Rates**
  - 2.5G
  - 10G
  - 100G
- **Transceivers**
  - SFP
  - XFP/SFP+
  - QSFP+
  - CFP

- **Selection of which type mainly depends on Speed, Reach**
  - 850nm, 1310nm, 1550nm, CWDM, DWDM Fixed Channel, DWDM Tunable
- Each type of transceiver's has its transmit power and receive power sensitivity (e.g. TX = [-3,+1], RX = [-25, -5] in dBm)

Basic DWDM Network View



Optical Multiplexer and De-multiplexer Selection

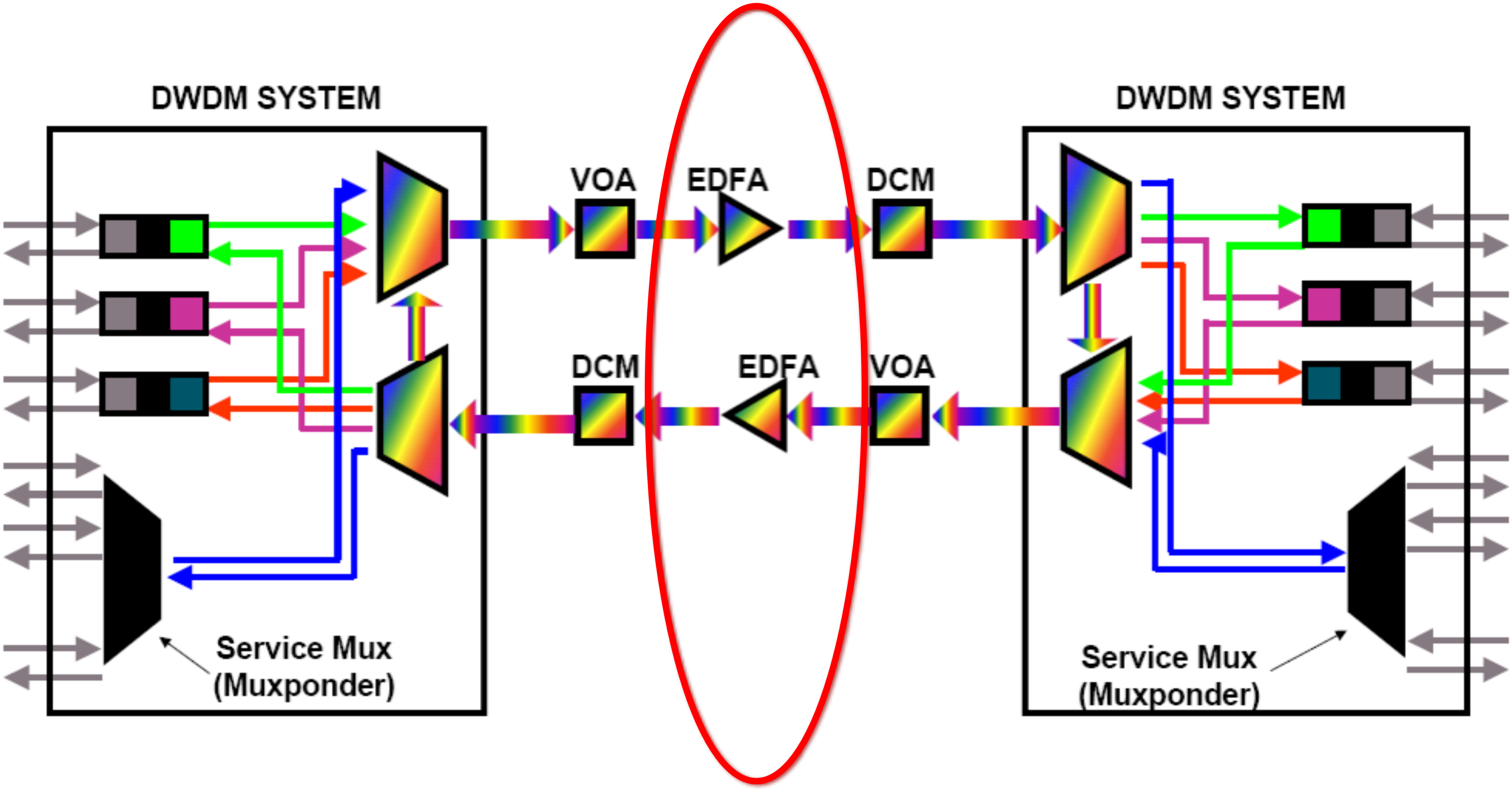


Works Like a Prism

Multiplex individual wavelengths onto a Fiber

Each Port is Associated With a Wavelength

Basic DWDM Network View



Optical Amplifiers Selection

Optical Amplifiers are Needed in Order to be Sure Optical Signals Can Be Accurately Detected by Receivers

Two Common Types of Optical Amplifiers

Erbium Doped Fiber Amplifier

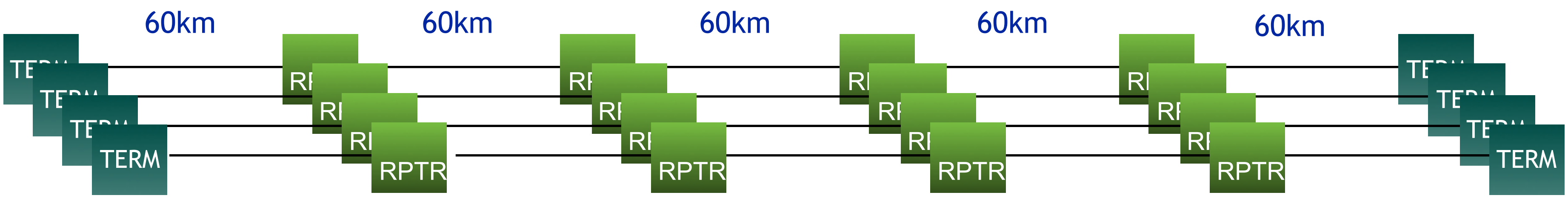
- Most common and simple to deploy
- Fixed gain or Variable gain

RAMAN Amplifier

- For high span loss and long distance transmission
- Used in Conjunction With EDFAs

Common Application of Optical Amplifiers

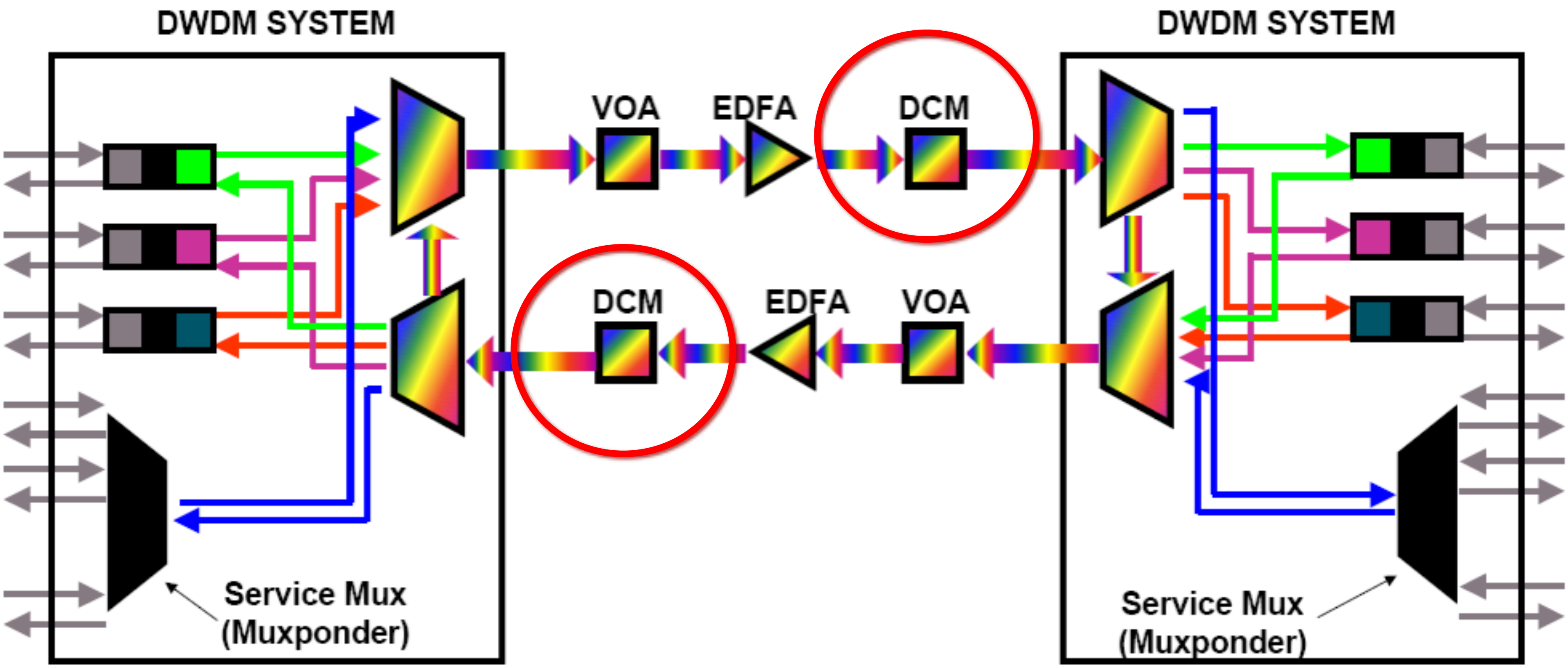
Conventional Optical Transmission



Wavelength Division Multiplexing

4 fibers→1 fiber; 16 regenerators→4 optical amplifiers

Basic DWDM Network View



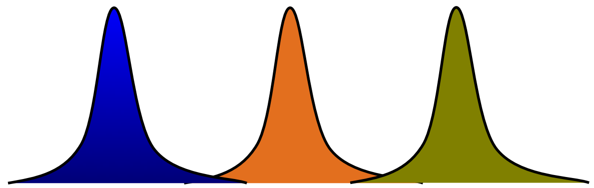
Chromatic Dispersion

Different wavelengths travel at different speeds through fiber causing optical pulses to broaden or “spread”

This broadening causes pulses to overlap

Receivers have a hard time to distinguish overlapped pulses

The longer the distance (or the higher the bitrate), the worst the spread…

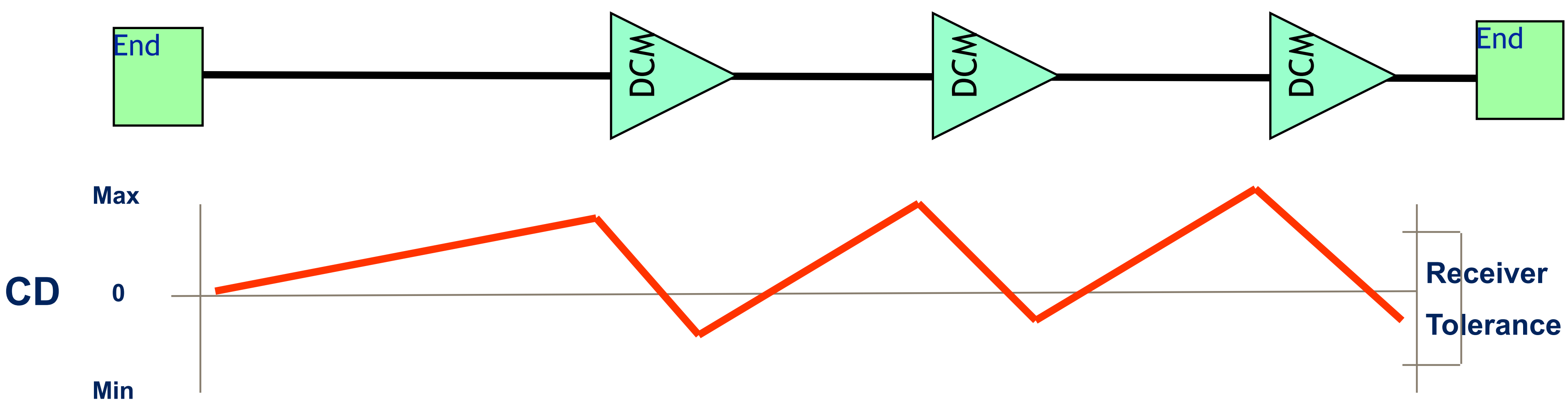


DCMs are used to compensate such impairment

DCM Selection

Span-by-Span CD Compensation – simple for network design

Simply match fiber distance to DCM type



Troubleshooting the Transmission Layer

Amplifier issues

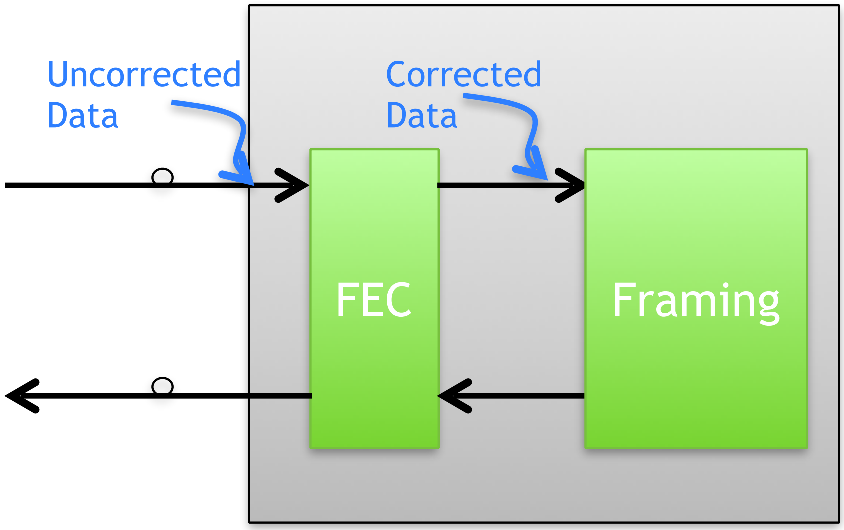
- Saturated amplifiers
  - Too many input channels at too high a power level will result in bit errors.
    - Using the gain curve of the amplifier, the user can determine the optimal power level for a given number of channels
  - Launch power per channel onto fiber is too high.
    - For 10G ch, maintain 6dBm per channel. Rule of thumb, doubling the channels increases power by 3dBm.

Fiber Type

- Double check fiber type:
  - SMF28 17ps/nm/km is normal, which determines DCM amount. If fiber type is not same, likely over compensating for dispersion.
  - Type also determines number of channels that can be carried. ZDSF (Zero dispersion shifted fiber) is not good for DWDM.

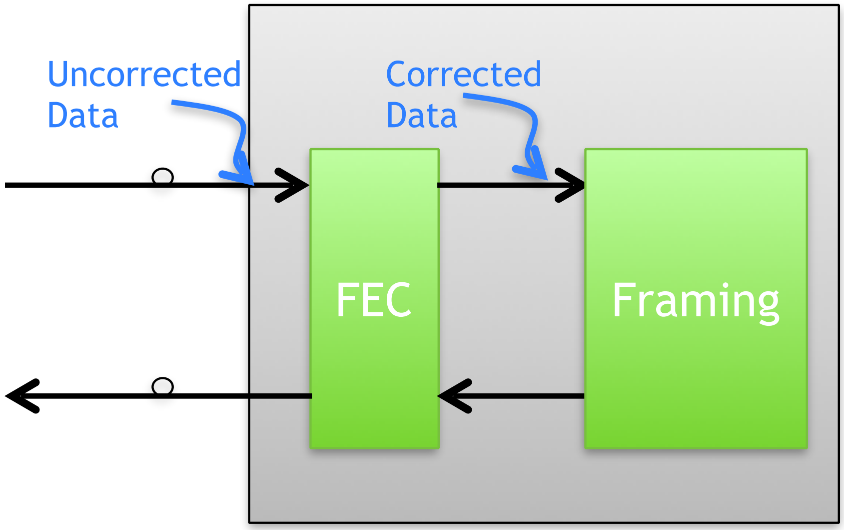
Trouble shoot before customer impact:
Pre-FEC BER monitoring

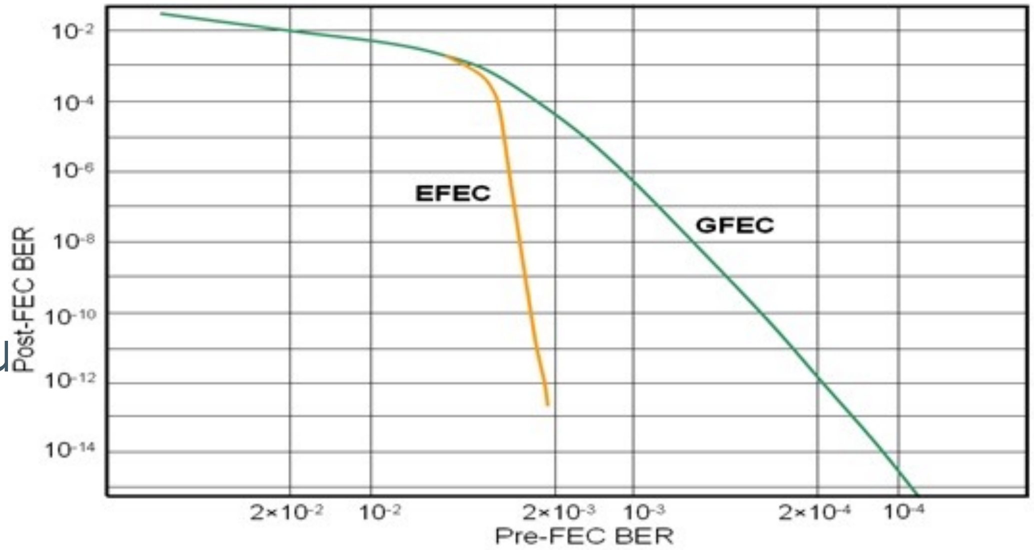
- One of the most effective ways to monitor for network degradation is via pre-FEC BER threshold monitoring.
- What is BER?
  - Bit Error Ratio
  - Number of errored bits received / Total Number of bits received
  - Ex. BER of 3.00E-05 is equal to 3 bits in error out of 100,000 bits transmitted.



Trouble shoot before customer impact:
Pre-FEC BER monitoring

- In the case of intermittent errors, FEC corrected bits can provide a pre-FEC BER indication
- One question that always gets asked: how long does it take to measure BER? Rule of thumb: for a 99% confidence in a BER, count 4.6 times the reciprocal of the BER.
  - Ex. For a BER of 1.0E-08, you must monitor 4.6 x 1/1x10-8 = 460,000,000 bits.

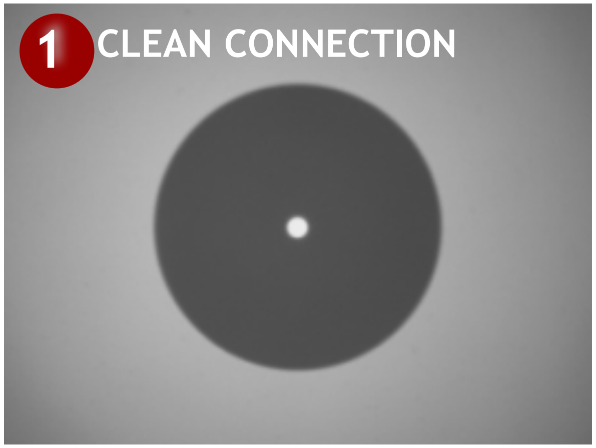




Now to the number one culprit:

- **Optical back reflection.** Amp “thinks” it’s driving an open connection and the safety shut down is enabled. Causes:
  - Bad/Loose/Dirty connectors
  - Poor splices
  - Too many patch cables.
  - Old fiber, too much back reflection
- Possible solutions:
  - Cleaning of fiber connections, consolidation of patch panels, check all connectors to be clean and tight
  - Back reflection must be -24 dBm or less (measured on amp).

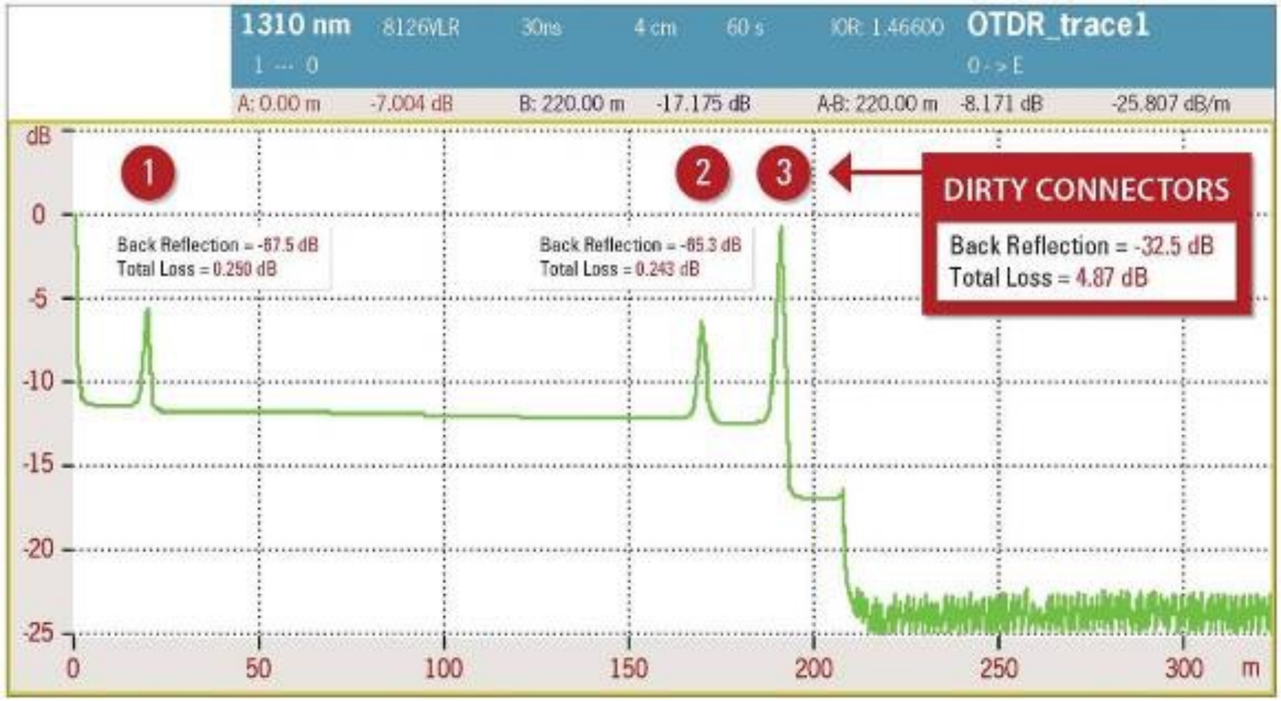
Fiber Testing



Back Reflection = **-67.5 dB**
Total Loss = **0.250 dB**

Back Reflection = **-32.5 dB**
Total Loss = **4.87 dB**

Fiber Contamination and Its Effect on Signal Performance



Clean Connection vs. Dirty Connection

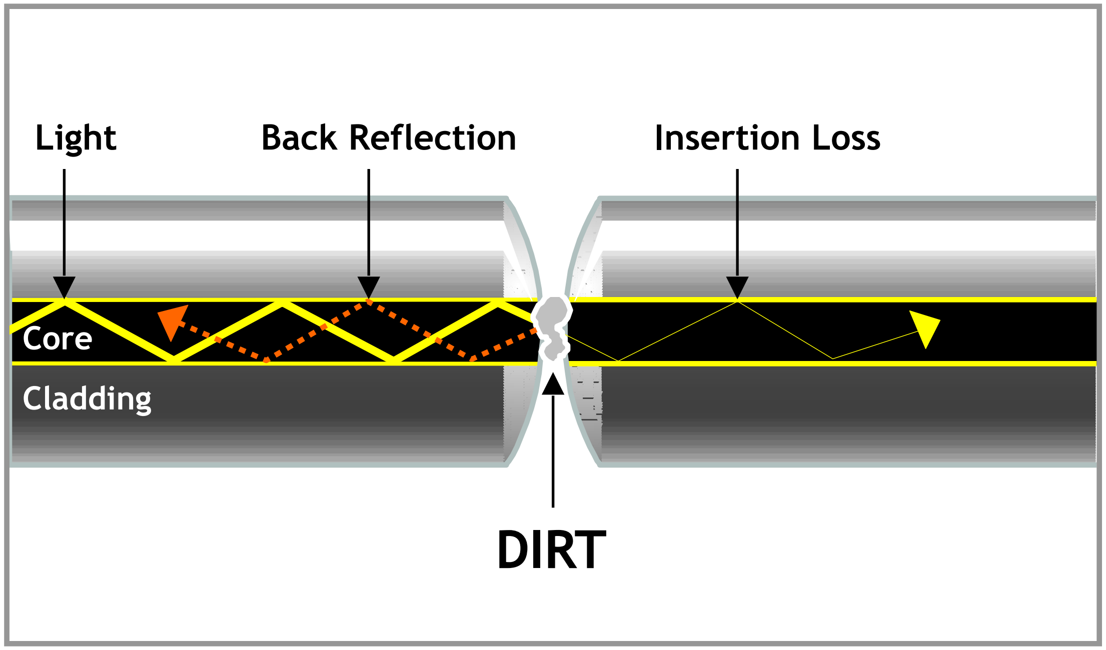
This OTDR trace illustrates a significant decrease in signal performance when dirty connectors are mated.

Access to all cross-connects recommended

What Makes a Bad Fiber Connection?

Today's connector design has eliminated most of the challenges to achieving core alignment and physical contact.

What remains challenging is maintaining a **PRISTINE END FACE.** As a result, **CONTAMINATION is the #1 source of troubleshooting in optical networks.**



- A single particle mated into the core of a fiber can cause significant **back reflection** and **insertion loss**

Inspect & Clean Connectors in Pairs During OTDR Testing

Inspecting BOTH sides of the connection is the **ONLY WAY** to ensure that it will be free of contamination and defects.

Patch Cord (“Male”) Inspection

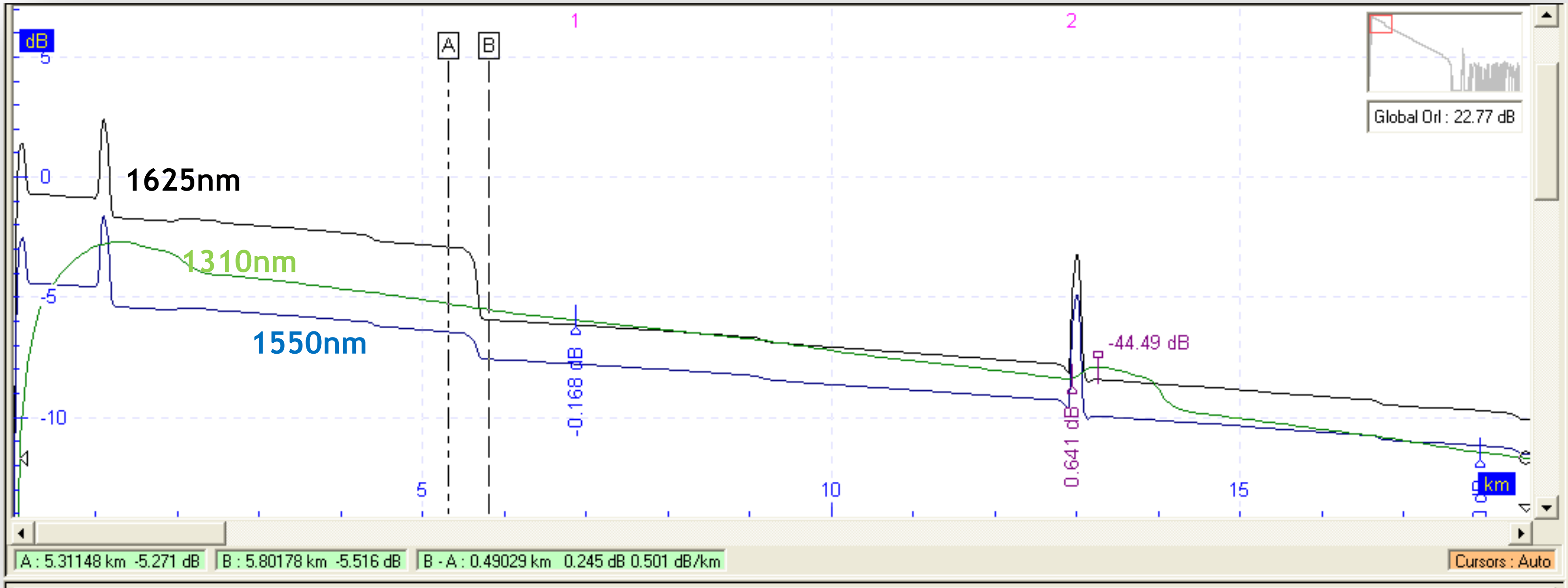
Bulkhead (“Female”) Inspection

Patch cords are easy to access compared to the fiber inside the bulkhead, which is often overlooked. The bulkhead side is far more likely to be dirty and problematic.

OTDR testing **always** results in fiber cleaning despite “Inspect before you connect methodology”

OTDR Testing May Also Uncover Macro-Bends

As OSP fiber ages and cross-connects are accessed macro-bends may appear.

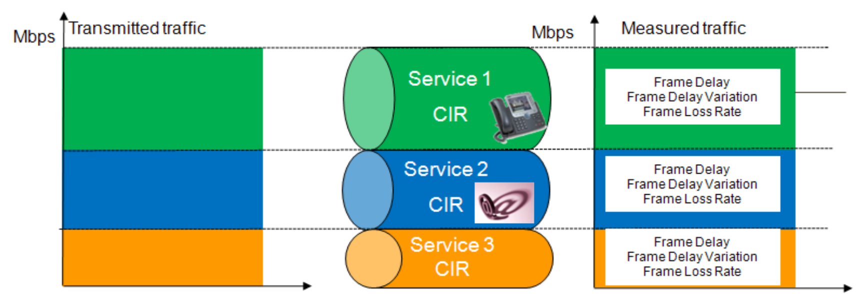


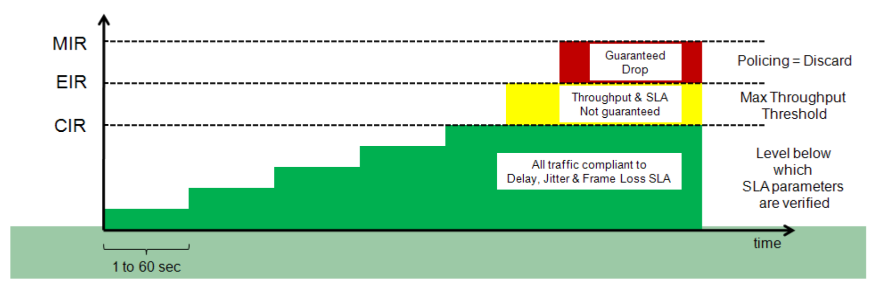
- Macrobend between markers A and B.
- Loss increases as the wavelength increases.
  - 1310nm - No Loss
  - 1550nm - 1 dB
  - 1625nm - 3 dB
- The tighter the bend the larger the loss differential

Beyond Basic BERT

Performance Testing

- **Layer 1 : Bit Error Rate Testing**
- **Layer 1-3: RFC 2544**
  - Frame throughput, loss, delay, and variation
    - Performed at all frame sizes
- **Layer 1-3 Multi-stream: ITU-T Y.1564**
  - Latest Standard to validate the typical SLA of Carrier Ethernet-based services
  - Provides for **Multi-Stream** test with pass/fail results
  - Service Configuration Test
    - Each stream/service is validated individually
    - Results compared to
      - Bandwidth Parameters (CIR and EIR)
  - Service Performance Test
    - All services tested concurrently at CIR
    - Results compared to SLAs
      - Frame Delay (Latency)
      - Frame Delay Variation (Packet Jitter)
      - Frame Loss rate
- **Customized Failover Testing**
  - Cable plant, power, chassis, card , optic,





In Summary

- Packet Optical
  - Latency
  - SLA
  - Test Methods
- DWDM Basics
  - Building blocks: Muxponders/Transponders, Mulitplexers & amplifiers
  - Troubleshooting: Amplifiers, Fiber, Reflections
  - Practical Test methods

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