DWDM Long-Haul Technology

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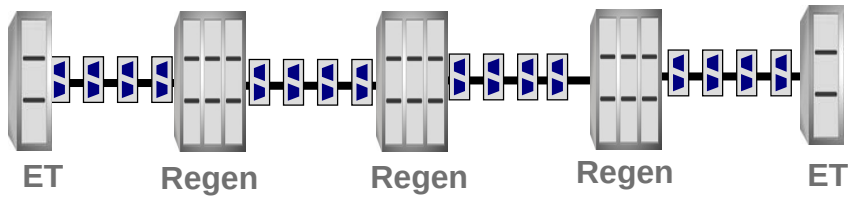
Outline

- Introduction
- Technology Enablers
  - Enhanced Optical Transponders
  - Raman Amplification and Dynamic Power Equalization
  - Reconfigurable Optical Add Drop Multiplexer (ROADM)
- Example Next Gen DWDM Transport System

DWDM Long-Haul Network Configuration Evolution

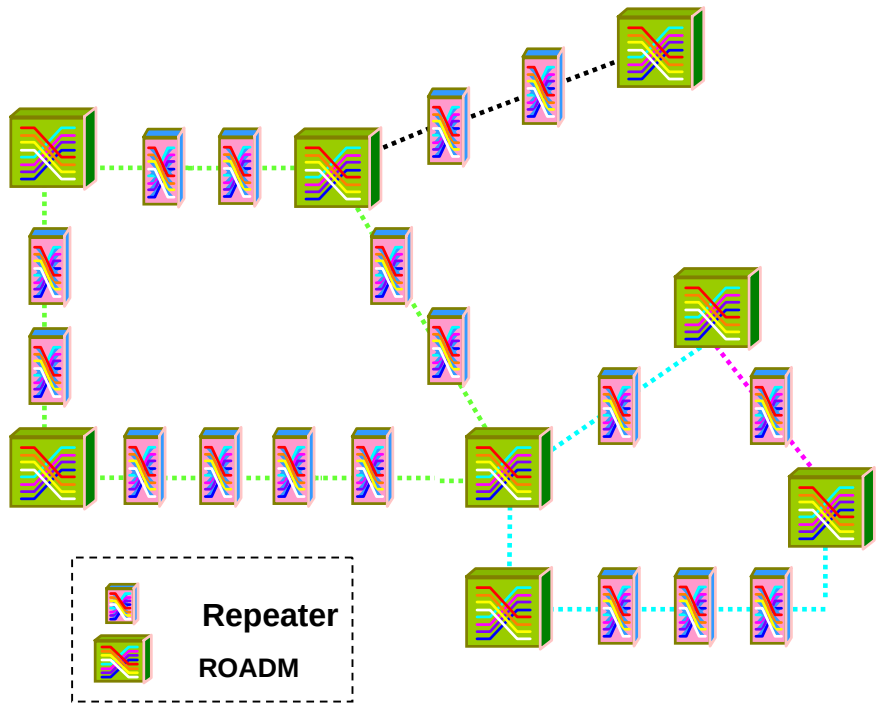
Before:

- Point-to-point linear configuration w/ end terminals
- 600km between regeneration sites



Now:

- 3000-4000km between regeneration sites - reduces regeneration cost
- Ring/Mesh configuration w/ ROADMs - fast and simple service provisioning



Business Priorities and Implications on Network Evolution

Ethernet Services

Imaging

Wavelength Services

E-Commerce

Mobility

Broadband Access

- **SCALABILITY AND FLEXIBILITY**
  - Mix of traffic patterns and types (SONET/SDH, Ethernet)
  - Strong traffic growth (voice, data, video, wireless)
- **LOW CAPEX/OPEX**
  - Ultra LH to reduce regen cost
  - Modular design to save startup cost; in-service upgradeable in the future
  - High density footprint and low power consumption
  - Remote routing and provisioning
- **FAST SERVICE TURN-UP TO SPEED UP REVENUE GENERATION**
  - Plug and play. Automatic wavelength provisioning and power control.
- **RELIABILITY**
  - Diverse traffic routing in ring/mesh configuration
  - Optical layer protection and ring/mesh restoration
  - Automatic fault detection, isolation, alarms and rapid recovery

Technology Enablers for Next Gen Long-Haul DWDM Systems

Feature	Enable Technology
Ultra-Long Reach	▪ 10Gb/s RZ format ▪ Enhanced forward error correction ▪ Dynamic dispersion compensation ▪ Distributed Raman amplification ▪ Dynamic gain equalization (DGE)
Ultra-High Capacity	▪ 40Gb/s CSRZ, Duobinary or DPSK modulation formats ▪ 40G tunable dispersion compensator
Reconfigurable Mesh Network	▪ Reconfigurable OADM based on blocker or wavelength selective switch ▪ Tunable Laser
Mixed traffic types	▪ ASIC technology provides mapping between various traffic types

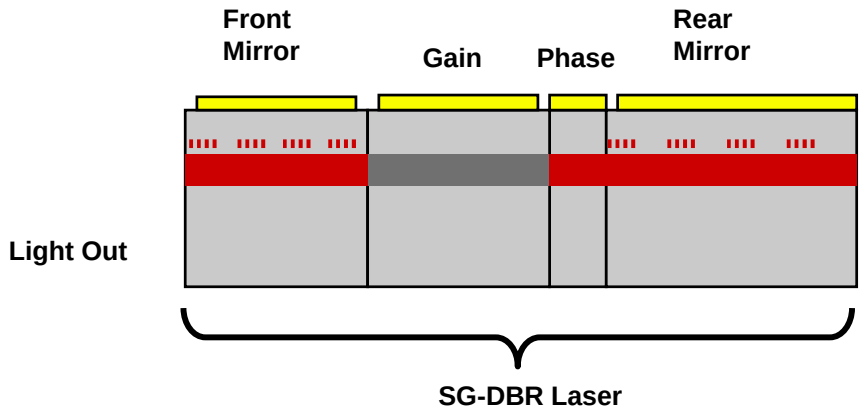
Enhanced Optical Transponders

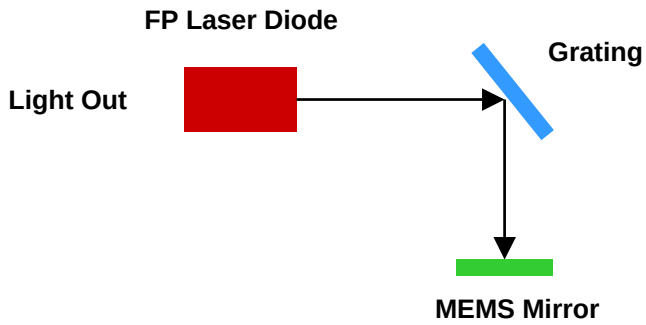
Maximum flexibility and reach are key

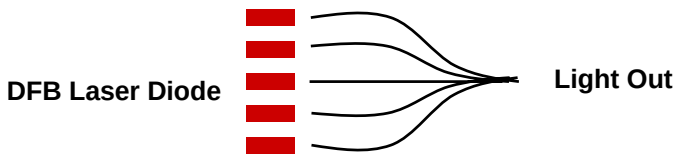
- Wide-band Tunability
  - Simplifies planning for capacity upgrades
  - Reduction in circuit pack codes leads to reduced sparing cost
  - Enables dynamic routing of traffic
- Enhanced Modulation Format to achieve longer reach without regeneration
  - 10G: RZ format enables 4000km transmission without regeneration
  - 40G: CSRZ, Duobinary, and DPSK enable 1000km to 2000km transmission without regeneration
- Dynamic Dispersion Compensation for flexible routing
  - 10G: electronic compensation
  - 40G: tunable optical dispersion compensator
- Enhanced Forward Error Correction (EFEC) provides additional system margin

Tunable Laser Technology

- Monolithically integrated Distributed Bragg Reflector (DBR) laser
  - Tuning is based on current induced index change in mirror and phase sections
  - Fast tuning speed ~ <10ms
- External cavity laser
  - Tuning is based on a spectral filter and a mirror
  - Fast tuning speed ~ 10 ms
- Arrayed DFB laser
  - Tuning is based on temperature
  - Slow tuning speed ~ s





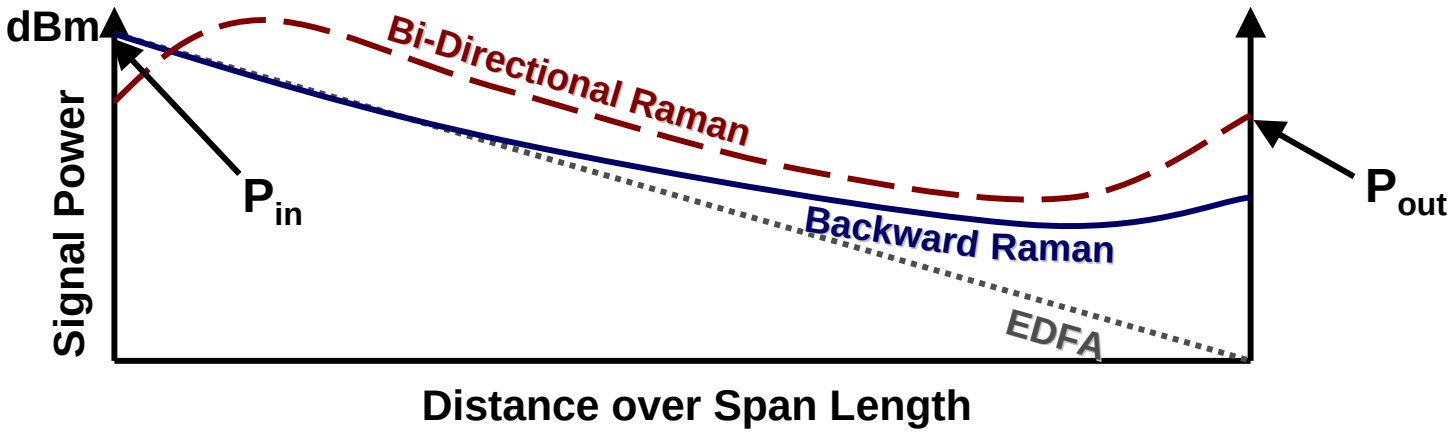


Dynamic Dispersion Compensation

- Enable flexible routing for ring/mesh networks
- 10G: Electrical dispersion compensation
  - Decision Feedback Equalization (DFE), Feed Forward Equalization (FFE), Maximum Likelihood Sequence Estimation (MLSE) in RX
- 40G: Tunable optical dispersion compensator
  - Fiber Bragg Grating, waveguide based ring resonator, or bulk optics

Next Generation Amplification - Raman Amplifier

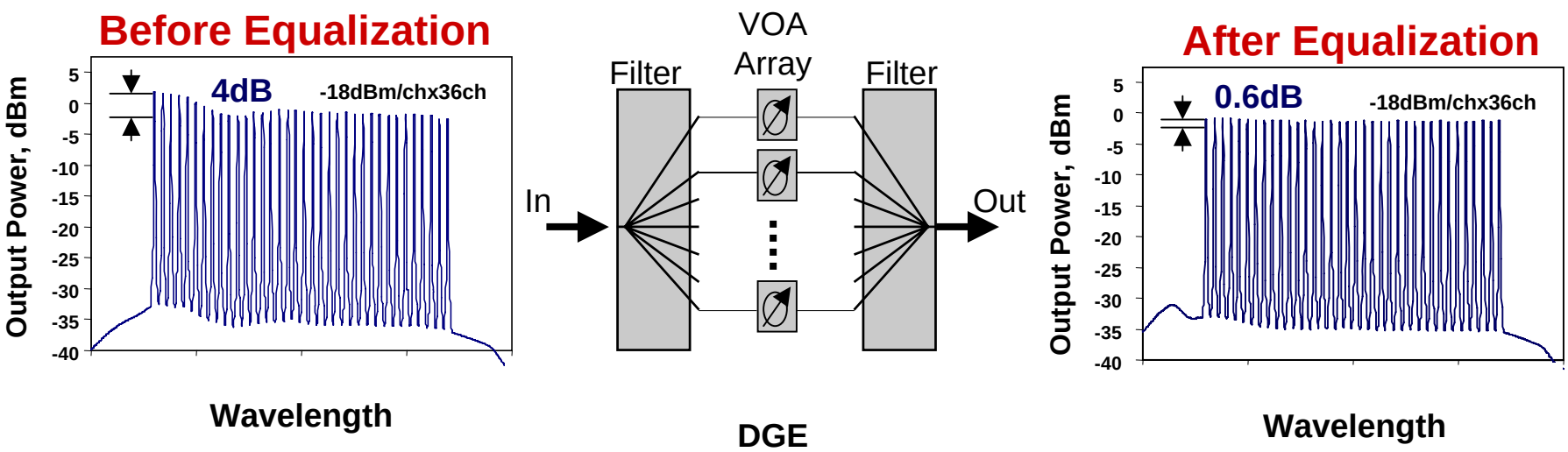
- **Traditional DWDM networks use Erbium-Doped Fiber Amplifiers (EDFA).**
- **Advantages of Raman amplifier:**
  - ***Distributed*** **amplification using transmission fiber as amplification medium => lower noise figure compared to discrete amplifier**
  - **5-7dB lower OSNR when compared to EDFA**
  - **Lower launch power compared to EDFA => minimize nonlinear penalty**



=> Raman Amplifier provides more system margin and enables longer reach

Dynamic Channel Power Equalization

- For long reach, gain ripple accumulates dramatically that can lead to nonlinear penalty and power divergence at receiver. Therefore gain flatness is critical.
- Dynamic Gain Equalizers (DGEs) automatically correct power divergence in the system
- Common implementations are MEMs, Liquid Crystal,or Planar Lightwave Circuit

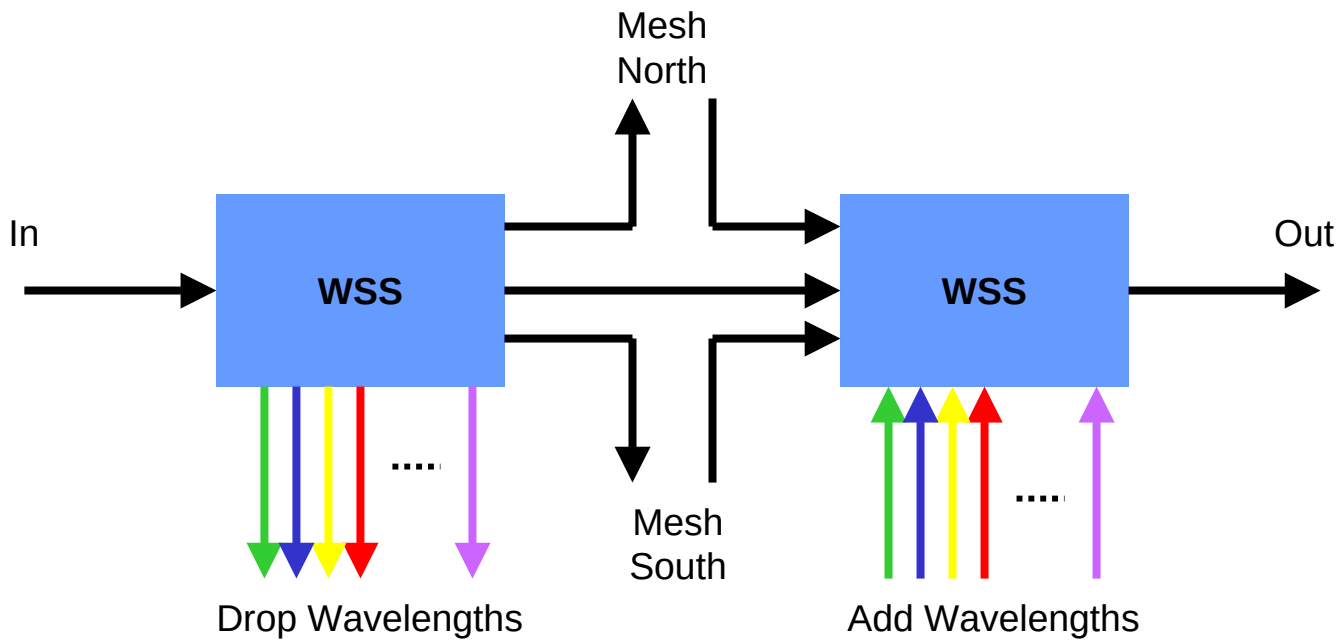


Reconfigurable Optical Add Drop Multiplexer (ROADM)

- Advantages of mesh network using ROADM
  - Eliminate O-E-O conversions for express traffic and ring interconnect (CAPEX reduction)
  - Remote configuration – automatic wavelength setup and switching (OPEX reduction)
  - Dynamic bandwidth management
- ROADM technology
  - PLC, MEMS, and Liquid Crystal based wavelength selective switch or wavelength blockers
  - Integrated functionalities provide wavelength add/drop, wavelength routing, and channel power equalization

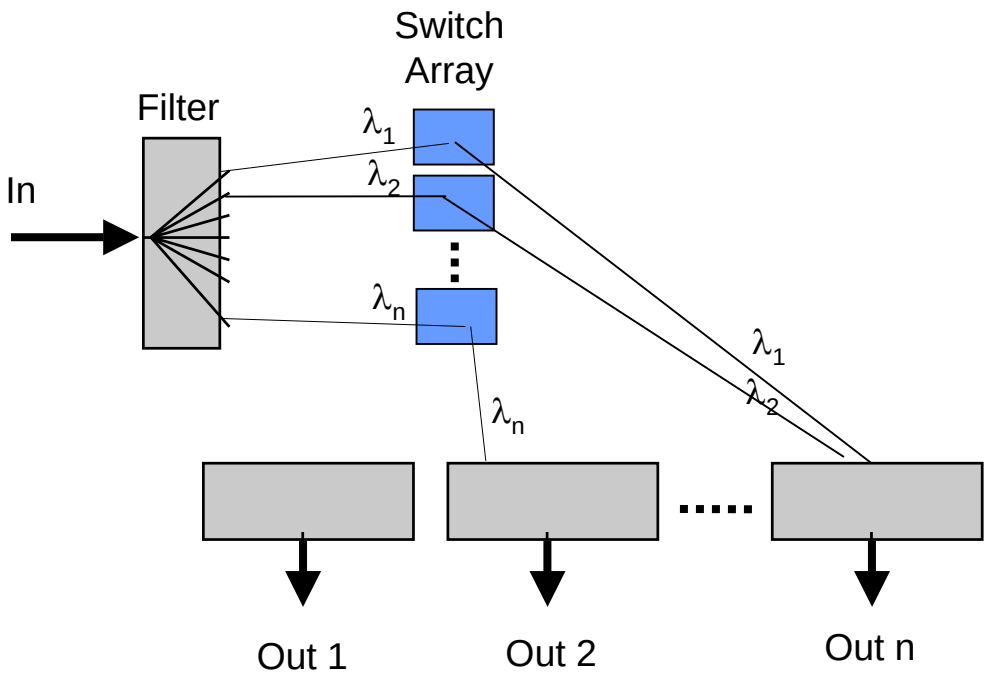
Degree 4 ROADM Architecture Based on Wavelength Selective Switch (WSS)

- WSS connects any wavelength or set of wavelengths to any port
- Provides re-configurable “colorless” Add/Drop, Thru, and Mesh connections
- Ultimate flexibility



Wavelength Selective Switch Technology

- Similar to DGE or blocker, but multiple output ports makes design much more challenging.
- Switch array provides both port selection and variable attenuation.
- Switch array typically implemented with MEMs or Liquid Crystals.



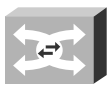
Example Next Gen DWDM Platform

Lucent's LambdaXtreme™ Transport

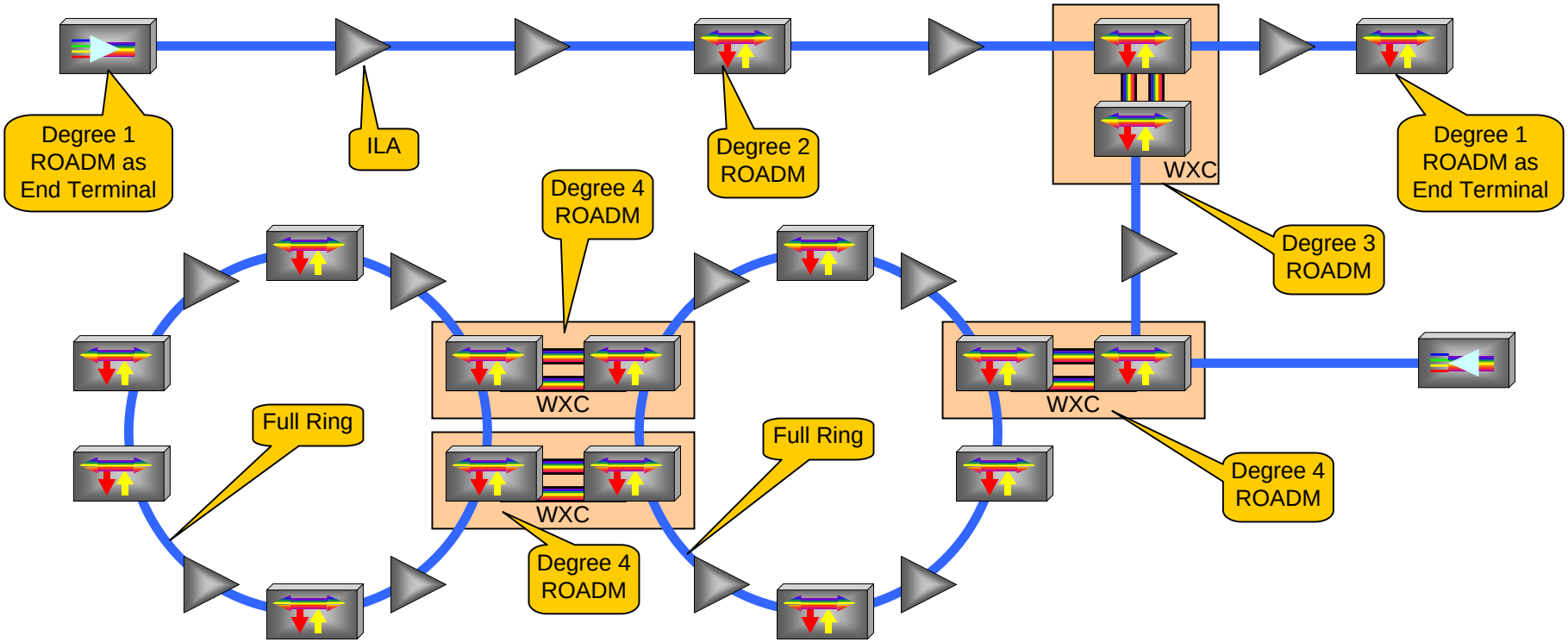
LambdaXtreme™ System Features:

- System reach and capacity: 128 ch of 10Gb/s up to 4000 km, 64 ch of 40Gb/s up to 2000 km
- Mixed 10G and 40G throughout network
- Fully flexible and remotely reconfigurable mesh ROADM
- In-Service Scalable Node Architecture
- Plug and play wavelength provisioning
- Automatic channel equalization
- Multi-rate transponders support 2.5G, 10G, 10GbE, 40G services

Basic Building Blocks

	Node Type	Function
	**ILA**	In-line amplifier that allows to extend the reach of LambdaXtreme Transport to up to 4,000 km.
	**ISUG ILA**	Deploy initially as an in-line amplifier, and convert to a Mini-ROADM when service add/drop is required.
	**Degree 1 ROADM**	Start as an End Terminal with flexibility to upgrade to a Degree 2 (D2), D3 or D4 ROADM.
	**Degree 2 ROADM**	Enable service add/drop for up to 64 channels. Can be upgraded to D3 or D4.
	**Degree 3 ROADM**	Allow for multi-segment cross-connection of signals. Can be upgraded to D4.
	**Degree 4 ROADM**	Maximum flexibility for wavelength add/drop and cross-connection between two rings.

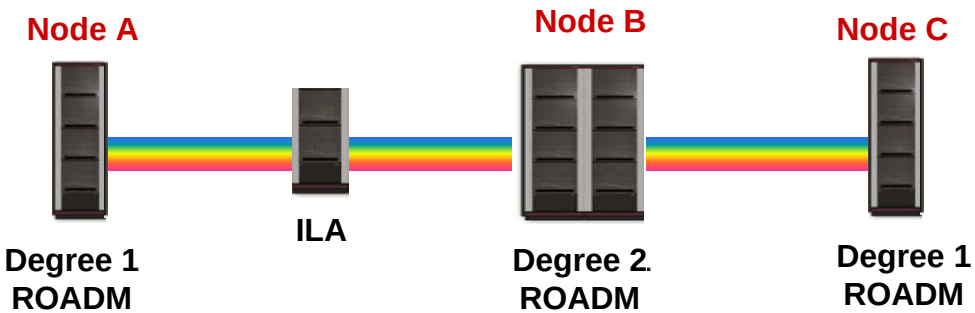
Example Link Layout Using LambdaXtreme Building Blocks



- ROADM provides 10Gb/s and 40Gb/s channel add/drop capability.
- Traffic can be remotely configured with software control.
- OEO regeneration is minimized for through and cross-connected channels.

Scalable Node Architecture

LambdaXtreme Transport provides scalable nodes that allow flexibility for future growth – pay as you grow



Example 1:
When node B is first deployed, the degree1 ROADM works like an end terminal.

When services are required beyond Node B, it can be scaled in-service to a D2 ROADM that allows for service extension without regeneration.

When connections are required beyond a D2 ROADM, it can be scaled in-service to a D3 or D4 ROADM.

Example 2:
When node Y is first deployed, the ISUG-ILA works like a simple in-line amplifier.

When node Y requires add/drop services, the ISUG-ILA is upgradeable to a ROADM.

2004 LambdaXtreme™ Network Deployment with RBOC

- 235 Nodes including 14 Degree-1 ROADMs, 25 Degree-2 ROADMs
- 9 Optical Line Systems (OLS)
- 13,100 Route miles, spanning 29 states
- 3,950 Circuit Packs
- 6,000 Fiber Connections
- Longest-reach single service channel: 3200Km
- Largest single OLS: Southwest
  - 85 nodes, spanning nearly 8000 Km in a single optical Ring