Optical DWDM Fundamentals
Agenda

- Introduction and Terminology
- Optical Propagation and Fiber Characteristics
- Attenuation and Compensation
- Dispersion and Dispersion Compensation
- Non Linearity
- SM Optical Fiber Types
- Simple SPAN Design
- DWDM Transmission
- ROADM: Operational Benefits
- Cisco ONS 15454 MSPP/MSTP Functionality
Introduction
Modern Lightwave Eras

- **Fiberization**
- **Digitization**
- **SONET Rings and DWDM Linear Systems**
- **Optical Networking**
- **Wavelength Switching**
- **ROADMs**
- **OXC’s**

Years:
- 1985
- 1990
- 1995
- 2000
- 2005

Capacity (Gb/s):
- 0
- 1
- 10
- 100
- 1,000
- 10,000

**Categories**:
- Research Systems
- Commercial Systems

Legend:
- Fiberization
- Digitization
- SONET Rings and DWDM Linear Systems
- Optical Networking
- Wavelength Switching
- ROADMs
- OXC’s
Optical Spectrum

- Light
  - Ultraviolet (UV)
  - Visible
  - Infrared (IR)

- Communication wavelengths
  - 850, 1310, 1550 nm

- Low-loss wavelengths

- Specialty wavelengths
  - 980, 1480, 1625 nm

\[ C = f \times \lambda \]

Wavelength: \( \lambda \) (Nanometers)
Frequency: \( f \) (Nerahertz)
Terminology

- **Decibels (dB):** unit of level (relative measure) – \( X \text{ dB} = 10^{-X/10} \)
- **Decibels-milliwatt (dBm):** decibel referenced to a milliwatt
  - dBm used for output power and receive sensitivity (absolute value)
  - dB used for power gain or loss (relative value)
  - \( X \text{ mW} = 10 \log_{10}(X) \) in dBm, \( Y \text{ dBm} = 10^{Y/10} \) in mW
- **Wavelength (Lambda):** length of a wave in a particular medium; common unit: nanometers, \( 10^{-9}\text{m} \) (nm)
- **Frequency (\( \nu \)):** the number of times that a wave is produced within a particular time period

Wavelength x frequency = speed of light \( \Rightarrow \lambda \times \nu = C \)
Terminology—Fiber Impairments

- Attenuation = Loss of power in dB/km
- Chromatic Dispersion = Spread of light pulse in ps/nm-km
- Optical Signal-to-Noise Ratio (OSNR) = Ratio of optical signal power to noise power for the receiver
ITU Wavelength Grid

- The International Telecommunications Union (ITU) has divided the telecom wavelengths into a grid; the grid is divided into bands; the C and L bands are typically used for DWDM.

- ITU Bands

<table>
<thead>
<tr>
<th>O</th>
<th>E</th>
<th>S</th>
<th>C</th>
<th>L</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>1260</td>
<td>1360</td>
<td>1460</td>
<td>1530</td>
<td>1565</td>
<td>1625</td>
</tr>
</tbody>
</table>

- Channel Spacing = 100 GHz

- ITU Bands:

\[
\begin{align*}
\lambda_0 &= 1530.33 \text{ nm} \\
\lambda_1 &= 1553.86 \text{ nm} \\
\lambda_n &= 1553.86 \text{ nm} + 0.80 \text{ nm} \\
\lambda &= 195.9 \text{ THz} \\
\nu &= 193.0 \text{ THz}
\end{align*}
\]
Bit Error Rate (BER)

- BER is a key objective of the optical system design
- Goal is to get from Tx to Rx with a BER < BER threshold of the Rx
- BER thresholds are on data sheets
- Typical minimum acceptable rate is $10^{-12}$
Optical Power

Definition:
Optical Power Is the Rate at Which Power Is Delivered in an Optical Beam

Optical Power Measurements:
- Power is measured in watts; however, a convenient way to measure optical power is in units of decibels (dB)
- The power measured on a particular signal is measured in dBm
- The gain/loss measured between two points on a fiber is in dB
  - Power loss is expressed as negative dB
  - Power gain is expressed as positive dB
Optical Power Budget

The Optical Power Budget is:
Optical Power Budget = Power Sent – Receiver Sensitivity

- Calculate using minimum transmitter power and minimum receiver sensitivity
- Attenuation/loss in the link, greater than the power budget, causes bit errors (dB)
- Design networks with power budgets, not distances
Optical Power Budget—Example

- Transmitter maximum power = –2 dBm
- Receiver sensitivity = –28 dBm

Transmitter

-2 dBm

Receiver

–28 dBm

Power Budget = 26 dB

### Calculate Power Budget = ??

<table>
<thead>
<tr>
<th>Reach Type</th>
<th>Power Budget</th>
<th>Loss Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Reach (SR)</td>
<td>6 dB</td>
<td>75% Power Loss</td>
</tr>
<tr>
<td>Intermediate Reach (IR)</td>
<td>13 dB</td>
<td>95% Power Loss</td>
</tr>
<tr>
<td>Long Reach (LR)</td>
<td>26 dB</td>
<td>99.75% Power Loss</td>
</tr>
</tbody>
</table>

**Key:** Every 3dB is loss of half of signal
Eye Diagram

- The vertical eye opening shows the ability to distinguish between a 1 and a 0 bit.
- The horizontal opening gives the time period over which the signal can be sampled without errors.
Eye Diagram

- For a good transmission system, the eye opening should be as wide and open as possible.

- Eye diagram also displays information such as maximum signal voltage, rise and decay time of pulse, etc.

- Extinction ratio (ratio of a 1 signal to a 0 signal) is also calculated from eye diagram.
A Few Words on Optical Safety

- Think optical safety at all times
- Wear specified optical eye protection
- Optical power is invisible to the human eye
- Never stare at an optical connector
- Keep optical connectors pointed away from yourself and others
- Glass (fiber cable) can cut and puncture
- Fiber splinters are extremely difficult to see
- Damage is usually permanent!
Laser Classifications/Safety Icons

Class 1
Lasers that are incapable of causing damage when the beam is directed into the eye under normal operating conditions. These include helium-neon lasers operating at less than a few microwatts of radiant power.

Class 2
Lasers that can cause harm if viewed directly for ¼ second or longer. This includes helium-neon lasers with an output up to 1 mW (milliwatt).

Class 3A
Lasers that have outputs less than 5 mW. These lasers can cause injury when the eye is exposed to either the beam or its reflections from mirrors or other shiny surfaces. As an example, laser pointers typically fall into this class.

Class 3B
Lasers that have outputs of 5 to 500 mW. The argon lasers typically used in laser light shows are of this class. Higher power diode lasers (above 5 mW) from optical drives and high performance laser printers also fall into this class.

Class 4
Lasers that have outputs exceeding 500 mW. These devices produce a beam that is hazardous directly or from reflection and can produce skin burn. Many ruby, carbon dioxide, and neodymium-glass lasers are class 4.
Protective Eyewear Available

- Protective goggles or glasses should be worn for all routine use of Class 3B and Class 4 lasers.

- Remember: eyewear is wavelength specific, a pair of goggles that effectively blocks red laser light affords no protection for green laser light.

Laser Safety Equipment Can Be Investigated in Greater Detail at the Following Link:
http://www.lasersafety.co.uk/frhome.html
Optical Propagation in Fibers
Analog Transmission Effects

- **Attenuation:**
  
  Reduces power level with distance

  ![Attenuation Diagram]

- **Dispersion and nonlinearities:**
  
  Erodes clarity with distance and speed

  ![Dispersion Diagram]

- **Signal detection and recovery is an analog problem**

  ![Signal Detection Diagram]
Fiber Geometry

An Optical Fiber Is Made of Three Sections:

- The core carries the light signals
- The cladding keeps the light in the core
- The coating protects the glass
Fiber Dimensions

- Fiber dimensions are measured in µm
  
  1 µm = 0.000001 meters
  (10^-6)

  1 human hair ~ 50 µm

- Refractive Index (n)

  n = c/v

  n ~ 1.46

  n (core) > n (cladding)
Geometrical Optics

Light Is **Reflected/Refracted** at an Interface

- $\theta_1 = \text{Angle of incidence}$
- $\theta_{1r} = \text{Angle of reflection}$
- $\theta_2 = \text{Angle of refraction}$

$\theta_c$—Is the Critical Angle

If Angle of Incidence Is Greater Than Critical Angle, All the Light Will Reflect (Instead of Refract); This Is Called Total Internal Reflection
Wavelength Propagation in Fiber

- Light propagates by total internal reflections at the core-cladding interface
- Total internal reflections are lossless
- Each allowed ray is a mode
Different Types of Fiber

- **Multimode fiber**
  - Core diameter varies
    - 50 µm for step index
    - 62.5 µm for graded index
  - Bit rate-distance product
    - > 500 MHz-km
  - Distance limited

- **Single-mode fiber**
  - Core diameter is about 9 µm
  - Bit rate-distance product
    - > 100 THz-km
Attenuation
Attenuation in Fiber

- Light loss in fiber is caused by two things
  - Absorption by the fiber material
  - Scattering of the light from the fiber

- Light loss causes signal attenuation

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Scattering</th>
</tr>
</thead>
<tbody>
<tr>
<td>850</td>
<td>Highest</td>
</tr>
<tr>
<td>1310</td>
<td>Lower</td>
</tr>
<tr>
<td>1550</td>
<td>Lowest</td>
</tr>
</tbody>
</table>
Other Causes of Attenuation in Fiber

- **Microbends**—Caused by small distortions of the fiber in manufacturing
- **Macrobends**—Caused by wrapping fiber around a corner with too small a bending radius
- **Back reflections**—Caused by reflections at fiber ends, like connectors
- **Fiber splices**—Caused by poor alignment or dirt
- **Mechanical connections**—Physical gaps between fibers
Optical Attenuation

- Pulse amplitude reduction limits “how far” (distance)
- Attenuation in dB = 10xLog(Pi/Po)
- Power is measured in dBm:
  \[ P(\text{dBm}) = 10 \times \log(\frac{P\text{ mW}}{1 \text{ mW}}) \]

<table>
<thead>
<tr>
<th>Examples</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10 dBm</td>
<td>10 mW</td>
</tr>
<tr>
<td>0 dBm</td>
<td>1 mW</td>
</tr>
<tr>
<td>–3 dBm</td>
<td>500 uW</td>
</tr>
<tr>
<td>–10 dBm</td>
<td>100 uW</td>
</tr>
<tr>
<td>–30 dBm</td>
<td>1 uW</td>
</tr>
</tbody>
</table>
Attenuation Response at Different Wavelengths

- **850nm Region**
- **1310 nm Region**
- **1550 nm Region**

Key processes:
- Rayleigh scattering
- Ultraviolet absorption
- Waveguide imperfections
- Infrared absorption
Attenuation: Compensated by Optical Amplifiers

- Erbium-doped fiber amplifiers (EDFA) are the most commonly deployed optical amplifiers
  - Commercially available since the early 1990s
  - Works best in the range 1530 to 1565 nm
  - Gain up to 30 dB (1000 photons out per one photon in)

- Optically transparent
  - Wavelength transparent
  - Bit rate transparent
Dispersion
Types of Dispersion

Chromatic Dispersion
• Different wavelengths travel at different speeds
• Causes spreading of the light pulse

Polarization Mode Dispersion (PMD)
• Single-mode fiber supports two polarization states
• Fast and slow axes have different group velocities
• Causes spreading of the light pulse
A Snapshot on Chromatic Dispersion

- Affects single channel and DWDM systems
- A pulse spreads as it travels down the fiber
- Inter-symbol Interference (ISI) leads to performance impairments
- Degradation depends on:
  - Laser used (spectral width)
  - Bit-rate (temporal pulse separation)
  - Different SM types
Limitations from Chromatic Dispersion

- Dispersion causes pulse distortion, pulse “smearing” effects
- Higher bit-rates and shorter pulses are less robust to Chromatic Dispersion
- Limits “how fast” and “how far”
Combating Chromatic Dispersion

- Specialized fibers: DSF and NZDSF fibers (G.653 and G.655)
  - Dispersion compensating fiber
- Transmitters with narrow spectral width
- Regenerate pulse (O-E-O)
Polarization Mode Dispersion

- Caused by ovality of core due to:
  - Manufacturing process
  - Internal stress (cabling)
  - External stress (trucks)

- Only discovered in the 90s

- Most older fiber not characterized for PMD
Polarization Mode Dispersion (PMD)

- The optical pulse tends to broaden as it travels down the fiber; this is a much weaker phenomenon than chromatic dispersion and it is of some relevance at bit rates of 10Gb/s or more.
Combating Polarization Mode Dispersion

Factors contributing to PMD
- Bit rate
- Fiber core symmetry
- Environmental factors
- Bends/stress in fiber
- Imperfections in fiber

Solutions for PMD
- Improved fibers
- Regeneration
  - Follow manufacturer’s recommended installation techniques for the fiber cable

PMD does not need compensation up to 10G in systems up to about 1600km optical transmission, while compensation is required for longer systems or 40G
How Far Can I Go Without Dispersion Issues?

Distance (Km) = \frac{\text{Specification of Transponder (ps/nm)}}{\text{Coefficient of Dispersion of Fiber (ps/nm*km)}}

A Laser Signal with Dispersion Tolerance of 3400 ps/nm Is Sent Across a Standard SM Fiber, Which Has a Coefficient of Dispersion of 17 ps/nm*km. It Will Reach 200 Km at Maximum Bandwidth.

Note That Lower Speeds Will Travel Farther.
Transmission Over SM Fiber—Without Compensation

<table>
<thead>
<tr>
<th>Transmission Rate</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 Gb/s</td>
<td>980 km</td>
</tr>
<tr>
<td>10 Gb/s</td>
<td>60 km</td>
</tr>
<tr>
<td>40 Gb/s</td>
<td>4 km</td>
</tr>
</tbody>
</table>

Industry Standard—Not Cisco Specific
Dispersion Compensation

Total Dispersion Controlled

Cumulative Dispersion (ps/nm)

Distance from Transmitter (km)

Dispersion Shifted Fiber Cable

Transmitter

Dispersion Compensators
Nonlinearity
From Linear to Non-Linear Propagation

- As long as optical power within an optical fiber is small, the fiber can be treated as a linear medium.
  
  Loss and refractive index are independent of the signal power.

- When optical power levels get fairly high, the fiber becomes a nonlinear medium.
  
  Loss and refractive index depend on the optical power.
Effects of Nonlinearity

Self-Phased Modulation (SPM) and Cross Phase Modulation (XPM)

A Single Channel’s Pulses Are Self-Distorted as They Travel (SPM)

Multiple Channels Interact as They Travel (XPM)
Four-Wave Mixing (FWM)

- Channels beat against each other to form intermodulation products
- Creates in-band crosstalk that cannot be filtered (optically or electrically)
Four-Wave Mixing (FWM)

- If you have dispersion the beat signal will not fall on a real signal
  Therefore, some dispersion can be good in preventing FWM in an optical network
FWM and Dispersion

Dispersion Washes out FWM Effects

FWM Efficiency (dB)

Channel Spacing (nm)
The Three “R”s of Optical Networking

The Options to Recover the Signal from Attenuation/Dispersion/Jitter Degradation Are:

- **Re-Gen to Boost the Power**
- **Re-Shape**
- **Re-Time**

*Simplification

Pulse as It Enters the Fiber

Pulse as It Exits the Fiber

**O-E-O**

Re-gen, Re-Shape, and Remove Optical Noise

Optimum Sampling Time

Optimum Sampling Time

Optimum Sampling Time
SM Optical Fiber Types
Types of Single-Mode Fiber

- **SMF** (standard, 1310 nm optimized, G.65)
  Most widely deployed so far, introduced in 1986, cheapest

- **DSF** (Dispersion Shifted, G.653)
  Intended for single channel operation at 1550 nm

- **NZDSF** (Non-Zero Dispersion Shifted, G.655)
  For WDM operation in the 1550 nm region only
  TrueWave™, FreeLight™, LEAF, TeraLight™, etc.
  Latest generation fibers developed in mid 90s
  For better performance with high capacity DWDM systems
  MetroCor™, WideLight™
  Low PMD ultra long haul fibers

TrueWave is a Trademark of Lucent; TeraLight is a Trademark of Alcatel;
FreeLight and WideLight Are Trademarks of Pirelli; MetroCor Is a Trademark of Corning
Fiber Dispersion Characteristics

- Normal fiber
- Non-Dispersion Shifted Fiber (NDSF) G.652
- > 90% of deployed plant

![Graph showing dispersion characteristics for different types of fibers (DS, NZDS+, NZDS-, SMF, DSF G.653, NZDSF G.655) across various wavelengths (1350-1650 nm).]
**Different Solutions for Different Fiber Types**

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| SMF (G.652)      | - Good for TDM at 1310 nm  
                  | - OK for TDM at 1550  
                  | - OK for DWDM (with Dispersion Mgmt) |
| DSF (G.653)      | - OK for TDM at 1310 nm  
                  | - Good for TDM at 1550 nm  
                  | - Bad for DWDM (C-Band) |
| NZDSF (G.655)    | - OK for TDM at 1310 nm  
                  | - Good for TDM at 1550 nm  
                  | - Good for DWDM (C + L Bands) |
| Extended Band (G.652.C) | - Good for TDM at 1310 nm  
                  | - OK for TDM at 1550 nm  
                  | - OK for DWDM (with Dispersion Mgmt  
                  | - Good for CWDM (> Eight wavelengths) |

The Primary Difference Is in the Chromatic Dispersion Characteristics
Span Design
Span Design Limits

Attenuation

- Source and receiver characteristics
  - Tx: 0dBm
  - Rx sensitivity: –28dBm
  - Dispersion tolerance: 1600ps/nm
  - OSNR requirements: 21dB

- Span characteristics
  - Distance: 120km
  - Span loss: .25dB/km (30dB total)
  - Dispersion: 18ps/nm*km
Span Design Limits
Amplification

- **Source and receiver characteristics**
  - Tx: 0dBm
  - Rx sensitivity: –28dBm
  - Dispersion tolerance: 1600ps/nm
  - OSNR requirements: 21dB

- **Span characteristics**
  - Distance: 120km
  - Span loss: .25dB/km (30dB total)
  - Dispersion: 18ps/nm*km

- **EDFA characteristics**
  - Gain: 23dB (max = 17dBm)
  - Noise figure: < 6dB
  - Max input: –6dBm
Span Design Limits

Dispersion

- Source and receiver characteristics
  - Tx: 0dBm
  - Rx sensitivity: –28dBm
  - Dispersion tolerance: 1600ps/nm
  - OSNR requirements: 21dB

- Span characteristics
  - Distance: 120km
  - Span loss: .25dB/km (30dB total)
  - Dispersion: 18ps/nm*km

*Time Domain*

- 0ps/nm

*Wavelength Domain*

- 360ps/nm
- 1800ps/nm
- 2160ps/nm
Span Design Limits
Dispersion Compensation

- Source and receiver characteristics
  - Tx: 0dBm
  - Rx sensitivity: –28dBm
  - Dispersion tolerance: 1600ps/nm
  - OSNR requirements: 21dB

- Span characteristics
  - Distance: 120km
  - Span loss: .25dB/km (30dB total)
  - Dispersion: 18ps/nm*km

- EDFA characteristics
  - Gain: 23dB (Max +17dBm)
  - Noise figure: < 6dB
  - Max input: –6dBm

- DCF characteristics
  - Dispersion: –600ps/nm
  - Loss: 10dBm
Span Design
Limits of Amplification (OSNR)

- **Source and receiver characteristics**
  - Tx: 0dBm
  - Rx sensitivity: –28dBm
  - Dispersion tolerance: 1600ps/nm
  - OSNR requirements: 21dB

- **Span characteristics**
  - Distance: 60km x 4 Spans
  - Span loss: .25dB/km (15dB/span)
  - Dispersion: 18ps/nm*km

- **EDFA characteristics**
  - Gain: 23dB (Max +17dBm)
  - Noise figure: < 6dB
  - Max input: –6dBm
Real Network Design Challenges

- Complicated multi-ring designs
- Multiple wavelengths
- Any to any demand
- Nonlinearities
- Advanced modulation

Simulation and Network Design Software Is Used to Simplify Design
Network Design Tools? Concept to Creation Easier

- GUI-based network design entry
- Any-to-any demand
- Comprehensive analysis = first-time success
- Smooth transition from design to implementation
- Bill of materials
- Rack diagrams
- Step-by-step interconnect
DWDM Transmission
DWDM Systems

- Transponder
- Mux-Demux
- Amplifier
- DCU
- OADM
- OA
- Mux-Demux

Diagram showing the components of a DWDM system, including OA, OADM, Mux-Demux, and Transponder.

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More DWDM Components

Optical Amplifier (EDFA)

Optical Attenuator
Variable Optical Attenuator

Dispersion Compensator (DCM / DCU)
Intelligent DWDMNetwork Architecture

Integrated system architecture

Intelligent DWDM SYSTEM

VOA

EDFA

OSC

DCM

Integrated system architecture

Intelligent DWDM SYSTEM

VOA

EDFA

OSC

DCM

Intelligent DWDM SYSTEM

VOA

Service Mux
2.5Gb Service Cards

SONET/SDH
- OC-3/STM-1
- OC-12/STM-4
- OC-48/STM-16

Ethernet
- 1xGigabit Ethernet
- 2.5G Multi-Rate Transponder

SAN
- ETR/CLO
- STP ISC-3
- 2.5G InfiniBand

Video
- SDI
- DV6000
- HDTV

2.5G DataMuxponder
- 8xESCON
- 2x1G FC/FICON
- 1x2G FC/FICON
10Gb Service Cards

OTN

SONET/SDH

Ethernet

SAN

10Gb Enhanced Transponder

10Gb SONET/SDH

10Gb LAN and WAN PHY

10Gb FC

10Gb ODU-2 XPonder

4x2.5G Muxponder

4xOC-48/STM-16

16xOC-3/STM-1

16xOC-1/STM-4

4xOC-48/STM-16

10Gb ODU-2

8x1G FC/FICON/ISC-1

4x2GFC/FICON/ISC-3

2x4GFC

8xGigabit Ethernet

Enhanced GE/10GE XPonder

20xGigabit Ethernet

2x10GE

8xGigabit Ethernet

OTN

10Gb SONET/SDH

10Gb LAN and WAN PHY

10Gb FC

MSPP on a Blade

10Gb ODU-2 XPonder
40Gb Service Cards

- **OTN**
  - 40Gb Transponder
  - 40Gb OTU-3

- **SONET/SDH**
  - 40Gb SONET/SD
  - 4x10Gb OTU-2
  - 4x10Gb OTU-2e

- **Ethernet**
  - 40Gb LAN
  - 4x10Gb SONET/SDH
  - 4x10Gb LAN

- **SAN**
  - 4x10Gb FC
  - 4x8Gb FC

- **BENEFIT:** All 40G applications covered by 1 transponder
- **BENEFIT:** Aggregation cards reduce the cost of service delivery and allow for “pay as you grow” using XFP
Optical Amplifiers and Filters

**EDFA**
- 17dBm Variable Gain Pre-Amplifier with DCU Access
- 17dBm Variable Gain Booster
- 21dBm Variable Gain Booster
- 17 dBm Fix Gain Booster
- 21dBm Variable Gain Regional Amplifier with DCU Access
- L-Band 17dB Variable Gain Booster
- L-Band 20 dB Variable Gain Pre-Amplifier with DCU Access

**RAMAN**
- 500mW RAMAN w/ integrated 7dBm
- Variable Gain Pre-Amplifier

**Filters**
- 40ch/80ch 2^0 WSS ROADM
- 40ch 8^0 WXC ROADM
- 40ch/80ch Mux/Demux
Optical Protection Schemes

- **Unprotected**

- **Client Protected**

- **PSM Protected**

- **Splitter Protected**

- **Y-Cable or Line Card Protected**
Availability Solutions Comparison

Cost vs Availability

- Platinum Available: 100.00%
- Gold Available: 99.999%
- Silver Available (Fiber Switched): 99.998%
- Silver Available (OCH PSM Protection): 99.99%
- Bronze Available: 99.9%
- Available Network: 99%
Unprotected

- 1 client & 1 trunk laser (one transponder) needed, only 1 path available

- No protection in case of fiber cut, transponder failure, client failure, etc..
Client Protected Mode

- 2 client & 2 trunk lasers (two transponders) needed, two optically unprotected paths
- Protection via higher layer protocol
Optical Trunk Protection

- Only valid in Point 2 Point topologies
- Protects against Fiber Breaks
Optical Splitter Protection

- Only 1 client & 1 trunk laser (single transponder) needed
- Protects against Fiber Breaks
Line Card / Y- Cable Protection

- 2 Transponders
- working lambda
- Only one TX active
- “Y” cable
- protected lambda

- 2 client & 2 trunk lasers (two transponders) needed
- Increased cost & availability
ROADM: Operational Benefits
Manual DWDM Network Life-Cycle: Present Mode of Operation (PMO)

- Complicated Network Planning
- Manual provisioning of optical design parameters
- Manual installation, manual power measurements and VOA tweaking at every site for every link
- Labor-intensive operation
- Manual provisioning of equipment & topology into EMS/NMS

Result: high OpEx costs
ROADM Based DWDM Networks
Simplify Opex, Simplify Network Architecture, Simplify Network Planning

OADM Based Architecture
Re-plan network every time a new services is added
Certain sites can only communicate with certain other sites
Extensive man hours to retune the network
Need to brake entire ring to prevent lasing

Physical Rings

1-8ch OADM
ROADM Based DWDM Networks
Simplify Opex, Simplify Network Architecture, Simplify Network Planning

OADM Based Architecture
- Re-plan network every time a new service is added
- Certain sites can only communicate with certain other sites
- Extensive man hours to retune the network
- Need to brake entire ring to prevent lasing

ROADM Based Architecture
- Plan network once
- All nodes can talk to all nodes day one
- The network automatically tunes itself
- Improved network performance with DGE at every site

1-8ch OADM 2° ROADM
**DWDM Mesh Benefits**

Capacity Increase, Efficient Fiber Usage, Increased Availability

**Physical Rings**

**Ring-Based Architecture**

Traffic must follow ring topology, constricted
Inefficient traffic routing increase regeneration
Costly transponders for OEO ring interconnects
Single choice for service path & protect path
**DWDM Mesh Benefits**

Capacity Increase, Efficient Fiber Usage, Increased Availability

**Ring-Based Architecture**
- Traffic must follow ring topology, constricted
- Inefficient traffic routing increase regeneration
- Costly transponders for OEO ring interconnects
- Single choice for service path & protect path

**Mesh Architecture**
- A–Z provisioning—data follows fiber topology
- More efficient use of fiber
- Better load balancing increases capacity
- Shorter distance = less regeneration
- Eliminate transponders
- More options for service & protect paths

- **2° ROADM**
- **OEO ring interconnect**
- **2° -8° ROADM**
Automated DWDM Network Life-Cycle: Next-Generation Cisco ONS 15454 MSTP

Automated provisioning of all parameters

Easy planning with Cisco MetroPlanner
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Easy design changes based on actual fiber plant

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Automated optical layer for end-to-end connection setup; Manual patching of client at endpoints only
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Simplified, graphical A-Z provisioning & trouble shooting via CTM
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- Automated provisioning of all parameters
- CTM learns everything from the network and stays in sync
- Easy design changes based on actual fiber plant
- Automated end-to-end setup
- Easy planning with Cisco MetroPlanner
- Automated optical layer for end-to-end connection setup; Manual patching of client at endpoints only
- Simplified, graphical A-Z provisioning & trouble shooting via CTM

Automated DWDM Processes: simplified, SONET-like operation
Result: Reduces OpEx, facilitates wide deployment
Cisco ONS 15454 MSPP/MSTP Functionality
Cisco Vision: Flexible and Intelligent Optical Network

Traditional Vendors

Inflexible
- Preplanning
- Rigid configurations
- Limited application support
- No linkage with service delivery/enables

Difficult to Manage

Cisco Optical

Flexible
- ROADM: Fully flexible design rules
- ROADM: Any wavelength anywhere
- Wide variety of applications
- Integrated TDM / Layer2 functionalities + Direct interconnection with L2 / L3

Intelligent Software Enables Automated Network Set-Up and Management Along Network Life
Cisco IP NGN Transport Network Innovation– Investment Protection

**Introduction:**
SONET/SDH + Ethernet (EoS)

**Multiservice Provisioning Platform**
ONS 15454 SONET and SDH

**Multiservice Transport Platform**
ONS 15454 SONET and SDH

**Reconfigurable Add/Drop Multiplexer (ROADM)**

**Multiservice Provisioning Platform**

**ROADM Solution**

**IP over DWDM**

**Efficient Core Transport:** Integrated Intelligent DWDM and Core Routing Solution: SW Management and Tunable ITU Optics on CRS-1

**2-Degree ROADM:** Industry-Leading ROADM Technology Drives Deployable Wavelength Services into the Metro

**Intelligent DWDM:** Consolidating MSPP and DWDM Functionality onto a Single Platform

**Mesh ROADM, Ethernet-Enabled DWDM**

**Cisco IP NGN: Optical Vision**
Operationalize, Packetize and Deliver Connected Life Experiences

**Over 75,000 Deployed**

**MSPP Introduction:** SONET/SDH + Ethernet (EoS)

**ONS 15454 MSTP**

**Mesh ROADM (WXC)**

**XPonder**

**MSPP-on-a-blade**
Compatible to Existing Management System (CTM)
Summary
Summary

- Introduction on terminology
- Optical Propagation
- Attenuation and Compensation
  - Chromatic
  - PMD
- Non-Linearity
- Fiber types
- Basic span design
- DWDM System/ROADM
- ONS 15454 MSPP/MSTP Functionality
Q and A