Introduction to Wave Division Multiplexing
BICSI South West Regional Meeting
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Agenda

- Basic WDM Application
- Fiber Basics
- CWDM
- DWDM
- U-DWDM
- Passive Components
- Effects of Data Rate
- Network Architectures
Example of backbone: One Fiber Pair per circuit

6 Individual Circuits Require 12 Single Mode Fibers

Site A

Site B

Video
OC12-ATM
10GE
10GE
10GE

40 GE
Wave Division Multiplexing: All circuits carried on fiber pair

Example: 6 Circuits Require only 2 Single Mode Fibers

DWDM can Carry up to 400x10 GigE circuits (4 terabits)
Fiber Basics
Spectral Characteristics of Light

**Light:**
- Ultra-Violet (UV)
- Visible
- Infrared (IR)

**Communication Wavelengths:**
- 850, 1310, 1550 nm
  - Low Loss Wavelengths

**Specialty Wavelengths:**
- 980, 1480, 1625 nm
Optics Fundamentals

**Reflection**
Light reflects *inside* medium

**Refraction**
Light passes *through* medium boundary

- Air
- Glass
- Light
- Light is refracted
The index of refraction (n) is the ratio of the speed of light in a vacuum (c) to the speed of light in the material (v). This is written as: \( n = \frac{c}{v} \).

Simply, Index of Refraction is a relative measure of the propagation speed of the signal.

For a vacuum: \( n=1 \); Air: \( n=1.0003 \); Water: \( n=1.333 \)

Also, different wavelengths have different indices of refraction. This is why a prism divides the visible colors of the spectrum.
Reflection - Refraction

Reflection

Refraction
Fiber Construction

- Optical Fiber is a cylindrical waveguide made of a high purity fused silica.
- The core has a refractive index slightly higher than the cladding which allows the propagation of light via total internal reflection.
- A single-mode core diameter is typically 5-10 µm.
- A multimode core diameter is typically 50 or 62.5 µm.
Macro and Micro-bends

- Macrobend refers to loss caused by bending the fiber beyond a minimum bend radius.
- Microbend refers to small bends or minute deviations in the core/cladding interface.
Due to the characteristic attenuation curve of fiber, there are two regions typically used for communications.
Single Mode Fiber

COATING

CORE

CLADDING

CLADDING

Input Pulse

Output Pulse

COATING

CLADDING

CORE

Cross-Section

9µm

250µm
Wave Division Multiplexing
Wavelengths of Light

• Light travels farther in fiber at certain wavelengths
• Those wavelengths are used for transmission systems

1310nm Region
• Used for LAN, metropolitan area systems and analog video transport

1550nm Region
• Light travels farther than at 1310
• Used for longer distances
• Can be Amplified
• DWDM - Between 1530 and 1560
• Wavelengths must be very specific
• Extra components needed to “lock” wavelengths to specific color
Wave Division Multiplexing

Single Mode Fiber

Input Pulse

10GE
OC12-ATM
Video
10GE
10GE
10GE
10GE
10GE

Output Pulse

Video
OC12-ATM
10GE
10GE
10GE
10GE
10GE
Evolution of WDM Systems

- **WDM** – one 1310 and one 1550 channel
- **CWDM** – 18 Windows, 20nm spacing with 1 carrier per window
- **Dense WDM** – 20 - 80 Windows, 50-200 GHz spacing with 1 carrier per window
- **Ultra Dense WDM** – Windows, 50 GHz spacing with 4 carriers per window
CWDM

• Course Wave Division Multiplexing
• Standard channel plan developed by the ITU
  – International Telecommunications Union
  – 20 nanometer spacing between channels
  – Starting at 1270nm and going thru 1610nm
  – 18 Channels
DWDM

- Dense Wave Division Multiplexing
- Standard channel plan developed by the ITU
  - International Telecommunications Union
  - 400, 200, 100, and now 50 GHz spacing between channels
  - Starting at 1530nm and going thru 1560nm
  - Channels
Channel Spacing (400GHz and 200GHz)

- **400 GHz Spacing**
  - 10 Channels in Amplified C Band
  
- **200 GHz Spacing**
  - 20 Channels in Amplified C Band

- Spacing between carriers is reduced by half
Channel Spacing (100GHz and 50GHz)

- **200 GHz Spacing**: 20 Channels in Amplified C Band
- **100 GHz Spacing**: 40 Channels in Amplified C Band
- **50 GHz Spacing**: 80 Channels in Amplified C Band
Ultra Dense Wave Division Multiplexing (U-DWDM)

- Ultra Dense Wave Division Multiplexing (U-DWDM)
- Standard channel plan developed by the ITU
  - International Telecommunications Union
  - 12.5 GHz spacing between channels
  - Starting at 1530nm and going thru 1560nm
  - 320 Channels

12.5 GHz Spacing
320 Channels in Amplified C Band

OpVista Technology
WDM, CWDM, DWDM, and U-DWDM

- WDM
- CWDM
- DWDM
- 2nd Generation DWDM
- Ultra-DWDM
Optical Passives
Wavelength MUX / DMUX

- Works like a prism
- Each port has an associated wavelength which is fixed
- Same device can be both MUX/DMUX
- Insertion loss increases with port count
- Splitter and combiner are the same device.
- They are wavelength agnostic.
  - Any wavelength can go to any port and any port can be multi-wavelength.
- The power loss is the same whether it is used as a combiner or splitter.
  - There is no such thing as lossless combiner.
  - Ideal loss 1/n. Add 0.5 dB insertion loss for connectors and splicing.
  - To convert to dB $\to 10\log(1/n)-0.5$
• Same dropped wavelength can be added back to the system (i.e. reuse), except carrying a different traffic signal.
• A wavelength filter is the same as an add/drop multiplexer with only the input and drop ports.
Optical Add / Drop Multiplexer

OADM

Tap

Wavelength Filter

Filter

Amplifier (optional)

Amplifier (optional)
Broadcast and Select ROADM

Adding & Dropping Wavelengths Dynamically and remotely

Reconfigurable Optical Add Drop Multiplexer
Effects of Data Rates
Dispersion

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

Polarization Mode Dispersion
- Single mode fiber supports two polarization states
- Fast and Slow axes have different group velocities
- Causes spreading of the light pulse
Impacts of Dispersion

- A normal undistorted pulse has a relatively well defined transition between high and low states, making it easy to determine a transition from one state to another.

- Once a pulse has encountered the effects of dispersion, the transition between high and low states becomes much less defined as shown above.

- When viewed through a data analyzer, the pulse now appears to be “smeared” along the horizontal (time) axis.
• The amount of transition edge “smearing” will be the same regardless of the data rate.
• However, the resultant signal quality caused by dispersion varies greatly with data rate.
• In the above example, the both 40Gb/s and 10Gb/s signals have propagated the same distance.
• A transition between high and low states is still distinguishable on the 10Gb/s signal, but not on the 40Gb/s signal.
Dispersion Engineering Rules

Typical Distances without Dispersion Compensation

- **2.5G Carriers**
  - 600km
  - 1000km with FEC
- **10G Carriers**
  - 80 km
- **40G Carriers**
  - 25km
- **100G Carriers**
  - 4km
OpVista 40G/100G Solutions

- Enables 40G and 100G Transport using sub-channel multiplexing scheme
- Seamlessly upgrade existing 10G networks supporting more capacity
  - Same OSNR requirements as existing 10G DWDM networks
  - Same dispersion tolerance as existing 10G DWDM networks
- Leverages 10G DWDM components and FEC to deliver 40G and 100G Transport
- 40G Client Interfaces: OC-768, 4x10GbE, 4xOC192c
- 100G Client Interfaces: 100GbE as standards progress
U-DWDM Spectrum

<table>
<thead>
<tr>
<th>Total Power</th>
<th>CH Threshold</th>
<th>ITU Grid</th>
<th>Marker A</th>
<th>Marker B</th>
<th>Mkr Delta/Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.361 dBm</td>
<td>-13.506 dBm</td>
<td>50 GHz</td>
<td>1556.268 nm</td>
<td>1518.781 nm</td>
<td>37.487 nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-32.229 dBm</td>
<td>-32.229 dBm</td>
<td>0.000 dB</td>
</tr>
</tbody>
</table>

50 GHz ITU Window

Channel 1 of 20
OSNR (dB) 20.107

Wavelength (nm) 1556.4741
Power (dBm) -4.461
Architecture
Building a Network

- **Safety**
  - 320 wavelengths = dangerous
  - Output of some optical amplifiers can actually burn skin (long haul)

- **Fiber Type**
  - Singlemode the only option
  - Reduced Water Peak Fiber (for CWDM)
  - Pay attention to PMD specs

- **Connecting Hardware**
  - UPC polish singlemode (>55 dB return loss)
  - Field Polished connectors not recommended

- **Testing**
  - OTDR Traces to verify loss, distance, and return loss
  - Optical Loss Test Sets for attenuation
  - Consider investing in video fiber scope
  - KEEP FIBERS CLEAN
Traffic Patterns Drive Architecture

- Start with the Physical Topology
- Determine Bandwidth Requirements
- Determine best-match physical routing
  - One Large Ring
  - Two Small Rings
  - Multiple Small Rings
  - Hub and Spoke
- Don’t overlook less obvious routing
  - Physical Star – Logical Ring
  - Collapsed Ring(s)
• Why Mesh?
• Unpredictable bandwidth demands
  – Traffic is rarely “Hub and Spoke” traffic pattern
  – Any to Any is the only safe architecture
Summary

- Fiber Basics
- Amplification
- WDM
- CWDM
- DWDM
- U-DWDM
- Passive Components
- Effects of Data Rate
- Network Architectures

Follow Safety Instructions

Do not look into laser with remaining good eye
Thank you

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