Fiber around the globe

WDM and DWDM Communication Revolution

Dr. BC Choudhary
Professor,
NITTTR, Sector-26, Chandigarh
Presentation Overview

- WDM Fundamentals
- Course/Dense WDM systems
- Passive/Active Components
- Engineering Solutions
Problems and Solutions

Problem:
Demand for massive increases in capacity

Immediate Solution:
Dense Wavelength Division Multiplexing

Longer term Solution:
Optical Fibre Networks
Increasing the channel bit rate

- Signal Code from a single-laser wavelength

Increasing the number of channels

- Extended transmission bands
- Increased channel density
Time-Division Multiple Access (TDMA)

- A technique used to transport data from multiple sources over the same serial data channel.

- TDM is a digital process that can be applied when the data rate capacity of the transmission medium is greater than the data rate required by the sending and receiving devices.
  - A digital multiplexing technique to combine data.
Wavelength Division Multiplexing (WDM)

- Multiplexes multiple **optical carrier signals** on a single optical fiber by using different wavelengths (colours) of laser light to carry different signals.

- Allows multiplication in **Capacity**.

- Enables **Bidirectional Communications** over one strand of fiber.

**Ultra - High BW Multichannel System**
The Revolution

✓ WDM and TDM are complementary
✓ Implementation is under way throughout the world
✓ International standards are emerging
Reasons for WDM

- **Classic response**
  - Limited fiber strands
  - More bandwidth
  - Greater non regenerated distances

- **Additional**
  - WDM layer protection
Basic Definition

- **WDM is the ability to combine**
  - Multiple sources of data using
  - Multiple wavelengths (colors) of light on
  - One strand of fiber cable

A unique and powerful aspect of OFC: many different wavelengths can be sent along a single fiber simultaneously in the 1300- to -1600 nm spectral band.
WDM CONCEPT

- Technology of combining a number of wavelengths onto the same fiber – Wavelength Division Multiplexing (WDM)

- Scheme is same as Frequency division Multiplexing (FDM) used in radio and microwave systems

- Wavelengths in WDM must be properly spaced to avoid interchannel interference.

Key System features

- Capacity upgrade
- Wavelength Routing
- Transparency
- Wavelength Switching
Bands in Light Spectrum

Approximate Attenuation of Single Mode fiber cable

Visible

Infrared

700

900

1100

1300

1500

1700 nm

“Oh” Band ~ 1270-1350 nm

“E” Band ~ 1370 - 1440 nm

“S” Band ~ 1470 - 1500 nm

“C” Band ~ 1530 - 1565 nm

“L” Band ~ 1570 - 1610 nm
Potential of WDM

- Standard point-to-point transmission makes use of only a very narrow portion of the transmission bandwidth capability of a fiber.

Optical Bandwidths

- **1310 nm window:**
  \[ \Delta v = 14 \text{ THz} \]
  \[ \Delta \lambda = 80 \text{ nm} \]

- **1550 nm window:**
  \[ \Delta v = 15 \text{ THz} \]
  \[ \Delta \lambda = 120 \text{ nm} \]

- Total available fiber BW \( \approx 30 \) THz (200 nm) in two low loss windows

Transmission bandwidths in 1310 nm and 1550 nm windows allow the use of many simultaneous channels for sources with narrow spectral widths.
Deployment of WDM Systems

- Since the spectral width of a high quality source occupies only a narrow optical bandwidth, the two low-loss windows provide many additional operating regions.

- Using a number of light sources, each emitting at a different peak wavelength sufficiently spaced from its neighbor can utilize full fiber bandwidth capability.
Wavelength Division Multiplexing (WDM)
Three Basic Types:

- **Broadband WDMs (WDMs):** combine & separate 1310 and 1550 nm channels or even 850 and 1310 nm channels.

- **Narrow band WDMs (CWDMs):** combine and separate wavelength channels with center to center spacing > 100 GHz.

- **Dense WDMs (DWDMs):** Operating with wavelength-channel spacing < 100 GHz.

- **ITU-T recommendation G.692** specifies channels from a grid of frequencies referenced to 193.100 THz (1552.52nm) and spacing them 100 GHz (0.8nm).
Trend is toward smaller channel spacings, to increase the channel count

ITU channel spacings are 0.4 nm, 0.8 nm and 1.6 nm (50, 100 and 200 GHz)

Proposed spacings of 0.2 nm (25 GHz) and even 0.1 nm (12.5 GHz)

Requires laser sources with excellent long term wavelength stability $\approx 10$ pm

One target is to allow more channels in the C-band without other upgrades
### ITU DWDM Channel Plan

**0.8 nm Spacing (100 GHz)**

<table>
<thead>
<tr>
<th>Wavelength 1 (nm)</th>
<th>Wavelength 2 (nm)</th>
<th>Wavelength 3 (nm)</th>
<th>Wavelength 4 (nm)</th>
<th>Wavelength 5 (nm)</th>
<th>Wavelength 6 (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1528.77</td>
<td>1534.64</td>
<td>1540.56</td>
<td>1546.52</td>
<td>1552.52</td>
<td>1558.98</td>
</tr>
<tr>
<td>1529.55</td>
<td>1535.43</td>
<td>1541.35</td>
<td>1547.32</td>
<td>1553.33</td>
<td>1559.79</td>
</tr>
<tr>
<td>1530.33</td>
<td>1536.22</td>
<td>1542.14</td>
<td>1548.11</td>
<td>1554.13</td>
<td>1560.61</td>
</tr>
<tr>
<td>1531.12</td>
<td>1537.00</td>
<td>1542.94</td>
<td>1548.91</td>
<td>1554.94</td>
<td></td>
</tr>
<tr>
<td>1531.90</td>
<td>1537.79</td>
<td>1543.73</td>
<td>1549.72</td>
<td>1555.75</td>
<td></td>
</tr>
<tr>
<td>1532.68</td>
<td>1538.58</td>
<td>1544.53</td>
<td>1550.52</td>
<td>1556.55</td>
<td></td>
</tr>
<tr>
<td>1533.47</td>
<td>1539.37</td>
<td>1545.32</td>
<td>1551.32</td>
<td>1557.36</td>
<td></td>
</tr>
<tr>
<td>1534.25</td>
<td>1540.16</td>
<td>1546.12</td>
<td>1552.12</td>
<td>1558.17</td>
<td></td>
</tr>
</tbody>
</table>

**Speed of Light assumed to be 2.99792458 \times 10^8 m/s**
### ITU DWDM Channel Plan

0.4 nm Spacing (50 GHz)

<table>
<thead>
<tr>
<th>Channel 1</th>
<th>Channel 2</th>
<th>Channel 3</th>
<th>Channel 4</th>
<th>Channel 5</th>
<th>Channel 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1528.77</td>
<td>1534.64</td>
<td>1540.56</td>
<td>1546.52</td>
<td>1552.52</td>
<td>1558.58</td>
</tr>
<tr>
<td>1529.16</td>
<td>1535.04</td>
<td>1540.95</td>
<td>1546.92</td>
<td>1552.93</td>
<td>1558.98</td>
</tr>
<tr>
<td>1529.55</td>
<td>1535.43</td>
<td>1541.35</td>
<td>1547.32</td>
<td>1553.33</td>
<td>1559.39</td>
</tr>
<tr>
<td>1529.94</td>
<td>1535.82</td>
<td>1541.75</td>
<td>1547.72</td>
<td>1553.73</td>
<td>1559.79</td>
</tr>
<tr>
<td>1530.33</td>
<td>1536.22</td>
<td>1542.14</td>
<td>1548.11</td>
<td>1554.13</td>
<td>1560.20</td>
</tr>
<tr>
<td>1530.72</td>
<td>1536.61</td>
<td>1542.54</td>
<td>1548.51</td>
<td>1554.54</td>
<td>1560.61</td>
</tr>
<tr>
<td>1531.12</td>
<td>1537.00</td>
<td>1542.94</td>
<td>1548.91</td>
<td>1554.94</td>
<td></td>
</tr>
<tr>
<td>1531.51</td>
<td>1537.40</td>
<td>1543.33</td>
<td>1549.32</td>
<td>1555.34</td>
<td></td>
</tr>
<tr>
<td>1531.90</td>
<td>1537.79</td>
<td>1543.73</td>
<td>1549.72</td>
<td>1555.75</td>
<td></td>
</tr>
<tr>
<td>1532.29</td>
<td>1538.19</td>
<td>1544.13</td>
<td>1550.12</td>
<td>1556.15</td>
<td></td>
</tr>
<tr>
<td>1532.68</td>
<td>1538.58</td>
<td>1544.53</td>
<td>1550.52</td>
<td>1556.55</td>
<td></td>
</tr>
<tr>
<td>1533.07</td>
<td>1538.98</td>
<td>1544.92</td>
<td>1550.92</td>
<td>1556.96</td>
<td></td>
</tr>
<tr>
<td>1533.47</td>
<td>1539.37</td>
<td>1545.32</td>
<td>1551.32</td>
<td>1557.36</td>
<td></td>
</tr>
<tr>
<td>1533.86</td>
<td>1539.77</td>
<td>1545.72</td>
<td>1551.72</td>
<td>1557.77</td>
<td></td>
</tr>
<tr>
<td>1534.25</td>
<td>1540.16</td>
<td>1546.12</td>
<td>1552.12</td>
<td>1558.17</td>
<td></td>
</tr>
</tbody>
</table>

So called ITU C-Band

81 channels defined

Another band called the *L-band* exists above 1565 nm

### Speed of Light

Assumed to be $2.99792458 \times 10^8$ m/s
Course WDM (CWDM)

- CWDM grid defined in ITU G.694.2
  - From 1270 nm to 1610 nm
  - Spaced 20 nm apart
  - Center frequency ($f_c$) deviate +/- 6 or 7 nm
    - Non Cooled lasers
    - Easier to Manufacture
    - Less expensive

- 13 nm CWDM filter bandwidth
Dense WDM (DWDM)

- **Grid defined in ITU G.694.1**
  
  - From 1525 nm to 1610 nm
  
  - Centered at 193.1 THz (1552.52 nm)
    
    - +/- 100, 50, 25 or 12.5 GHz
    
    - ~ +/- 0.8, 0.4, 0.2 or 0.1 nm

  
  - DFB lasers drift ~0.1 nm/°C

  
- High stability (cooled) lasers
- Harder to manufacture
- More expensive
Implementation of WDM networks requires a variety of passive and/or active devices to combine, distribute, isolate and amplify optical power at different wavelengths.
Passive/Active Components

- Passive devices: operate completely in optical domain to split, isolate and combine light streams.
  - Couplers, Power splitters, Optical isolators
  - WDM, DWDM, OADM, power taps etc.
    - Fabricated either from optical fibers or by means of planar optical waveguides.

- Active devices: controlled electronically
  - Tunable sources
  - Optical amplifiers (EDFA)
  - Optical filters
Fused biconical tapered (FBT) coupler

- Perform both power combining and splitting
Four-channel Wavelength Dependent Multiplexer

- Made using Mach-Zehnder Interferometry Technique

Four channel WDM made using three $2 \times 2$ MZI elements
A grating can separate individual wavelengths since the grating equation is satisfied at different points in the imaging plane for different wavelengths.
Fiber Bragg Grating (FBG)

- Constructed within an optical fiber for accessing individual wavelengths in the closely spaced spectrum of DWDM systems.

- High-performance all fiber device; low cost, low loss, easy to couple, simple to packaging etc.

FBG Video
WD_DEMUX Device

- DEMUX to extract desired wavelength, a circulator is used in conjunction with the FBG.

Simple demultiplexing function Using FBG and optical circulator

Infinera ‘s Photonic ICWDM
Tunable DFB/DBR Laser Sources

Tunning achieved either by:

- Changing the temperature (0.1nm/°C)
- Altering injection current

Tunable DBR Laser

Tunable laser characteristics
Tunable Optical Filter

- Operates over a frequency range $\Delta \nu$, and is electrically tuned to allow only one optical frequency band to pass through.

**Basic concept of tunable optical filter**
Optical Add/Drop MUX (OADM)

- To add or drop wavelengths to DWDM system

Multiple tunable fiber grating used in conjunction with two optical circulators to add and drop any number of N different wavelength.
Each wavelength still behaves as if it has its own "virtual fibre"

Wavelengths can be added and dropped as required at some intermediate location
WDM/DWDM Ring
DWDM Long Haul

- Uses DWDM standard optics
- Introduces three regions; S, C & L
  - S band from 1440 nm to 1500 nm
  - C band from 1530 nm to 1565 nm
  - L band from 1570 nm to 1620 nm
- Amplifiers only available in the C&L bands
- Dispersion compensation with amplifier
Nonlinear effects are a function of the total power coupled to the fiber and the interaction length, they limit the maximum number of wavelength channels that can be transmitted over a particular distance.

- Five optical NLEs that can cause degradation of the transmitted signals as listed:
  - Stimulated Brillouin Scattering (SBS)
  - Stimulated Raman Scattering (SRS)
  - Self Phase Modulation (SPM)
  - Cross Phase Modulation (XPM)
  - Four Wave Mixing (FWM)
Among the five fiber nonlinearity effects

- SBS and SRS arise from interaction between light and acoustic or optical phonon (due to lattice or molecular vibrations),

- whereas SPM, XPM and FWM are caused by the *Kerr effect*, where intensity modulation of a signal is converted through refractive index nonlinearity to modulation of phase leading to excessive pulse broadening.
Engineering Problems

- DWDM is an analog problem
  - Optical noise floor/SNR on amps
  - Guard bands on adjacent signals
  - Linear impairments
    » Attenuation
    » Chromatic Dispersion
  - Non linear, cumulative impairments
    » Polarization Mode Dispersion (PMD)
    » Four Wave Mixing
    » Non Linear Effects

- Requires high degree of Signal maintenance
Important challenges in designing DWDM networks

- Transmission of different wavelength channels at the highest possible bit rate.
- Transmission over the longest possible distance with the smallest number of optical amplifiers.
- Network architecture that allow simple and efficient network operation, control, and management.

To meet these challenges, various signal-impairment effects that are inherent in OFC links must be taken care in design practices.
- **Group velocity dispersion (GVD):** limit the bit rate by temporally spreading a transmitted optical pulse.
  - Can be minimized by operation in low-dispersion window;
    - 1310nm for SMF
    - 1550nm for DSF

- **Nonuniform gain across the desired wavelength range of EDFAs in WDM link.**
  - Must be equalized over the desired wavelength range.

- **Polarization-mode dispersion (PMD):** very serious impediment for links operating at 10 Gb/s and higher.
  - Cannot be easily mitigated
- Reflections from splices and connectors that can cause instabilities in laser sources.
  - Can be eliminated by the use of optical isolators.

- Nonlinear inelastic scattering processes, SBS and SRS
  - Keeping launched power below these thresholds.

- Nonlinear variations of the refractive index in a silica fiber that occur because the R.I. is dependent on intensity changes in the signal.
  - Either working at low input powers or large core fibers.
Signal maintenance using Optical Devices

After fiber-optic transmission, high-speed optical signal pulses spread out, and 0 can be mistaken for 1 due to spread of neighboring pulses. (waveform distortion)
High Capacity OFC System

Experimental setup for 55 wavelengths WDM transmission using SMFs and DCFs in the link.

- Achieved data rate of 1.1 Tb/s — corresponds to sending almost the entire contents of 1000 copies of a 30-volume encyclopedia in 1 second.
The Optical Network System

Transmitters

Optical Layers

Optical Multiplexing Section Layer (OMS-L)
Optical Transmission Section Layer (OTS-L)

Add/Drop

Receivers

Digital Client Layer

SONET/SDH/PDH/ATM/ IP/etc. Digital Hierarchy Layer

EDFA = Erbium-doped fiber amplifier
MUX = Multiplexer
DEMUX = Demultiplexer
FORESIGHT...

Lightwave Communication Systems Employing DWDM, EDFAs and Soliton Pulses

“ZERO LOSS & NEAR INFINITE BANDWIDTH”

Provide with a network capable of handling almost all our information needs and resulting in a true information based society!
Questions?
Thank You

Dr. BC Choudhary
Email: bakhshish@yahoo.com
Mobile: 9417521382