Lecture 15

Wavelength Division Multiplexing Elements
WDM = Wavelength Division Multiplexing

- Multiplexing technique realized using optics – no speed limitations due to slow electronics

- Optical channels (lightpaths) – protocol-independent connections

- Wavelength-routing networks – wavelength serves as a destination address
WDM network elements:

OLT – Optical Line Terminal

OADM – Optical Add-Drop Multiplexers

OXC – Optical Crossconnects

Architectures:

- Ring
- Mesh
Figure 7.1 A wavelength-routing mesh network showing optical line terminals (OLTs), optical add/drop multiplexers (OADMs), and optical cross-connects (OXCs). The network provides lightpaths to its users, such as SONET boxes and IP routers. A lightpath is carried on a wavelength between its source and destination but is get converted from one wavelength to another along the way.
Features of the WDM networks

- wavelength reuse
- wavelength conversion
- transparency
- circuit switching (light path on demand)
- reliability (protection schemes, survivability)
Optical Line Terminals

\[ O \rightarrow E \rightarrow O \]

Figure 7.2 Block diagram of an optical line terminal. The OLT has wavelength multiplexers and demultiplexers and adaptation devices called transponders. The transponders convert the incoming signal from the client to a signal suitable for transmission over the WDM link and an incoming signal from the WDM link to a suitable signal toward the client. Transponders are not needed if the client equipment can directly send and receive signals compatible with the WDM link. The OLT also terminates a separate optical supervisory channel (OSC) used on the fiber link.

OLT may include

- transponders (wavelength converters)
- wavelength multiplexers
- optical amplifiers

used at end or point-to-point links to multiplex wavelengths.
Optical line Amplifier

Figure 7.3  Block diagram of a typical optical line amplifier. Only one direction is shown. The amplifier uses multiple erbium gain stages and optionally includes dispersion compensators and OADMs between the gain stages. A Raman pump may be used to provide additional Raman gain over the fiber span. The OSC is filtered at the input and terminated, and added back at the output.

Used typically every 80 - 120 km (depending on fiber loss)

- Raman or Er-ion amplifiers
- automated gain control
- dispersion compensation
- flat amplification over wide range of wavelengths
Optical Add/Drop Multiplexers

Figure 7.4 A three-node linear network example to illustrate the role of optical add/drop multiplexers. Three wavelengths are needed between nodes A and C, and one wavelength each between nodes A and B and between nodes B and C. (a) A solution using point-to-point WDM systems. (b) A solution using an optical add/drop multiplexer at node B.
O A & M Architectures

- Total number of wavelengths
- Max number of wavelengths to be dropped/added
- Add/drop technology: does it disrupt other channels?
- Scalability (modular technology)
- Overall complexity
- Reconfigurability (under remote software control)
Different OADM architectures. (a) Parallel, where all the wavelengths are separated and multiplexed back; (b) modular version of the parallel architecture; (c) serial, where wavelengths are dropped and added one at a time; and (d) band drop, where a band of wavelengths are dropped and added together. $W$ denotes the total number of wavelengths.
Table 7.1 Comparison of different OADM architectures. $W$ is the total number of
channels and $D$ represents the maximum number of channels that can be dropped by
a single OADM.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Parallel</th>
<th>Serial</th>
<th>Band Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D$</td>
<td>$= W$</td>
<td>1</td>
<td>$\ll W$</td>
</tr>
<tr>
<td>Channel constraints</td>
<td>None</td>
<td>Decide on channels at planning stage</td>
<td>Fixed set of channels</td>
</tr>
<tr>
<td>Traffic changes</td>
<td>Hitless</td>
<td>Requires hit</td>
<td>Partially hitless</td>
</tr>
<tr>
<td>Wavelength planning</td>
<td>Minimal</td>
<td>Required</td>
<td>Highly constrained</td>
</tr>
<tr>
<td>Loss</td>
<td>Fixed</td>
<td>Varies</td>
<td>Fixed up to $D$</td>
</tr>
<tr>
<td>Cost (small drops)</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Cost (large drops)</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Increased Loss

Figure 7.6 Impact of traffic changes on a network using serial OADMs. (a) Initial situation. (b) A new lightpath is added between node A and node C, causing lightpath BD to fail. (c) Lightpath BD is regenerated by adding a regenerator at node C. However, this causes other lightpaths flowing through C to be impacted.
Reconfigurable OADM

(a)

(b)

(c)

(d)

Figure 7.7  Reconfigurable OADM architectures. (a) A partially tunable OADM using a parallel architecture with optical add/drop switches and fixed-wavelength transponders. T indicates a transmitter and R indicates a receiver. (b) A partially tunable OADM using a serial architecture with fixed-wavelength transponders. (c) A fully tunable OADM using a serial architecture with tunable transponders. This transponder uses a tunable laser (marked T in the shaded box) and a broadband receiver. (d) A fully tunable OADM using a parallel architecture with tunable transponders.
- Service provision
- Protection
- Transparency (bit rate)
- Performance monitoring
- Wavelength conversion
- Monitoring and reconditioning

Figure 7.8 Using an OXC in the network. The OXC sits between the client equipment of the optical layer and the optical layer OLTs.
OXC technology

Figure 7.9 Different scenarios for OXC deployment: (a) Electrical switch core, (b) optical switch core surrounded by O/E/O converters, (c) optical switch core directly connected to transponders in WDM equipment, and (d) optical switch core directly connected to the multiplexer/demultiplexer in the OLT. Only one OLT is shown on either side in the figure, although in reality an OXC will be connected to several OLTs.

Advantage of optical core — no bit rate limitation due to slow electronics.
Table 7.2  Comparison of different OXC configurations. Some configurations use optical to electrical converters as part of the crossconnect, in which case, they are able to measure electrical layer parameters such as the bit error rate (BER) and invoke network restoration based on this measurement. For the first two configurations, the interface on the OTTs is typically a SONET short-reach (SR), or very-short-reach (VSR) interface. For the opaque photonic configuration, it is an intermediate-reach (IR) or a special VSR interface. The cost, power, and footprint comparisons are made based on characteristics of commercially available equipment at OC-192 line rates.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Opaque Electrical</th>
<th>Opaque Optical with O/E/Os</th>
<th>Opaque Optical</th>
<th>All-Optical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Figure 7.9(a)</td>
<td>Figure 7.9(b)</td>
<td>Figure 7.9(c)</td>
<td>Figure 7.9(d)</td>
</tr>
<tr>
<td>Low-speed grooming</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Switch capacity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Highest</td>
</tr>
<tr>
<td>Wavelength conversion</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Switching triggers</td>
<td>BER</td>
<td>BER</td>
<td>Optical power</td>
<td>Optical power</td>
</tr>
<tr>
<td>Interface on OLT</td>
<td>SR/VSR</td>
<td>SR/VSR</td>
<td>IR/serial VSR</td>
<td>Proprietary</td>
</tr>
<tr>
<td>Cost per port</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Power consumption</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Footprint</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>
All-optical configurations for OXC

Figure 7.11 A realistic "all-optical" network node combining optical core crossconnects with electrical core crossconnects. Signals are switched in the optical domain whenever possible before being down to the electrical domain whenever they need to be groomed, reorganized, or eventually converted to another wavelength.
Figure 7.12: A typical core wavelength plane OXC, consisting of a plane of optical switches, one for each core wavelength. With F fibers and F wavelengths, one can switch any wavelength to any other wavelength.
Figure 7.1.3. Diagram with optical terminations in a wavelength plane approach. Additional optical switch is required between the tunable transponders and the waveband plane switch. Here, 'F' denotes a transmitter, assumed to be a tunable transmitter on the WDM side, and 'R' denotes a receiver.