6.3. WDM point-to-point links

In point-to-point links, wavelength division multiplexing is used strictly to increase capacity by allowing transmission of many (up to 10 Gb/sec) channels. A WDM point-to-point link is shown in the figure. A WDM system is limited by the amplification, dispersion, and loss characteristics of the worst channel. In addition, as the number of channels $N$ increases, the extinction ratio of the system components (i.e. leading to interchannel crosstalk) becomes a critical issue.

WDM systems are the 4th generation in the evolution of system technology, and will constitute a large fraction of the 5th generation systems.

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>$4 \times 2.5$ Gb/sec</td>
</tr>
<tr>
<td>1996</td>
<td>$16 \times 2.5$ Gb/sec and $4 \times 10$ Gb/sec (0.8 nm channel spacing)</td>
</tr>
<tr>
<td>1997</td>
<td>$32 \times 2.5$ Gb/sec</td>
</tr>
</tbody>
</table>

The trend in WDM systems is to decrease channel spacing and increase the bit-rate per channel. Currently, most systems use 100 GHz (0.8 nm) channel spacing, but systems with 50 GHz (0.4 nm) channel spacing are becoming more common. Most systems use 2.5 Gb/sec per channel (and in some cases, up to 10 Gb/sec), but 40 Gb/sec per channel bit-rate is expected soon. This may represent the practical limit for electrical modulation. However, optical time-division multiplexing can be used to increase the per-channel capacity.

6.4. WDM system performance issues

The key enabling components of a WDM system are transmitters that operate at specific wavelengths and filters that combine (at the transmitter end) and separate (at the receiver end) wavelengths. One of the major limiting factors of WDM systems is then filter-induced crosstalk, which causes interchannel interference.

At its very basic level, the function of the filter is to select 1 of $N$ WDM channels. This operation can be expressed mathematically as

$$P = P_m + \sum_{n \neq m}^{N} T_{mn} P_n.$$
where $P$ is the total received power at the photodetector, $P_m$ is the received power of the intended wavelength channel, $P_n$ is the power of the unintended channels, and $T_{mn}$ is the matrix that represents the filter transmission for channel $n$ when channel $m$ is selected. Therefore, crosstalk occurs when $T_{mn} \neq 0$ for $m \neq n$. This form of crosstalk is called out-of-band because the interference originates from sources outside of the spectral band of the intended channel. Note that we assumed that $T_{mm} = 1$.

As expected, there is a power penalty due to interchannel crosstalk. The total photocurrent can be written

$$I = R_m P_m + \sum_{n \neq m}^N R_n T_{mn} P_n = I_{ch} + I_x,$$

where the responsivity in general depends on wavelength $R_m = \eta m q/\hbar \nu m$, $I_{ch}$ is the photocurrent due to the intended channel, and $I_x$ is the current due to crosstalk. $I_x$ is maximum when all channels are transmitting “1” bits. The power penalty can be estimated by using the eye diagram.

The total photocurrent for a transmitted “1” bit in the intended channel is written

$$I_1 = \delta_x I_{ch} + I_x,$$

where $\delta_x$ is the factor by which $I_{ch}$ much be increased to compensate for out of band interference, or crosstalk. The threshold level is set at $I_D = I_1/2$, and $I_0 = I_x$. In the absence of crosstalk, the eye opening from the decision threshold to the peak current would be $I_{ch}/2$. In order to maintain that same eye opening in the presence of crosstalk, we must have

$$I_1 - I_D - I_0 = \frac{\delta_x I_{ch} - I_x}{2} = \frac{I_{ch}}{2},$$

which leads to the power penalty

$$\delta_x = 10 \log_{10} (1 + I_x/I_{ch}).$$

The type of filter (i.e. Fabry-Perot, phased-array, acousto-optic, etc), the channel spacing, and the number of channels strongly influence the power penalty. For most systems, the power penalty is less than 0.25 dB.