WDM in optical access networks

Workshop on Optical Access Networks
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Outline

• Introduction about optical access networks
• WDM background
• CWDM key components
• System performance and applications
• Summary and outlook on WDM access networks
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Incentives for optical access networks

- Growing demand for bandwidth
  (>100 Mb/s residents / up to 10 Gb/s business)

- Existing copper lines don’t support high-speed access

- Future proof broadband solution
  (FTTB / FTTCab)
Objectives for access networks

- Low-cost implementation (reuse of existing ducts, locations e.g. remote nodes)
- Scalability (passed /connected customers, data rates, network operators)
- Passive outside plant infrastructure as far as possible (high reliability, low maintenance)
## Optical access network requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>target distance</td>
<td>typ. &lt; 10 km, max. 20 km</td>
</tr>
<tr>
<td>peak data rate</td>
<td>100 Mb/s (private customers) N x 1 Gb/s up to 10 Gb/s (business, WDM)</td>
</tr>
</tbody>
</table>
| temperature range  | Controlled operation: +10 °C to + 50 °C  
uncontrolled operation in buildings: - 5 °C to + 85 °C  
uncontrolled operation in the field: - 33 °C to + 85 °C |
|                    | humidity and vibrations at non-weather-protected locations |
|                    | long lifetime (10^5 h)                        |
|                    | no optical amplifiers in the field            |
|                    | Support of different topologies              |
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Motivation of WDM in access networks

- Simplified implementation of the fiber infrastructure
  - Savings in terms of fibers, connectors, splices etc.
  - Simplified fiber management especially at the CO
- Better exploitation of installed and planned fiber routes

WDM allows for sharing the bandwidth of fibers while maintaining the transparent, protocol-agnostic properties of SDM.
## Typical WDM channel spacings

<table>
<thead>
<tr>
<th></th>
<th>Typ. channel spacing</th>
<th>Channel allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BWDM</td>
<td>&gt; 50 nm</td>
<td>![Diagram 1]</td>
</tr>
<tr>
<td>CWDM</td>
<td>50 nm to 5.7 nm (1000 GHz)</td>
<td>![Diagram 2]</td>
</tr>
<tr>
<td>DWDM</td>
<td>50/100/200 GHz</td>
<td>![Diagram 3]</td>
</tr>
</tbody>
</table>
**BWDM**

**Transmitter**
- 1310 nm

**Receiver**
- 1490 nm

- **Bidirectional communication over a single fiber**
  - < 50 € / transceiver
  - Upgrade with further wavelength e.g. at 1550 nm (TV distribution)
  - Transmission at identical wavelengths (DDM)

**Image: Infineon**

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CWDM overview

- Increased fiber sharing (compared to BWDM)
- CWDM generally defined in ITU-T G.671
- Currently used CWDM schemes
  - LX4 format (25 nm, 4 x 3.125 Gb/s / 10 GbE)
  - 850 nm wavelength range
  - ITU-T Rec. G.694.2 (CWDM grid)
  - ITU-T Rec. G.695 (system specifications, interfaces...)
CWDM ITU-T recommendations

  - Support of up to 18 channels (1271 -1611 nm)
  - Channel spacing 20 nm, > 13 nm passband width
    relaxed manufacturing tolerances (lasers, filters)
  - Initially designed for metro applications

- Applications based on G.694.2 defined in G.695 (2004)
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CWDM transceiver considerations

**Important SFP characteristics**

- No thermal-electric cooler (TEC)
- Receiver based on PIN or APD photo diodes
- Ambient temperature range -10°C – +70 °C
- Temperature dependent wavelength drift < 0.1 nm/K

Small Form-factor Pluggable (SFP)

Electrical ports hot pluggable (including digital diagnostics)

Dual optical ports (small footprint connector)

Image: Luminent
SFP transceiver performance

Power budget:
24 dB @2.7 Gb/s

Output Power (DFB)
Sensitivity BER 10^{-9} (PIN)

Wavelength / nm

Power budget:
24 dB @2.7 Gb/s
SFP transceiver at a glance

- Transmitter with directly modulated laser (DML) without TEC
- Current maximum data rate 2.7 Gb/s (state-of-the-art). R&D: 10 Gb/s
- Full spectrum wavelengths increasingly available (second source demand)
- Operating temperature range meets FTTB demand
- Still expensive (some hundreds of €) due to the lacking volume market
CWDM filter considerations

Channel oriented broadband filter technologies

- AWG (arrayed waveguide grating)
- VBG (volume bragg grating)
- PLT (planar lightwave circuit)
- FBT (fused biconic taper)
- TFF (thin film filter)

Emerging technologies

R&D

Technology of choice

Image: Tsunami
TFF performance

Drift (70°C) FTTB

Manufacturing tolerance

6 nm (DFB laser)

ITU

passband 13 nm

CWDM channel 1611 nm nominal: 20 nm

Transmission / dB

Wavelength / nm

1280 1320 1360 1480 1520 1560 1600

0 10 20 30 40 50 60 70

18
TFF at a glance

- Full spectrum DeMux (further filter types) increasingly available
- DeMux < 50 € / channel
- Low insertion loss (e.g. < 4 dB 18:1 DeMux combination)
- TFF extremely stable (temperature drift < 1 pm/K)
- Industrial temperature range (-33°C - +85°C) increasingly available
  (outside plant operation)
CWDM fiber considerations

Standard single mode fiber (SSMF) G.652

Increased capacity by using additional wavelengths between 1370 and 1430nm
CWDM fiber performance

SSMF G.652 Cat D (L/ZWPF)

- Fiber attenuation: 0.45 dB/km
- Dispersion: 20 [ps/(nm*km)]
CWDM fiber at a glance

- G.652 fiber (Cat D) potentially support full spectrum operation
  - Permanently low insertion loss in the range of 1390 nm (OH peak)
  - Costs comparable to Cat B fibers
  - Dispersion comparable to Cat B fibers
- G.652 fiber (Cat B) supports a limited number of CWDM channels or limits transmission distances in the range of 1390 nm
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CWDM system considerations

Eye diagram optical signal @2.7 Gb/s

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## CWDM system performance

### Power margin consideration (1611 nm)

<table>
<thead>
<tr>
<th>Component</th>
<th>Penalty</th>
<th>GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 km ZWPF</td>
<td>8 dB</td>
<td>2.7</td>
</tr>
<tr>
<td>4 Connectors</td>
<td>2 dB</td>
<td></td>
</tr>
<tr>
<td>10 Splices</td>
<td>1 dB</td>
<td></td>
</tr>
<tr>
<td>DeMux (combi.)</td>
<td>4 dB</td>
<td></td>
</tr>
<tr>
<td>Penalty (disp.)</td>
<td>3 dB</td>
<td></td>
</tr>
<tr>
<td>Margin</td>
<td>3 dB</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>~18 dB</td>
<td></td>
</tr>
</tbody>
</table>

Power budget: ~27 dB@1.25 Gb/s. Extra power margin: ~9 dB e.g. extra components (OADMs)

![Graph showing power penalty versus fiber length for different wavelengths](image)

**Graph Notes:**
- **10 Gb/s, SSMF, DML/a=4**
- **Wavelengths:**
  - 1270 nm
  - 1310 nm
  - 1330 nm
  - 1390 nm
  - 1530 nm
  - 1550 nm
  - 1610 nm

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CWDM system at a glance

- Full spectrum operation demonstrated up to 2.7 Gb/s using commercially available SFP transceivers
- Early products available
- CWDM systems are loss limited (link length < 20 km, data rate < 2.7 Gb/s) (Link can be easily designed by power budget and insertion loss considerations)
- Short wavelengths up to 1350 nm (SSMF/DML) can be easily upgraded 10 Gb/s can become critical in the long wavelengths range due to the increasing influence of fiber dispersion
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Summary

• WDM technologies are gaining momentum in access networks. BWDM, CWDM and DWDM (dedicated lasers) are mature first mile technologies.

• CWDM provides cost-effective system architecture for BB multi-channel transmission over a single fiber:
  – BB PON architecture without power splitting
  – Standards are in place, supplements could be beneficial
  – Full spectrum components increasingly available even for adoption in harsh environments
  – Different topologies (e.g. ring based networks)

• SSMF G.652 Cat D supports full spectrum operation to a great extend
Outlook R&D trends

• CWDM
  – Upgrade strategies towards larger channel count
    • 10 nm channel spacings allow for up to 36 channels per fiber
    • DWDM over CWDM grid
    • Bidirectional over a single CWDM channel even at identical wavelength
  – Upgrade strategies towards higher data rates / channel
    • e.g. 10 Gb/s (10 GbE)
      – Electronic dispersion compensation w/o FEC
      – Improved transmitter signal (EML, dispersion managed lasers)

• DWDM
  – Research on WDM PON architectures using uniform components without dedicated wavelengths (allow for simplified equipment at the customer premises – colourless ONUs)
Limits of WDM systems

Thank You!

“No ma’am. This fiber system will **better** deliver, not deliver better, cable programs.”

Source: GTH