Bidirectional Transmission in CWDM Channels using Nominally Identical Wavelengths

K. Habel, C. Kottke, J. Vathke, K.-D. Langer
## Outline

- Introduction
- Reference model and receiver considerations
- Significance of
  - discrete reflections
  - Rayleigh backscattering
- Reach limits
- ORL requirements
- Conclusions
Motivation

- Bidirectional transmission on a single $\lambda$ allows doubling of capacity in short-reach single-fibre systems.
- Inevitable impairments due to Rayleigh backscattering ($\lambda$-dependent) and discrete reflections must be considered.
- Requirements for covering typical distances in access networks should be met by fibre infrastructure and standard low-cost components.
- Limitations for an arbitrary $\lambda$-channel in the CWDM grid + optional FEC-support investigated analytically and by experimental verification.
Reference link for bidirectional transmission

- Zero / low water-peak fibre to support CWDM band
- Minimum extra effort for bidirectional transmission (Two 3-dB-couplers)
- Challenge: sufficient reach considering all kinds of reflections and backscattering throughout entire CWDM band
Outline

> Introduction
> Reference model and receiver considerations
> Significance of
  • discrete reflections
  • Rayleigh backscattering
> Reach limits
> ORL requirements
> Conclusions
Investigations

- Receiver sensitivity penalty due to crosstalk
  - Single reflections (due to connectors, devices, splices)
  - Crosstalk (coherent, incoherent)
- ORL requirements
- Reach limitations
- Power of FEC for performance improvement
Scheme of measurement setup

- **PRBS**:2^{23}-1
- **DFB 1550 nm**
- **BERT**
- **Tx**
- **Rx**
- **CDR**
- **OPM**
- **POL**
- **BERT**
- **Data signal**
- **fibre (optional)**
- **Single Reflection with variable reflectivity**
  (Optional too)

**Legend**:
- **CDR**: Clock and data recovery
- **OPM**: Optical power meter
- **POL**: Polarisation controller
- **BERT**: BER test set

BBEurope, December 3-5, 2007 — 7
Receiver sensitivity penalties

Sensitivity Penalty [dB]

S/C [dB]

- w/o FEC
- 1d FEC
- 2d FEC

ORL=32dB
Single reflection at the near end

- S/C decreases with fibre length
- Max. reach: (--) S/C = 22 dB
  ~20 km @ 1270 nm and
  ~40 km @ 1590 nm
- More realistic S/C value: (--) 22.0 dB (limit) + 4 dB (Tx power spread) + 2 dB (margin) = 28.0 dB
  ~ 7 km @ 1270 nm and
  ~20 km @ 1590 nm
- With FEC → Max. reach again!
Conclusion on single reflections

> Reflection at the far end: more relaxed S/C, as crosstalk power attenuated two times, signal power only once

> Moving point of reflection towards near end: approaching the worst case:
  - fibre span attenuates wanted signal
  - reflected interferer is attenuated less

> Without FEC only a few km can be bridged → With a Standard-FEC (20…40 km possible)
\( \lambda \)-dependency of Rayleigh backscattering

- Analytical formula applied to CWDM wavelength grid (1270…1610 nm)
- Fibre parameters fitted to measured data of low water-peak fibre
Penalty vs. S/C for Rayleigh Backscattering

> Minimum Signal-to-Crosstalk ratio (S/C) ≈ 25.5 dB

(for a 2dB-penalty at BER = 10⁻⁹)
S/C (Rayleigh) at local Rx for CWDM grid

- S/C decreases with fibre length
- Max. reach: \(-\)
  S/C = 25.5 dB
  \(~20\) km @ 1270 nm and
  \(~45\) km @ 1610 nm

- More realistic S/C value: \(-\)
  25.5 dB (limit)
  + 4 dB (Tx power spread)
  + 2 dB (margin)
  = 31.5 dB

  \(~7\) km @ 1270 nm and
  \(~20\) km @ 1610 nm

- But with FEC \(\rightarrow\) Max. reach again!
Outline

> Introduction
> Reference model and receiver considerations
> Significance of
  • discrete reflections
  • Rayleigh backscattering
> Reach limits
> ORL requirements
> Conclusions
Bidirectional transmission limits in CWDM grid

- Noise limit (1.25G, w/o FEC)
- Noise limit (2.5G, w/o FEC or 10G FEC)
- Noise limit (10G, w/o FEC)
Bidirectional transmission limits in CWDM grid

SR... Single reflection
RBS... Rayleigh backscattering
Bidirectional transmission limits in CWDM grid

- **Noise limit (1.25G, w/o FEC)**
- **Noise limit (2.5G, w/o FEC or 10G FEC)**
- **SR-Limit (FEC)**
- **RBS-Limit (FEC)**
- **SR-Limit (w/o FEC)**
- **RBS-Limit (w/o FEC)**

Fiber Length [km] vs. Wavelength [nm]

- 10G, w/o FEC
- 2.5G, w/o FEC or 10G FEC
- 1.25G, w/o FEC
- FEC
- w/o FEC
Outline

> Introduction
> Reference model and receiver considerations
> Significance of
  • discrete reflections
  • Rayleigh backscattering
> Reach limits
> ORL requirements
> Conclusions
Requirements on optical return loss (ORL)

> Existing standards
  - PONs: 20 dB (non-terminated taps)  
    → less suitable for single-λ transmission  
  - long-haul systems: 27 dB  → 30 dB reasonable for local loops

> APC connectors provide up to 60 dB  → sufficient margin for cascading

> Links with in-line elements (e.g. OADMs) would relax crosstalk,  
  however IL keeps power budget rather low  → reach < 10 km

> Note: Due to system's symmetry increased Tx power or improved Rx sensitivity is no solution  
(System not noise limited)
Conclusions

- Our investigations have considered
  - Optical Return Loss of the link ≤ 30 dB
  - Output power imbalance of 4 dB between local and remote TRx
  - Receiver penalty of 2 dB

- For the same signal-to-crosstalk ratio (S/C) Rayleigh Backscattering (RBS) limits the performance

- Short reach of 7 … 20 km (depending on λ) without FEC

- FEC gains 6…7 dB and is recommended for 10G and longer reach (20 km and more)

- Bidirectional transmission is a viable option if additional bandwidth is needed → Demonstration planned for Q1/2008
Acknowledgments

> Thanks to the MUSE project, particularly to the R&D partners of the subproject on optical access

> Funding within EU research programme IST “Broadband for all” is gratefully acknowledged

Contact
Name: Kai Habel
Phone: +49 30 31002 465
Fax: +49 30 31002 250
eMail: habel@hhi.de
Internet: http://www.hhi.de
Single reflections and Rayleigh backscattering

- 1550nm, 0km, w/o FEC
- 1550nm, 12km, w/o FEC
- 1550nm, 24km, w/o FEC
- 1550nm, RBS limited, w/o FEC

> Additional fibres increase S/C requirement
> Required S/C: 22 → 23.2 → 24 dB
> worst case set by RBS, S/C: 25.5 dB