Enhancing PON capabilities using the wavelength domain


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Introduction

Optical fiber deployment in access represents a large capital investment for carriers

But current PONs only partly exploit the huge optical bandwidth of fibers (50 THz)

Questions:

- What could be the benefits in better exploiting this bandwidth?
- How can we harness it?
- What are the technical issues that need to be tackled?
Agenda

- Wavelength bands and channels: status in PONs today
- WDM applications in PONs
- Technological challenges in realizing low cost WDM
- Conclusion
Transmission spectrum of standard fibers and usual WDM channel definitions

**CWDM (G.694.2):**
- for uncontrolled operation of DFB lasers in moderate environment (not outdoor)
  - channel spacing 20 nm: $\lambda_c = 1271 + N \times 10$ nm ($N = 1, 2, \ldots$)
  - filters: 12-14 nm clear window

**DWDM (G.694.1):**
- requires temperature controlled singlemode (DFB) lasers
  - channel spacings on a variety of grids having different granularities: 12.5 / 25 / 50 / 100 / … GHz
Wavelength bands in existing PON standards and 10G-EPON

**existing:**
- BPON (983.1,3)
- GPON (984.2)
- EPON (802.3)

**new bands for NG-PON:**
- 10G-EPON (802.3av)

**upstream**
- specified: 1260 - 1360 nm
- deployed: 1290 - 1330 nm

**downstream**
- 1480 - 1500 nm
- video overlay: 1550 - 60 nm
- OTDR: >1600 nm

**wavelength, nm**

- 1260 1300 1400 1500 1600

**“water peak” (OH⁻) affected region**

- 1330 – 1360 nm
- 1500 – 1550 nm

Attractive ranges for additional wavelength overlays: 1330 – 1360 nm, 1500 -1550 nm
Long wavelength issues of standard singlemode fibers (G.652)

SMF fibers typically deployed in PONs suffer from higher attenuation due to
- “water peak“ around 1380 nm
  → lower loss fibers (G.652D) being deployed today
- macrobending losses at long wavelengths
  - cabled fibers can be used beyond 1580nm, but long wavelengths are prone to losses from bends resulting from fiber management in PONs:
    - handling fibers and patch cords in distribution frames
    - unintentionally moving unprotected fibers in splice enclosures during repair
    - inhouse fiber routing
  → fiber patch cords and inhouse cables should employ low bend loss fibers (G.657A)

Older power splitters have not been specified beyond 1580 nm

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SMF macrobending induced losses vs. wavelength for different bending radii (source: ADC-Krone Germany 2008)
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What are the benefits that WDM technology can bring to PON?

Capacity increases of existing networks („sparse WDM“)
- introducing new 10G systems into existing networks on new wavelengths, coexisting with legacy systems on the same ODN
- 4 x GPON on parallel wavelengths having 4 times reduced split factor

Optimized utilization of fiber infrastructure („massive WDM“)
- parallel operation of many TDM-PONs
- add services
- high speed connections in overlay for select customers (business, FTTB)
- point-to-point links for many users
- flexible reconfiguration of optical links
- suitable wavelength ranges: 1330 - 1360 nm, 1500 -1550 nm including guard bands
Saving feeder fibers: multiple parallel TDM-PONs via DWDM

Application and expected benefits
- longhaul feeder for Central Office consolidation
- large number of customers are aggregated on single feeder fiber

Experimental realization in EU projects PIEMAN and MUSE
- PIEMAN demonstrator specifications (early 2009):
  - 10 Gbit/s down- and upstream
  - 90 km metro link / 10 km drop
  - 1 : 512 split factor
  - 32 PONs multiplexed via DWDM in feeder section
  - „colourless“ ONUs
- similar specifications for MUSE demonstrator

PIEMAN demonstrator architecture
Point-to-point links for many users via WDM over PON

Location of CO based WDM router has impact on system architecture

1) **WDM router inside OLT**:
   - fixed architecture, no simple upgrade per user
   - comparison to TDM-PON: 2*N WDM-TRx + 2 WDM-router vs. N+1 TDM-TRx + 1 power splitter

2) **WDM router outside OLT**:
   - flexibility in reconfiguring / upgrading on a per-user-basis
   - but: more floorspace for fiber management required (cf. point-to-point home run)
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Constraints from component technology

WDM is a „commodity“ in other parts of the network, but access is different

in access cost is key, and next to it comes ...... cost

Critical components in this respect:

- optical filters
- WDM sources
- (optical amplifiers, not addressed here)
- (dispersion compensation, not addressed here)

and
- optical layer monitoring
Optical filters: internal WDM filters for DS/US discrimination

Current transceivers allow only for wide guard bands due to internal WDM filter design limitations
- 45 degree incidence angle
- divergent (unpol.) beam optics
- small number of dielectric layers (cost limited)
→ reason for relaxed guard band specifications in G.984.5 (30-39 nm)

Planar Lightwave Circuit (PLC) transceivers bear the potential for realizing narrower guard bands
- near zero degree incidence angle and near parallel beam optics allow for improved filter performance using affordable number of layers
Optical filters: wavelength routing vs. power splitting ODN

WDM routing filters vs. power splitters at Remote Node
- improved optical power budget
- WDM channel allocation is easily modified by replacing a single filter only
- but: loss of wavelength transparency in ODN

Wavelength routing filter technologies
- AWG (Arrayed Waveguide Grating)
  - narrow passbands, compact design
  - viable only for high port counts, no filter cascades (centralized split only)
- TFF (Thin Film Filter)
  - useable for multichannel WDM routers as well as for single channel selection
  - gradually extendeable filter cascades, „any“ filter shape design, mature technology
  - tilted wavelength response for filter cascades
WDM sources: resolving logistical issues

High numbers of WDM sources for many different wavelength channels in PONs:
- logistics (installation and repair) ask for single optical source solutions
- technology should offer inherently secure WDM channel provisioning

Known technologies for single optical sources
- **tuneable lasers** (DFB via temperature, DBR lasers, external cavity lasers)
  - need control of multiple parameters, high electrical power consumption, prone to instabilities
- **spectrally sliced LED or SLED**
  - up to 20 dB power loss
- **remotely seeded sources** (RSOA and wavelength locked Fabry-Perot lasers)
  - need additional sources at the OLT
  - high seed power required, even increases for bitrate upgrades
  - nevertheless: today these are the only solutions that come close to what is needed for DWDM in PONs

![Diagram of automatic wavelength locking](source: Novera Optics website)
WDM sources: asking for a new approach

There is no need for reversible wavelength tuneability: setting the wavelength once and then freezing it would be sufficient
- wavelength programmable lasers: "set-and-forget"
- suitable technologies with low cost potential need to be identified

Setting the ONT laser wavelength is initiated by OLT (needs new "one way" protocol)

OLT:
1) request ONT to tune to specific WDM channel

ONT:
2) adjust laser wavelength
3) check wavelength
4) freeze it
5) start normal operation
Optical layer monitoring: integrated wavelength monitoring

An integrated optical edge filter is sufficient to detect wavelength drifts of unstabilized lasers in wide grid WDM networks (several 100 GHz spacing)

Conceptual idea:
- filter response and integration into transceiver module
- wavelength is derived from measured powers using internal look-up table

(this solution is being investigated within the German BMBF project COMAN (01BP0701))
Optical layer monitoring: fiber monitoring through wavelength routing ODN

Conventional OTDR equipment at OLT needs wavelength tuneable test laser for measuring through each wavelength route in the ODN
- interferes with data channel

Alternative solution:
**Embedded OTDR** re-uses the data laser for in-service fiber testing
- WDM transceivers measure exactly their own wavelength route through the ODN during normal operation, passing through all WDM filters and splitters and into attached drop fibers
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PONs will increasingly exploit the wavelength domain for
- system migration (e.g. 10G overlay)
- service overlay (video, dedicated high speed channels, …)
- improved utilization of the ODN (TDM-PON per wavelength, ptp per wavelength)
- improved flexibility of optical link configuration

Additional efforts are required to develop affordable technologies for
- narrowband optical filters inside WDM transceivers
- low cost WDM sources
- optical layer monitoring

Restrictions on possible channel allocation in future WDM-PONs arise from
- existing waveband allocations and deployed system equipment
- spectral attenuation of fibers, particularly in long wavelength region
- amplifier and dispersion characteristics