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

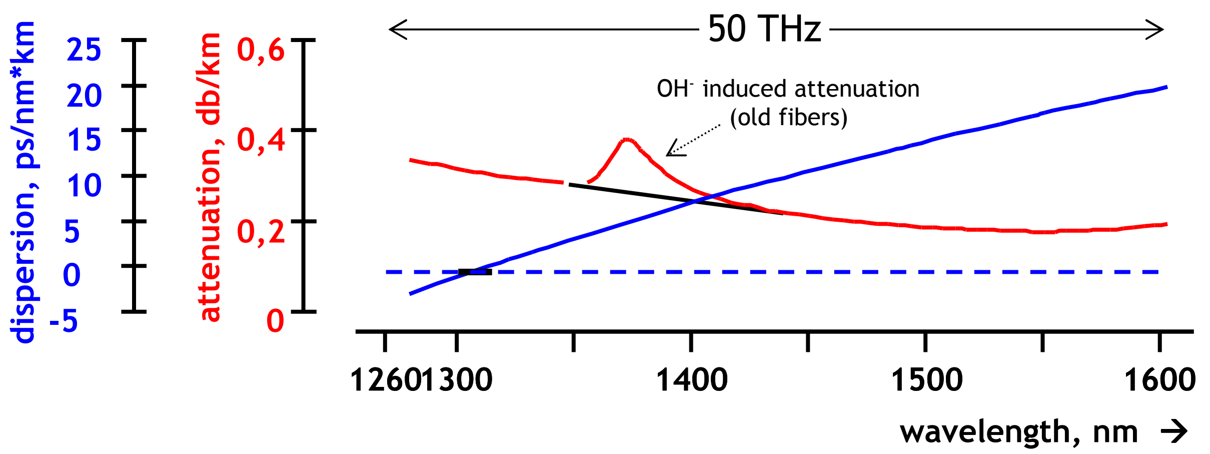
Wavelength bands and channels : status in PONs today

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: λ_c = 1271 + N x 10 nm (N = 1, 2, ...)
- 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

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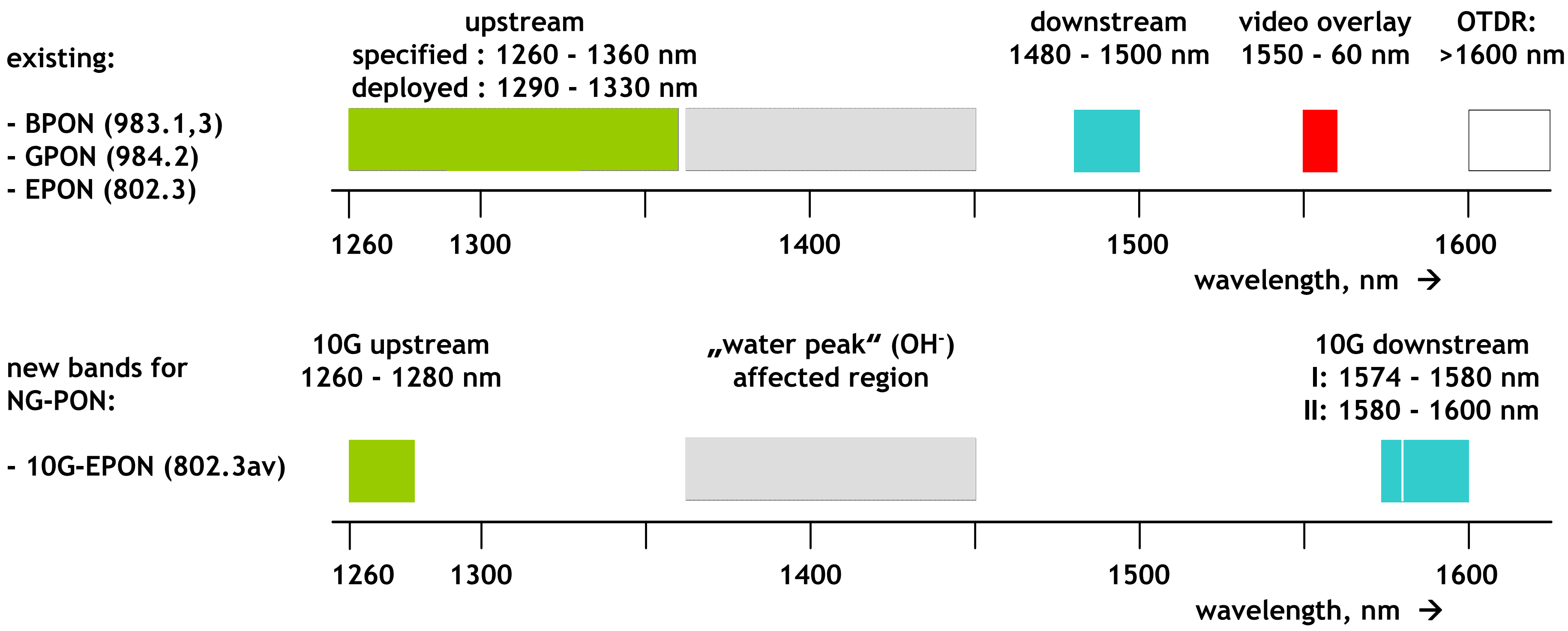
Wavelength bands in existing PON standards and 10G-EPON



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

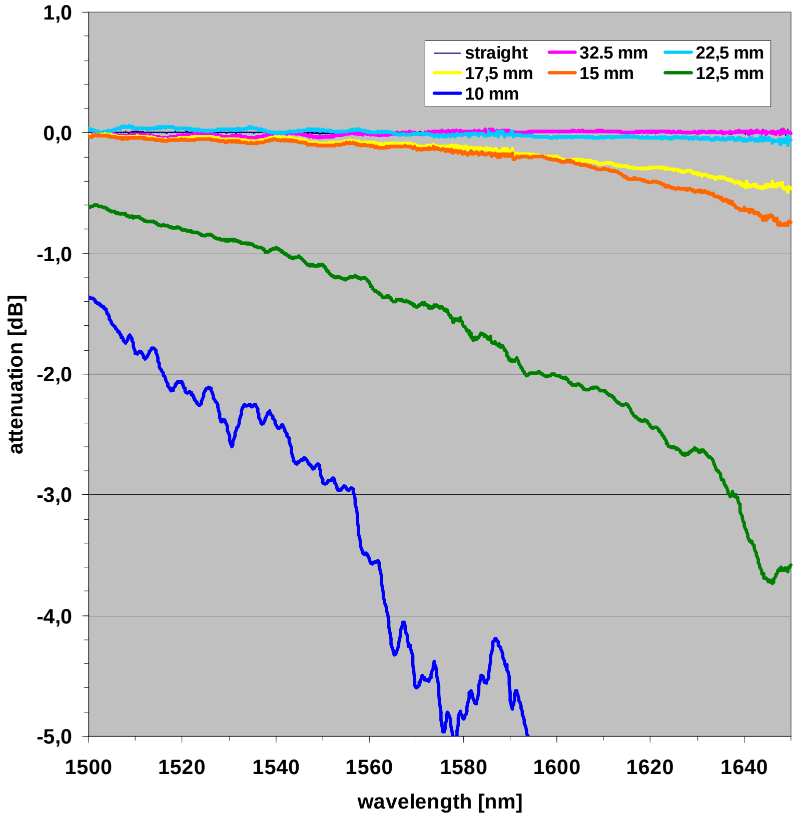
- „water peak“ around 1380 nm

  →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



SMF macrobending induced losses vs. wavelength for different bending radii (source : ADC-Krone Germany 2008)

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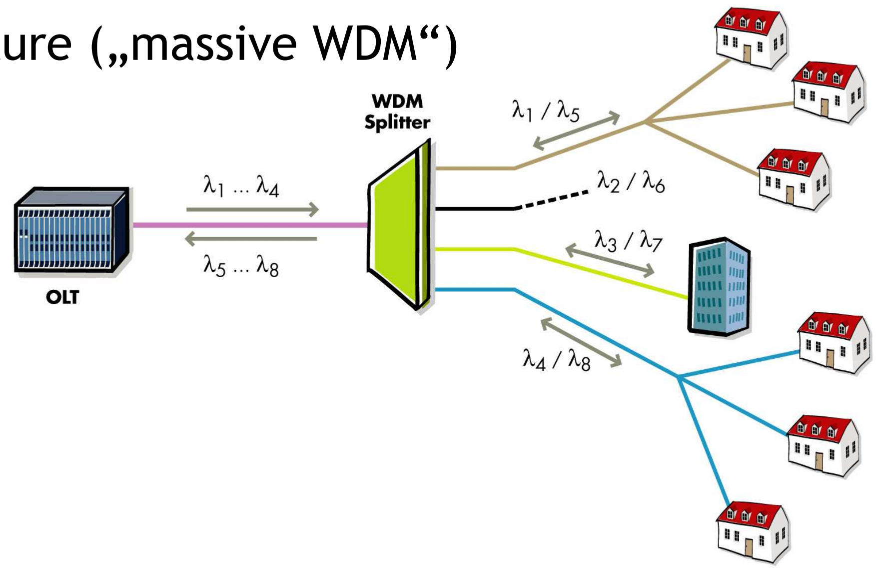
What are the benefits that WDM technology can bring to PON ?

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

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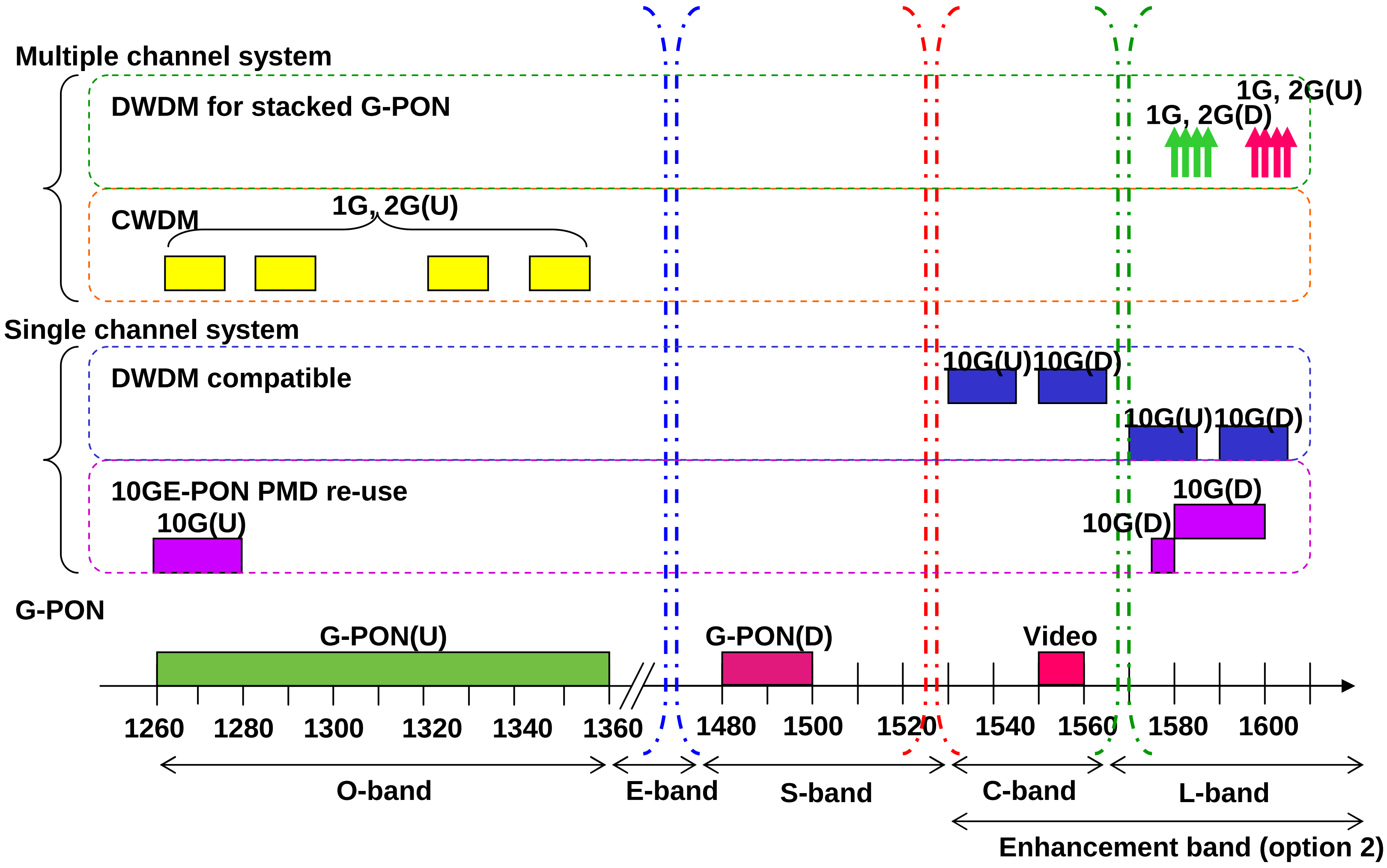
10G WDM overlay options (cf. FSAN)



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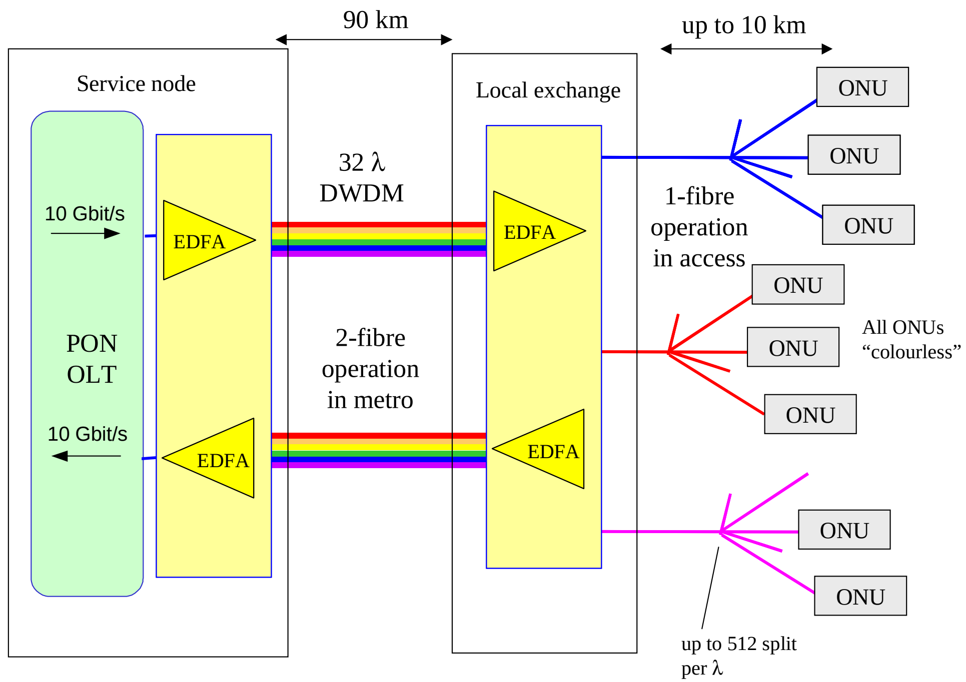
Saving feeder fibers: multiple parallel TDM-PONs via DWDM

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 specificatons (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

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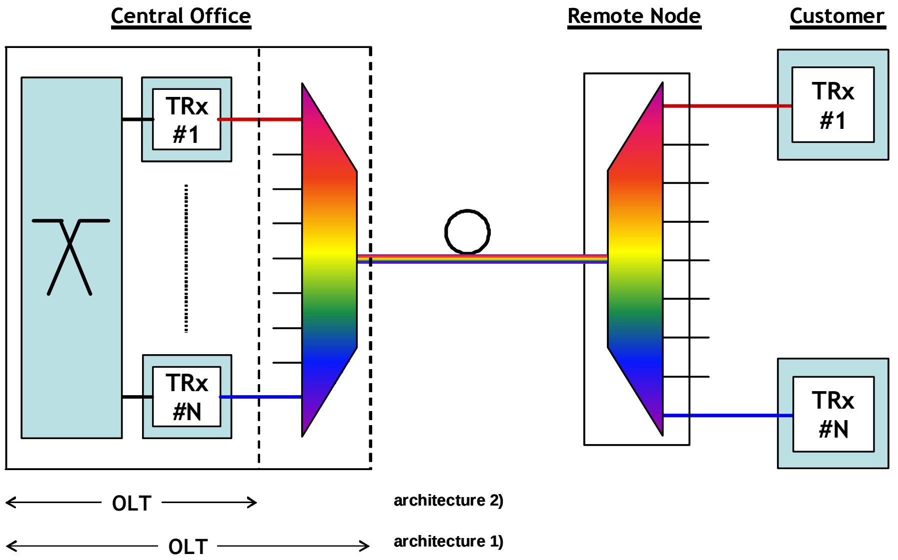
Point-to-point links for many users via WDM over PON



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

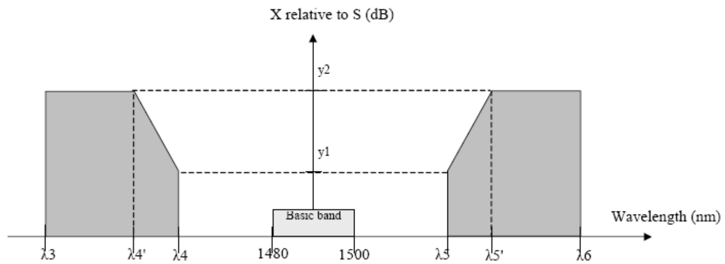
- **optical layer monitoring**

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)



Wavelength(nm)	λ3	λ4'	λ4	λ5	λ5'	λ6
	1415/1400 *(Informative)*	1441 *(Informative)*	1450 *(Informative)*	1530	1539	1580 to 1625
X relative to S (dB)	y2	y2	y1	y1	y2	y2
	22 *(Informative)*	22 *(Informative)*	7 *(Informative)*	7	22	22

S : Received power of basic band

X : Maximum total power of NGA and video received in the blocking wavelength range.

X/S in the mask (hatching area) should not cause the sensitivity of the basic band receiver to fail to meet the specified limit.

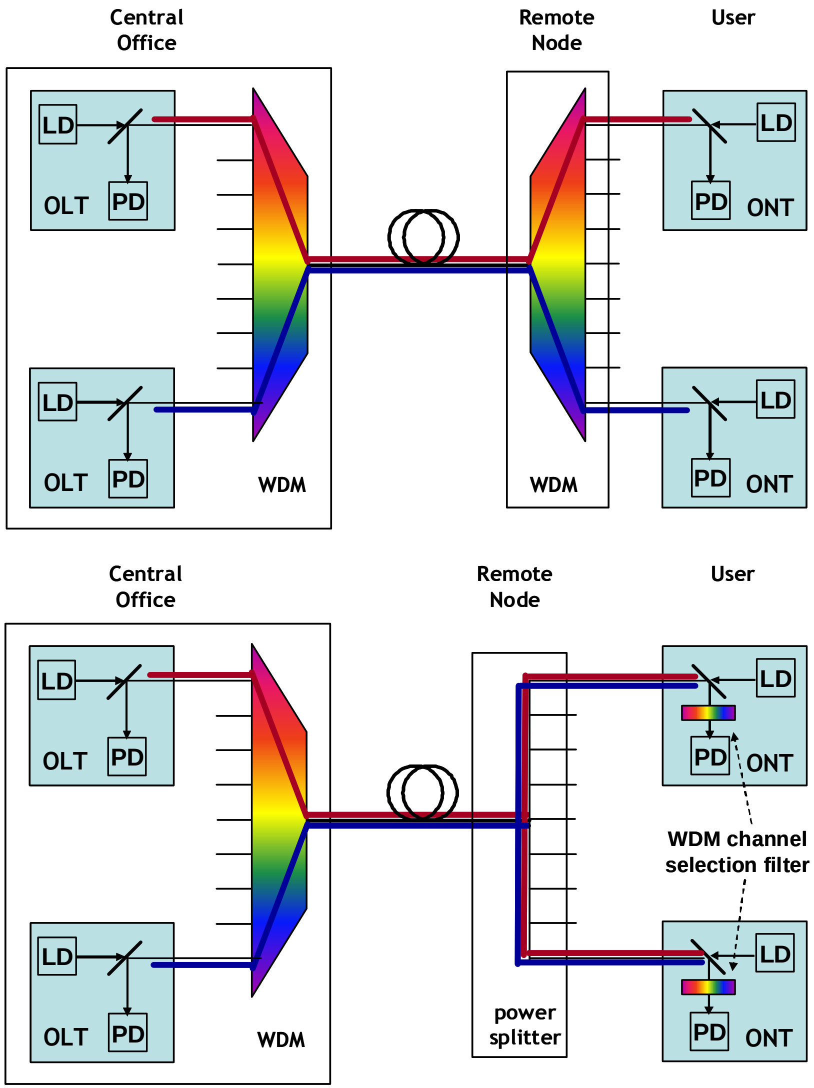
NOTE 1 – λ3 value of 1400 *(Informative)* may be applicable for low-water-peak fibre only.

Figure 5/G.984.5 – S/X tolerance mask for ONU

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

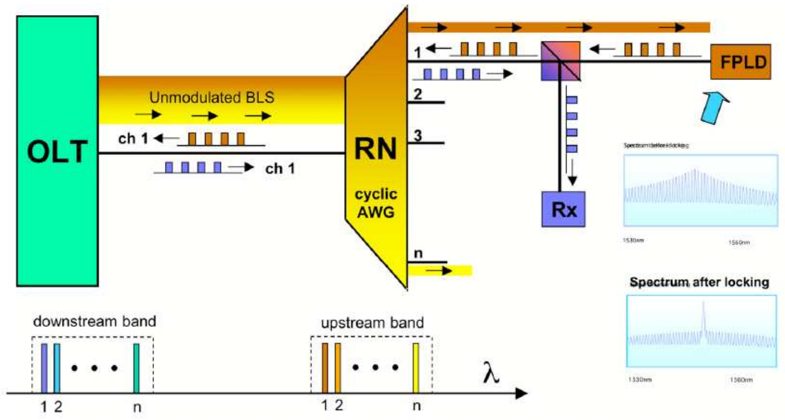


Figure 5. Basic description of automatic wavelength locking

(source : Novera Optics website)

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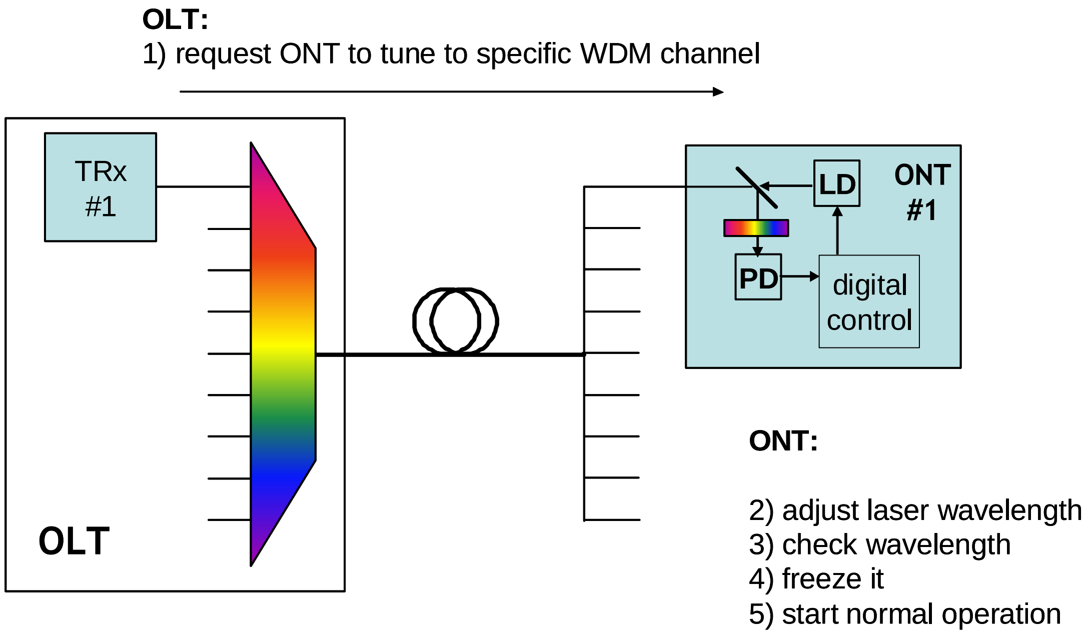
WDM sources : asking for a new approach

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)



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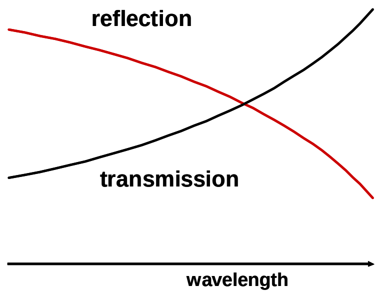
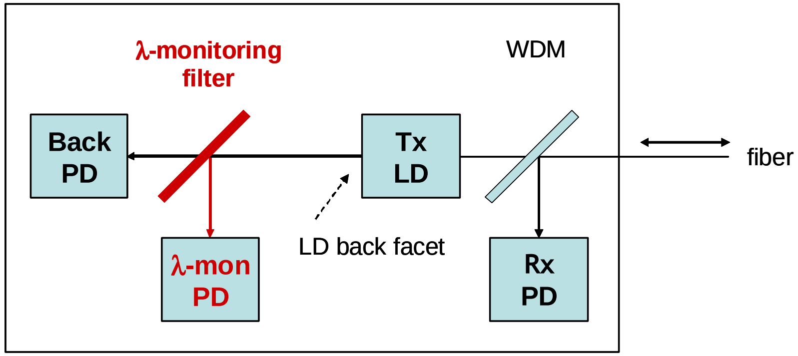
Optical layer monitoring : integrated wavelength monitoring

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))

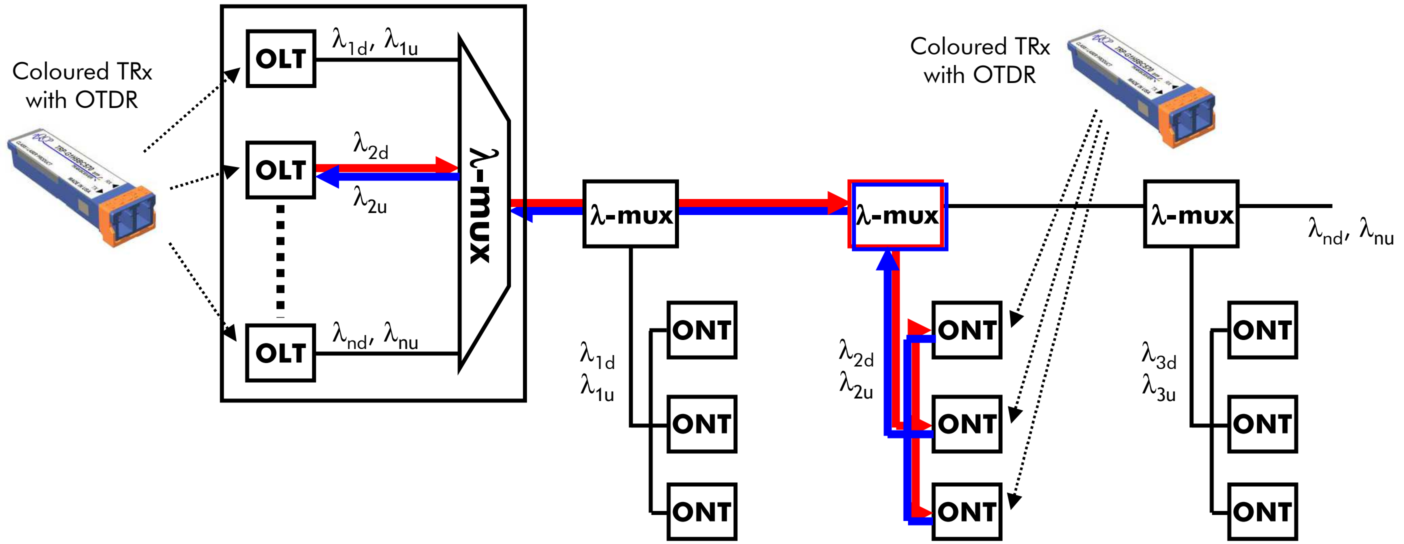
Optical layer monitoring : fiber monitoring through wavelength routing ODN

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

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