TDM vs. WDM co-existence with 10G EPON: update

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Updates to harstead_3ca_2a_1116

1. Consider 1+3 architecture only (1+4 architectures removed)
2. Added use case: TDM vs. WDM co-existence upstream capacity: 1 Gb/s upstream ONUs
3. ONU diplexer: DS/US gap in WDM and TDM co-existence
4. More detail on 25G OLT optical module comparison
5. TDM co-existence impact on wavelength plan: allows for relaxed requirements on filters and lasers.
6. Uncooled ONU 25G DML: updated upstream loss budget
7. Technical feasibility of multi-rate OLT receivers
8. 100G OLT receiver: feasibility of λ_0 receiver sensitivity in TDM co-existence
9. Changed summary accordingly.

Outline

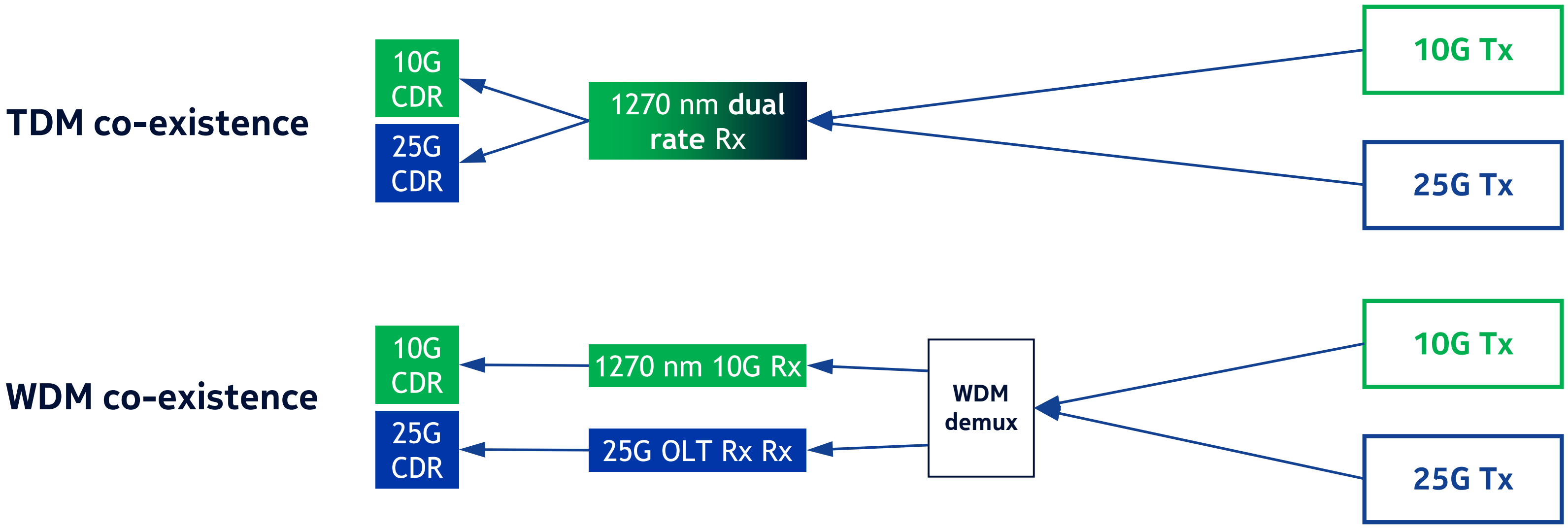
A. Comparison criteria
   1. TDM co-existence: sharing of upstream channel of first wavelength pair
      a) 25G upstream sharing with 10G upstream
      b) 25G upstream sharing with 1G upstream
   2. Cost
      a) DS/US gap and diplexer loss in 25G ONUs
      b) Uncooled DML in 25G/25G ONUs
      c) 25G OLT module complexity
      d) 100G: laser and filter requirements

B. Technical feasibility
   1. 25G uncooled DML
   2. 100G OLT receiver sensitivity
   3. Multi rate OLT receiver

C. Summary

10G/25G sharing of upstream channel of first wavelength pair

TDM and WDM co-existence



Assumptions

- The upstream 25G channel supports 20 Gb/s of real L2 capacity (the actual value is variable depending on traffic conditions, and could be higher or lower)
- For the same content, a 10 Gb/s upstream burst requires 25÷10 = 2.5x more time than a 25 Gb/s upstream burst.

Use case: business users with symmetric ONUs and residential users with 25/10 ONUs on the same PON

- TDM co-existence: 10G and 25G upstream ONUs on the same PON
- Business users have 25/25, 50/50, or 100/100 ONUs and are offered service level agreements (SLAs) with committed information rate (CIR)
- Residential users have 25/10 ONUs.
- Residential U/S traffic is small
  - ~200 kb/s average/subscriber during peak hour. This is negligible in the context of 10G and 25G upstream on a PON.
  - Even if every ONU simultaneously engages in an HD video call @1.5 Mb/s, this is negligible. Residential applications don't generate significant sustained upstream throughput.
- But sometimes there will be large bursts during very large file uploads and especially during speed tests. This is what has to be accommodated.
  - Assume the PON is not engineered to support multiple simultaneous speed tests.
- What is impact on business subscribers' upstream channel capacity compared to WDM co-existence? See chart next slide.
  - Example, if 1 Gb/s U/S service level is offered to residential users, 2.5 Gb/s must be reserved, or 12.5% of λ0 U/S capacity.

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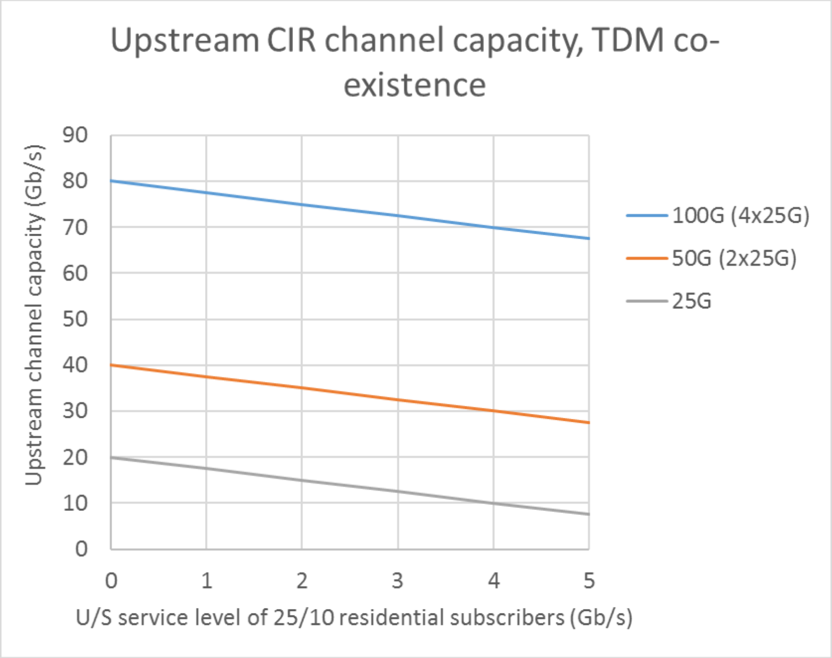
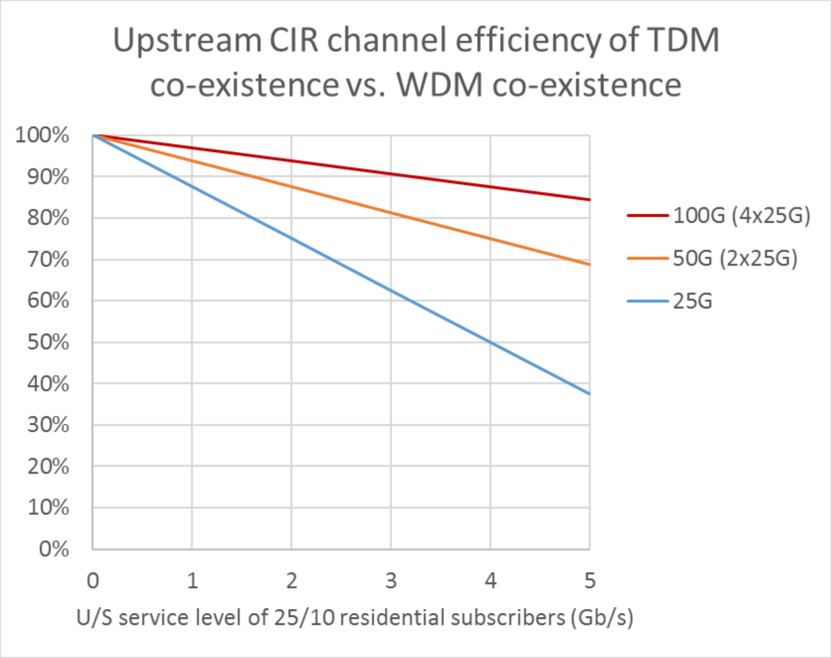
Use case: TDM vs. WDM co-existence upstream capacity





- For 1 Gb/s upstream service levels offered to 25/10 residential subscribers, minimal impact on business subscribers.
- For 5 Gb/s upstream service levels offered to 25/10 residential subscribers, minimal impact on100G business subscribers, but ~60% impact on available CIR for 25G business subscribers

Use case: TDM vs. WDM co-existence upstream capacity: 1 Gb/s upstream ONUs

- Per discussion in San Antonio, CTC indicated that they might require 25/50/100G EPON ONUs to co-exist with 10/1 EPON ONUs, where the upstream 1 Gb/s channel is constrained to 1260-1280 nm.
- In this case, TDM co-existence would require sharing the first 25G upstream channel with 10/1 ONUs
- The analysis on the previous slides is repeated for this case. See next slide.
- The results look the same because **the upstream service levels that can be offered to subscribers is proportional to their upstream ONU bandwidth.**

- When 25/50/100G EPON ONUs co-exist with 10/10 and 10/1 ONUs, then a triple rate 1/10/25G OLT receiver will be required
  - 1/10G dual rate OLT receivers are commercially available today.
  - A 1/10/25G triple rate receiver will be more complex, but it’s not clear that there is new and important technical problem to be solved.

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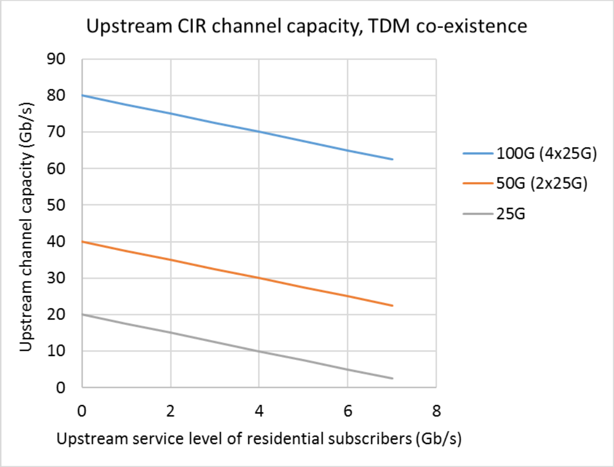
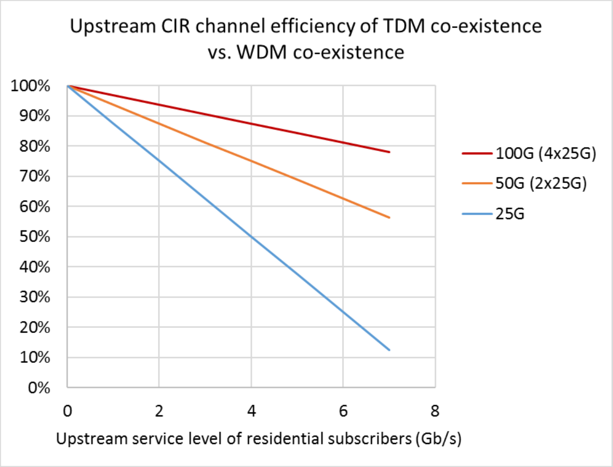
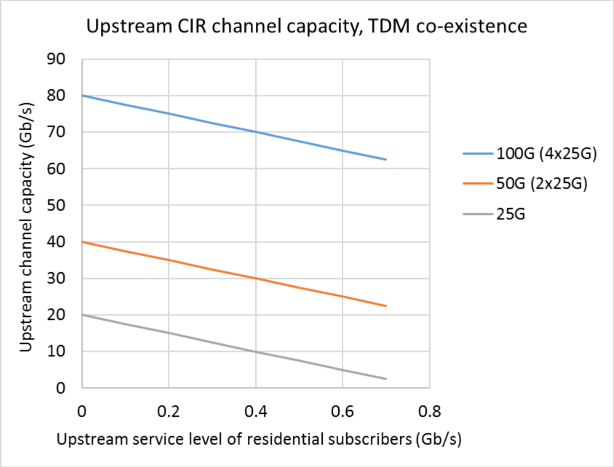
TDM co-existence upstream capacity

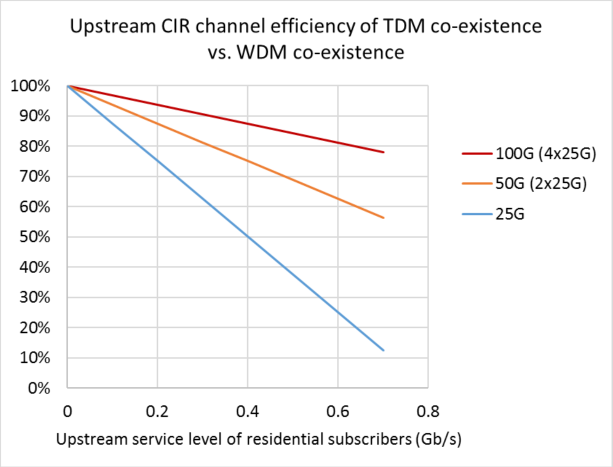
TDM co-existence with 10 Gb/s upstream





TDM co-existence with 1 Gb/s upstream





Cost

TDM co-existence allows for uncooled DML in 25G/25G ONU → cost savings

- TDM co-existence will allow for an uncooled laser in the ONU because 20 nm between 1260-1280 nm is available.
- An uncooled 25G DML TOSA will cost ~40% less than a cooled 25G DML TOSA
- In a 25/25 ONU BOSA, the 25G transmitter will represent the large majority of the cost. If 75%, then, compared to WDM co-existence:

  TDM co-existence will allow for a 33% savings in 25/25 ONU optical module.

TOSA	Relative cost (2020)
10G EML	1
25G uncooled DML	0.8
25G cooled DML	1.4
25G EML	1.8

Source: harstead_3ca_1a_0716.pdf

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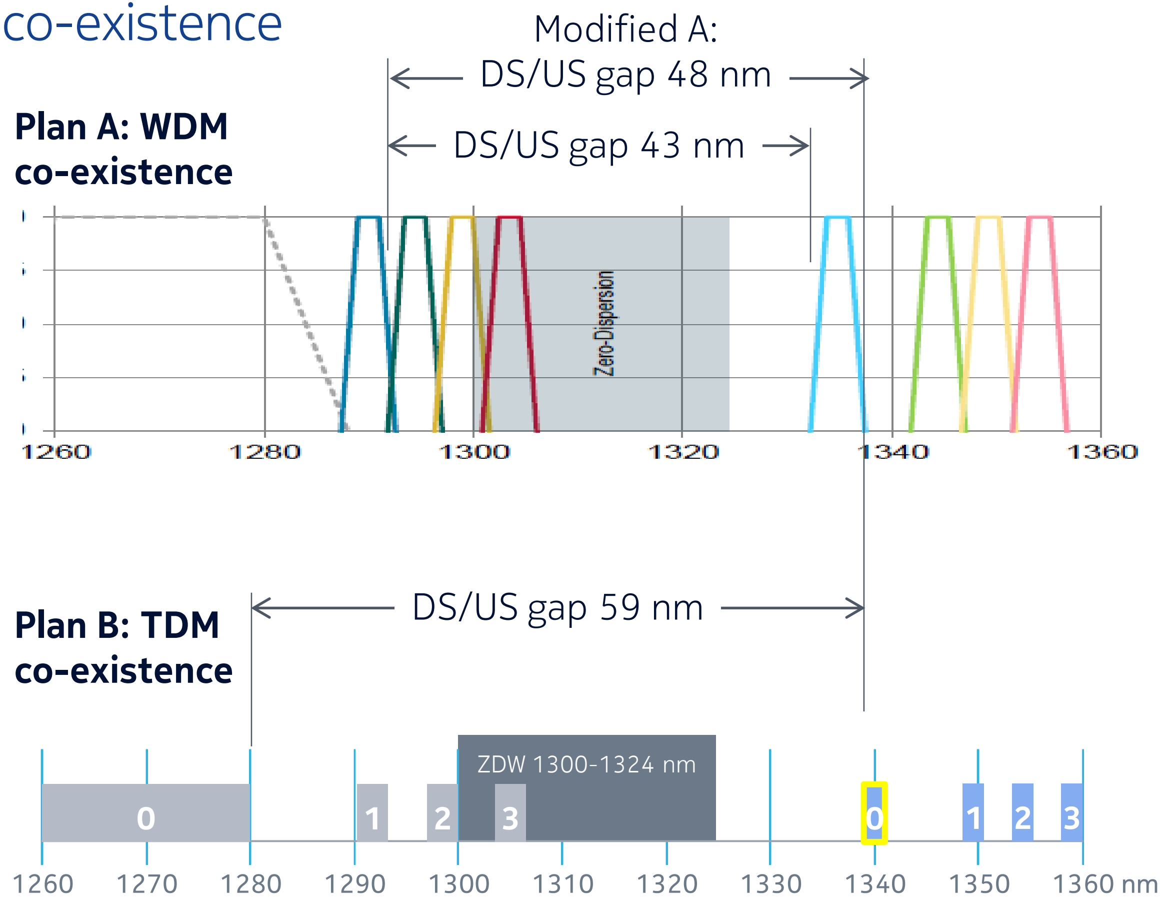
DS/US gap in WDM and TDM co-existence

- DS/US gap starts at
  - WDM co-existence: 1291 nm
  - TDM co-existence: 1280 nm
- Therefore, for the same downstream plan, TDM co-existence will have 11 nm wider DS/US gap.
- This will have an impact on 25G ONU diplexer loss.



DS/US gap: TDM co-existence relaxes power budget → cost savings

- Receiver sensitivity is derived from low cost 10G EPON ONU focus beam BOSA with 295 nm DS/US gap.
- There may be additional filter loss for smaller DS/US gap.

Wavelength plan	10G EPON co-existence	Reference	DS/US gap (nm)	Excess diplexer loss (funada_3ca_1_0117)
A	WDM	johnson_3ca_1a_0916	43 nm	<0.5 dB
Modified A	WDM	previous slide	48 nm	<0.2 dB
Modified Plan B(2)	TDM	harstead_3ca_1_0117	59 nm	0 dB
D	WDM	johnson_3ca_2a_0916	240 nm	0 dB

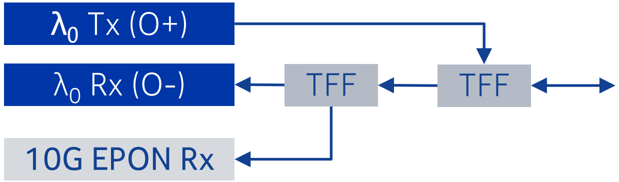
- Of the two all-O-band plans, TDM co-existence will relax the power budget by up to 0.2 dB.

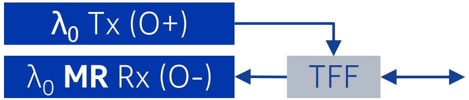
25G OLT optical module architecture: WDM and TDM co-existence with 10G EPON

WDM co-existence

TDM co-existence

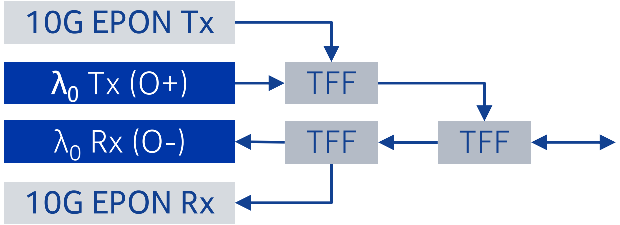
Support 25/10 ONUs
Greenfield optimized

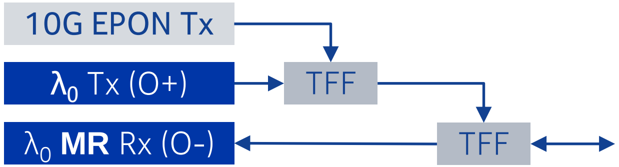




MR = multi-rate (10G+25G or 1G+10G+25G)

Support 10/10 ONUs
Brownfield support





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TDM co-existence allows for simpler 25G OLT module → cost savings

	WDM co-existence		TDM co-existence	
	greenfield	**brownfield**	**greenfield**	**brownfield**
Separate 10G Rx	Yes		✓No	
Number of TFFs	2	3	✓1	✓2
Additional TFF insertion loss*: 25G Rx	0.5 dB	0.5 dB	✓0 dB	✓0 dB

*in addition to standard BOSA. TFF insertion loss: assume 0.5 dB each

✓ = advantage

TDM co-existence may lead to a significantly lower cost 25G OLT module

- Fewer optical components and optical connections
- 0.5 dB better receiver sensitivity (reduces launch power requirements on ONU).

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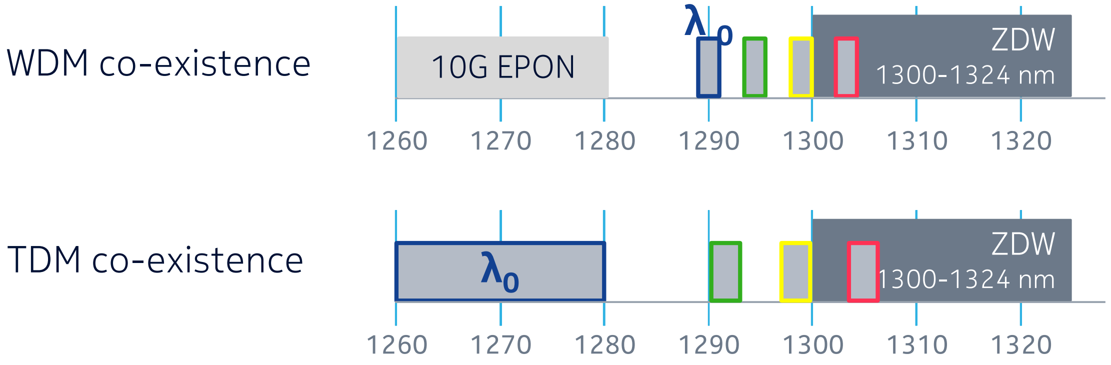
TDM co-existence relaxes requirements of 100G ONU and OLT→ cost savings



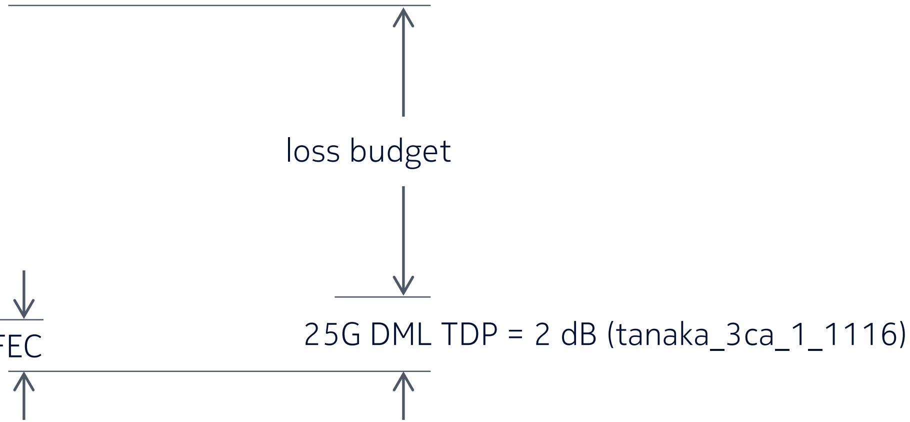
Advantages of TDM co-existence: More available upstream spectrum allows

- 25G OLT
  - Larger upstream λ0-λ1 gap accommodates 10 nm per zhang_3ca_1_1116
- 100G ONU
  - For cooled DML burst operation: 3 nm wavelength tolerance leads to ~25% lower cost than 2 nm, per zhang_3ca_1_1116
- 100G OLT
  - Upstream CS relaxed to support 3 nm wavelength tolerance, per zhang_3ca_1_1116
- Eliminate FWM risk

Technical feasibility

Feasibility of 25G uncooled DML in 25/25 ONU

Loss budget	ONU launch power AVP_{min}
PR20 (24 dB)	**2.0 dBm**
PR30 (29 dB)	**7.0 dBm**



- Uncooled DML launch power easily meets PR20 loss budget.
- For PR30 loss budget, technology improvements will need 1.0 more dB than indicated by harstead_3ca_2a_0716 (6 dBm/ER=6 dB).
  - This does not appear to be overly unlikely over the lifetime of 25G PON.

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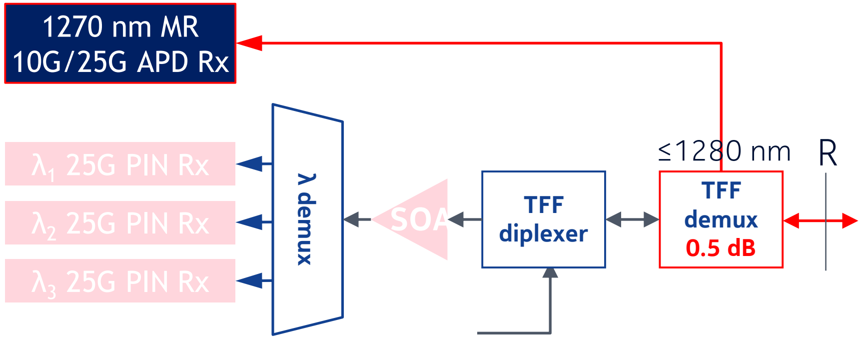
100G OLT receiver: feasibility of λ_0 receiver sensitivity in TDM co-existence (1)

Reference: bonk_3ca_1_0117

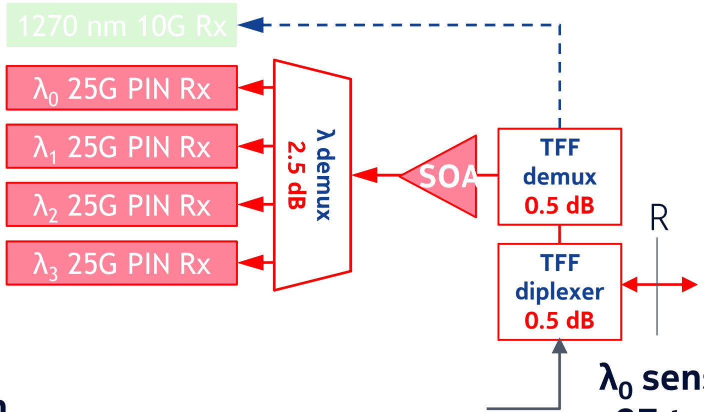
- With the selection of the 1+3 architecture, the 100G OLT must support 1260-1280 nm for $\boldsymbol{\lambda_0}$ in the case of TDM co-existence.
- The SOA→demux→PIN implementation provides significant benefit for $\boldsymbol{\lambda_1}$- $\boldsymbol{\lambda_3}$ but not for $\boldsymbol{\lambda_0}$ in the case of TDM co-existence, due to the 20 nm ASE filter width.
- Let's compare $\boldsymbol{\lambda_0}$ TDM co-existence to $\boldsymbol{\lambda_0}$- $\boldsymbol{\lambda_3}$ WDM co-existence

TDM co-existence



λ0 sensitivity =
-26 to -27 dBm

WDM co-existence



λ0 sensitivity =
-27 to -28 dBm

- λ_0 TDM co-existence has a 1 dB worse performance. Does it matter?

100G OLT receiver: feasibility of λ_0 receiver sensitivity in TDM co-existence (2)

- 100G power budget requires 2 x 2.5 dB = 5 dB more power to overcome 1x4 mux and demux insertion losses.
- The SOA→demux→PIN neutralizes the 2.5 dB demux loss and provides about 0.5/1 dB extra sensitivity relative to WDM/TDM co-existence respectively.
- So gains 3-3.5 dB of the required 5 dB: not adequate to overcome the loss of the 1x4 mux at the 100G ONU.
- In which case,
  - we need post-amps in the 100G ONU anyway.
  - The post amps will probably launch enough power to overcome the 1 dB performance deficit of λ_0 TDM co-existence.

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Feasibility of dual-rate OLT receivers

Dual-rate 1G/10G receiver

- Already commercially implemented. Can be done with static TIA, with some penalty.

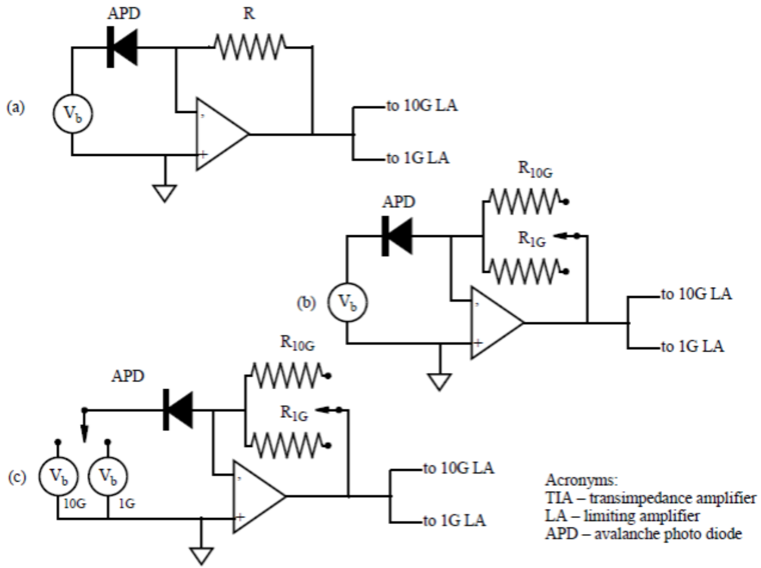
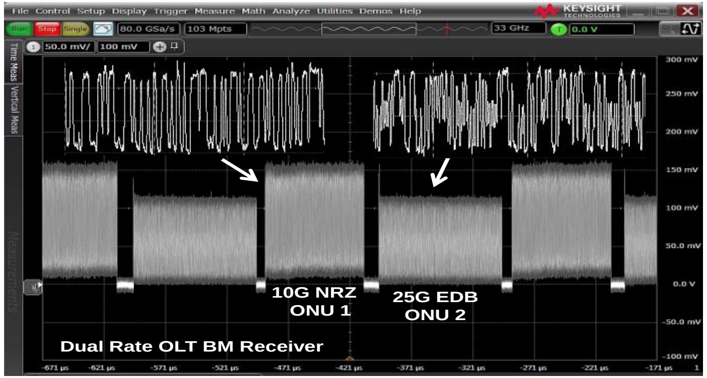


Figure 75A–2—Dual rate APD–TIA implementations: (a) static, (b) half–dynamic, (c) fully–dynamic

Dual-rate 10G/25G receiver

- 2.5x speed range vs. 10x: should be implementable with a smaller penalty.
- Or, a dynamic TIA could be implemented, with theoretically no penalty
- Or, In the case of duobinary detection, only a single static 10G-optimized TIA is required– should be no dual-rate TIA penalty.



10G NRZ is detected as 10G NRZ while 25G NRZ is detected as 25G EDB (houtsma_3ca_1_0516)

Feasibility of triple-rate OLT receivers

- In the case where 1G EPON upstream is limited to 1260-1280 nm, there is the possibility of 1G, 10G and 25/50/100G EPON co-existence.
- If TDM co-existence with 10G EPON is chosen for 25/50/100G EPON, then the OLT will require a triple rate 1G/10G/25G receiver
- A triple rate 1G/10G/25G receiver is feasible:

1. David Li, Ligent. Dynamic TIA plus switchable CDR. Statement is based on experience in 10G EPON design.
2. Jun Zhang, Accelink.
3. Duobinary detection of 25G. Extension of houtsma_3ca_1_0516. Would only require a dual rate 1G/10G receiver design, which exist commercially.

Summary

Summary: TDM co-existence pros and cons and technical feasibility

Pro#1: Lower cost implementation

Element	Advantage
25/25 ONU	• Potential use of uncooled DML: 33% optics cost savings
25G OLT	• Fewer components and connections • Larger upstream λ0-λ1 gap for lower cost filtering.
25G power budget	• Wider DS/US gap: up to 0.2 dB advantage • One less filter in OLT: 0.5 dB advantage • Total advantage: 0.7 dB
100G ONU	• Relaxed wavelength tolerance (3 nm vs. 2 nm): 25% transmitter cost savings

Cons:

1. **λ0 25G upstream capacity shared with lower speed ONUs**

   Significant but only when very high upstream service levels are offered on those low speed ONUs

2. **10G EPON and 25/25/100G EPON must use the same OLT line card**

   But this was the driver for adopting 1+3 architectures

Pro #2: No FWM risk with 1300-1324 nm ZDW fiber

Technical feasibility: in the first analysis, appears to be OK:

- Receiver sensitivity for λ0 in 100G OLT
- Multi-rate receiver implementation

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Back-up: 100G OLT optical modules supporting 10G EPON