The Case for TDM Coexistence in O-Band

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TDM coexistence vs. WDM coexistence

- Given previous arguments that having all channels in O-band is the best performing and lowest cost choice for NG-EPON wavelength plan (johnson_3ca_1_0117), the remaining choice is whether to implement 10G-EPON upstream coexistence with WDM or TDM.
- WDM coexistence is the default choice for a new PON standard since it preserves all of the available capacity for subscribers to the new PON, but the <u>cost of that incremental capacity</u> must be considered.
- For TDM coexistence to be chosen to the exclusion of WDM coexistence, there should be <u>significant advantages</u> to compensate for the incremental loss of capacity inherent in TDM.
- In this contribution, we present arguments that TDM coexistence confers significant cost and performance advantages over WDM, and is the best choice for NG-EPON.

The case for TDM coexistence

- Whether TDM is sufficient for coexistence with 10G-EPON without significantly impacting 25/50/100G upstream capacity is critical to the wavelength plan decision.
  - Harstead_3ca_2a_1116 showed that TDM coexistence has little impact on 25/50/100G upstream capacity for expected 10G service levels (<1Gb/s).
- TDM coexistence brings several important advantages over WDM
  - Sharing 1270±10nm spectrum with 25G US0 channel allows wider US channel spacing and laser accuracy, resulting in lower ONU optics cost
  - Enables the possibility of a low-cost uncooled upgrade path from 25/10G to 25/25G ONUs as upstream capacity demand grows.
  - Enables smaller, lower cost OLT optics using a single 10/25Gb/s dual-rate RX without extra coexistence splitter loss.
- TDM has minor challenges, but they are outweighed by the significant advantages listed above.
  - Demux with mix of passband width and channel spacing – solvable using TFF demultiplexers.
  - Dual-rate 10/25G burst-mode TIA is to be developed, but not considered high risk. Proprietary tri-rate 1/10/25G TDM can also be supported.
  - Lower sensitivity of optically amplified 100G RX with 20nm passband – Bonk_3ca_1_0117 predicts that this is a wash vs APD Rx if the 1270nm signal is demultiplexed with low insertion loss.

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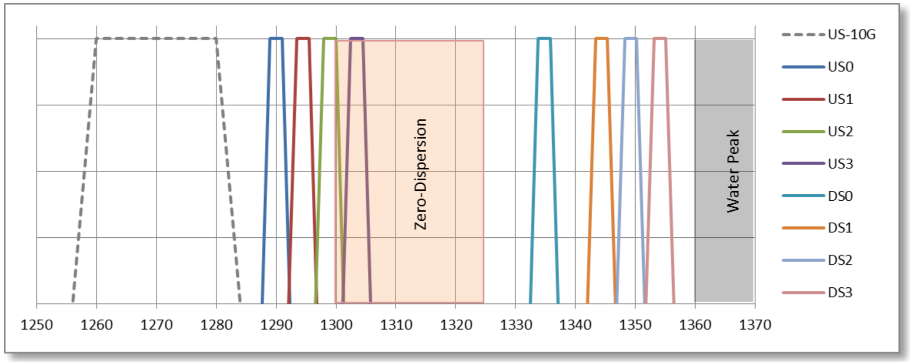
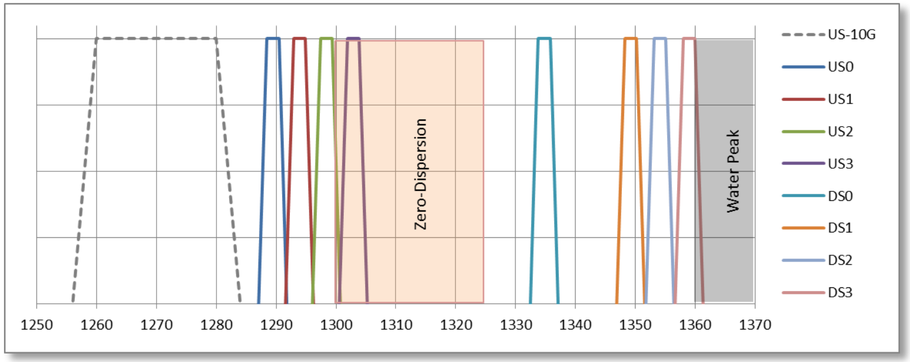
Plan A with WDM coexistence



Original Plan A (johnson_3ca_1_0916)

- 800GHz channel spacing US and DS
- ±1nm laser accuracy US and DS
- Narrow US-DS gap for 25G ONU
- Marginal DS0-DS1 guardband
- US0 marginal to 10G-EPON US
- US2 too close to ZDF region



Revised Plan A

- Shift US channels by +100GHz so US2 > 0.64nm from ZDF. Trade-off vs. smaller 10G/US0 gap.
- Increase DS0-DS1 spacing to 2.4 THz (12.4nm gap). Trade off vs. DS3 closer to 1360nm water peak region.

Even with revisions the significant costs of 2nm US passband remain.

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Discussion of Plan A with WDM coexistence

- WDM coexistence can be achieved with all channels in O-band, but there are some aspects that are not ideal.
- Upstream:
  - Channel spacing is 800GHz which increases ONU mux cost (Traverso_03_0308, 802.3ba).
  - Requires 2nm passband which increases ONU laser cost and may be too narrow to support BM thermal transient (zhang_3ca_1_1116).
  - US0 must be cooled, increasing entry-level 25/25G ONU cost (harstead_3ca_1a_0716).
  - Narrow gap between 10G and US0 increases OLT filter cost.
- Downstream:
  - Channel spacing is 800GHz, increasing ONU demux cost.
  - DS3 is close to edge of water peak so loss could be high. Can shift to lower wavelength at the expense of ONU blocking filter guardband.
- Most of the upstream issues can be relieved by the use of TDM coexistence. These are the most important since they have the largest effect on ONU cost.

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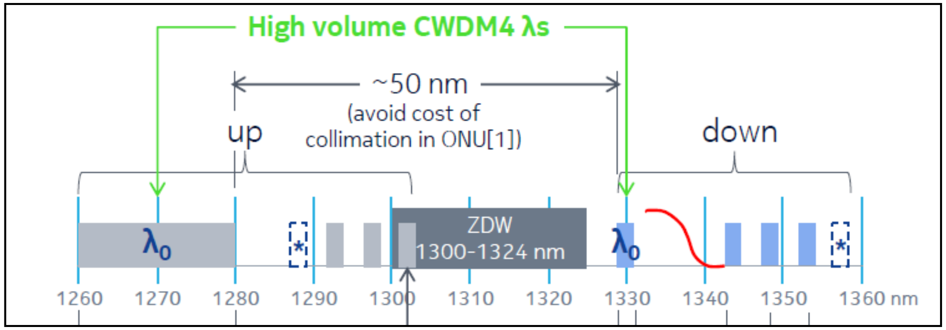
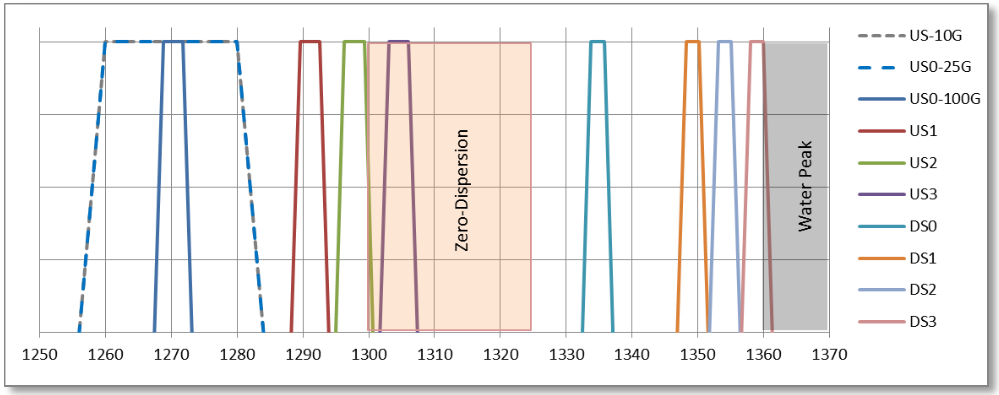
Plan B with TDM coexistence

Harstead_3ca_2b_0916

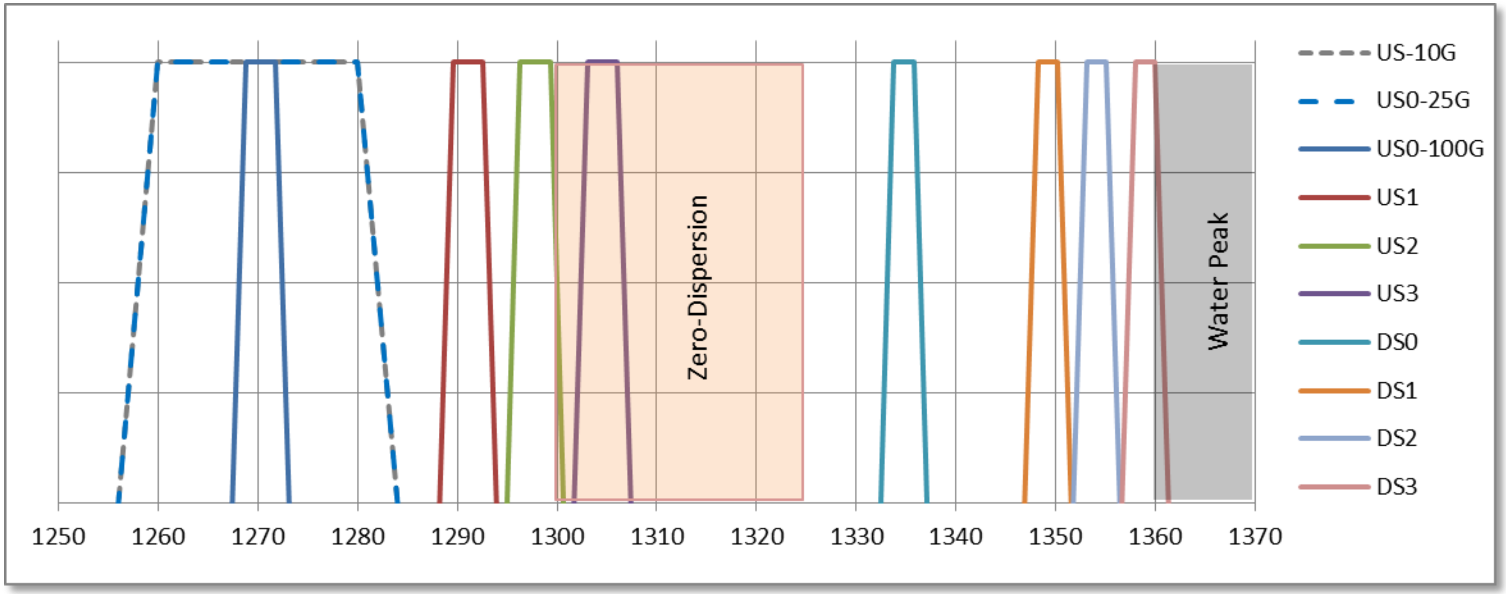




Revised Plan B

- Relative to original Plan B keep the most important aspects:
  - TDM coexistence with 10G-EPON
  - Uncooled or semi-cooled 25G US0 is possible
- Optimize channel spacing and passband width for cost and performance:
  - Increase 100G US CS to 1.2THz and PB width to 3nm, enabling ±1.5nm laser accuracy
  - Increased guardband to US-10G and ZDF compared with Plan A
  - Same DS channel plan as the revised Plan A

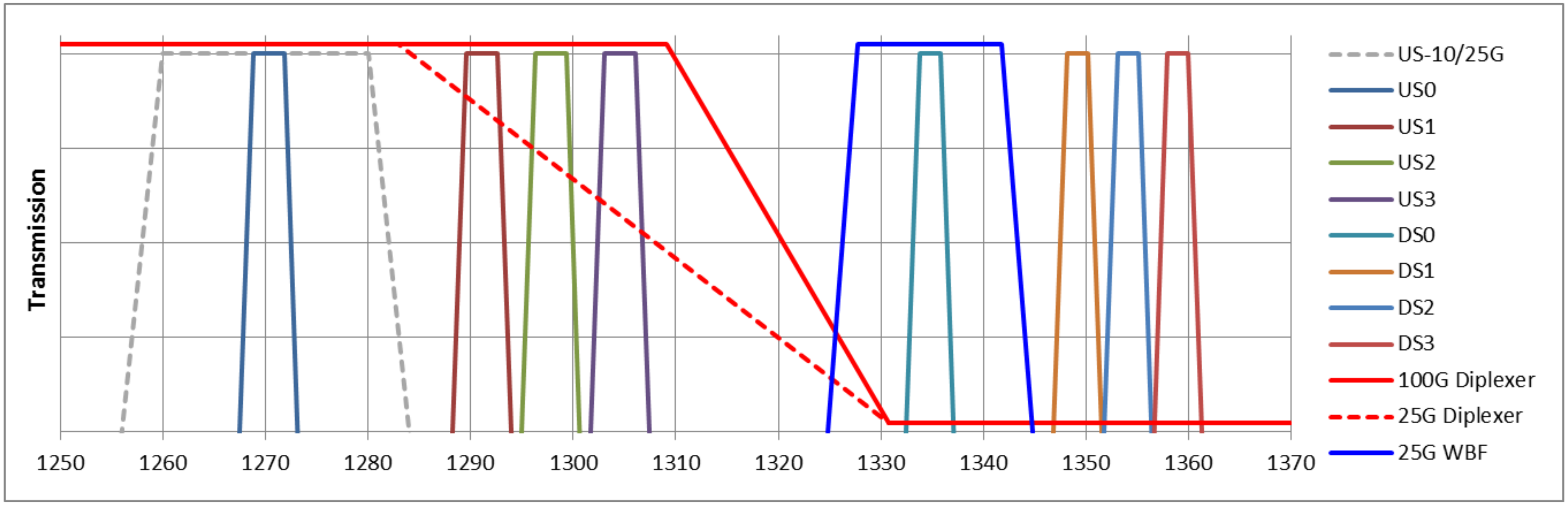
Details of revised Plan B channel plan



Lane	Center Freq (THz)	Center WL (nm)
US0-25G	236.06	1270.00
US0-100G	236.00	1270.31
US1	232.20	1291.10
US2	231.00	1297.80
US3	229.80	1304.58
DS0	224.60	1334.78
DS1	222.20	1349.20
DS2	221.40	1354.08
DS3	220.60	1358.99

- Channel spacing: 800GHz (DS), 1200GHz (US)
- Laser accuracy: ±1nm (DS), ±1.5nm (100G US), ±10nm (25G US)
- DS-US gap (min): 53.8nm (25G), 27.7nm (100G)
- DS0-DS1 gap (min): 12.4nm
- US0-US1 gap (min): 9.6nm (uncooled US0)
- US2 to zero dispersion range (min): 0.7nm (124GHz)

Plan B ONU optical filtering



- The 53.8nm minimum guardband enables 25/25G and 25/10G ONU diplexers using low-cost focused beam BOSA optics with < 0.1dB excess loss. (Funada_3ca_1_0117)
- The 27.7nm minimum guardband for 100G ONU diplexer dictates use of collimated beam optics. This is acceptable since standard TO-BOSA construction may not apply and 100/100G will be a premium business service.
- The 12.4nm DS0-DS1 gap allows for low-cost 25G blocking filter with focused beam.

Discussion of Plan B with TDM coexistence

- TDM coexistence Plan B addresses nearly all of the ONU cost issues identified in WDM coexistence Plan A.
- The re-use of the 1260-1280nm spectrum for US0 not only allows for the possibility of an uncooled 25/25G ONU but reduces the cost of cooled ONUs as well.
  - Harstead_3ca_1a_0716 vendor input predicts uncooled 25G DML TOSA cost is 57% of a cooled 25G DML TOSA.
  - Zhang_3ca_1_1116 vendor input predicts the cost of laser die with ±1.5nm accuracy is 69% of the cost of laser die with ±1nm accuracy.
  - Even if uncooled laser performance doesn't meet the power budget requirements, cooled DML with relaxed wavelength specs can be used.
  - Uncooled laser performance is expected to improve over the next 5 years so it is highly likely that they will be able to be deployed.
- 3nm passband width is wide enough to support burst-mode thermal transients (Zhang_3ca_1_1116).
- The 53.8nm minimum guardband enables 25/25G and 25/10G ONU diplexers using low-cost focused beam BOSA optics with < 0.1dB excess loss. (Funada_3ca_1_0117)

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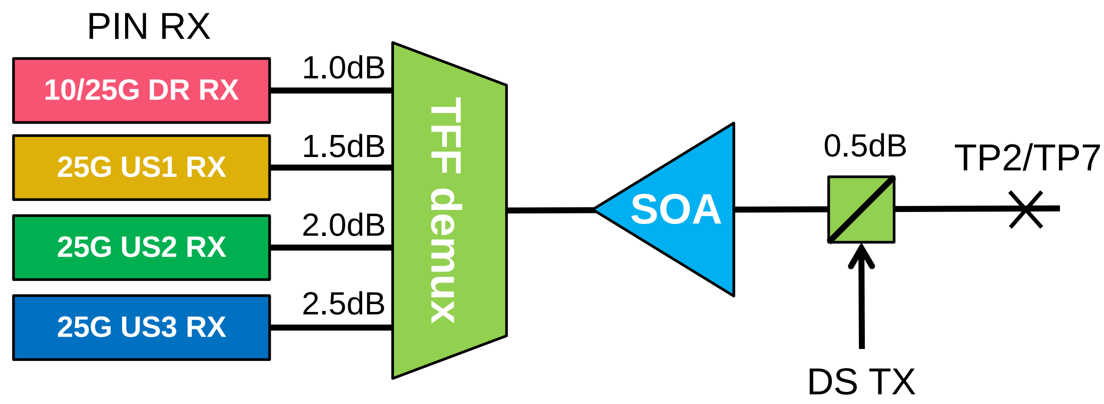
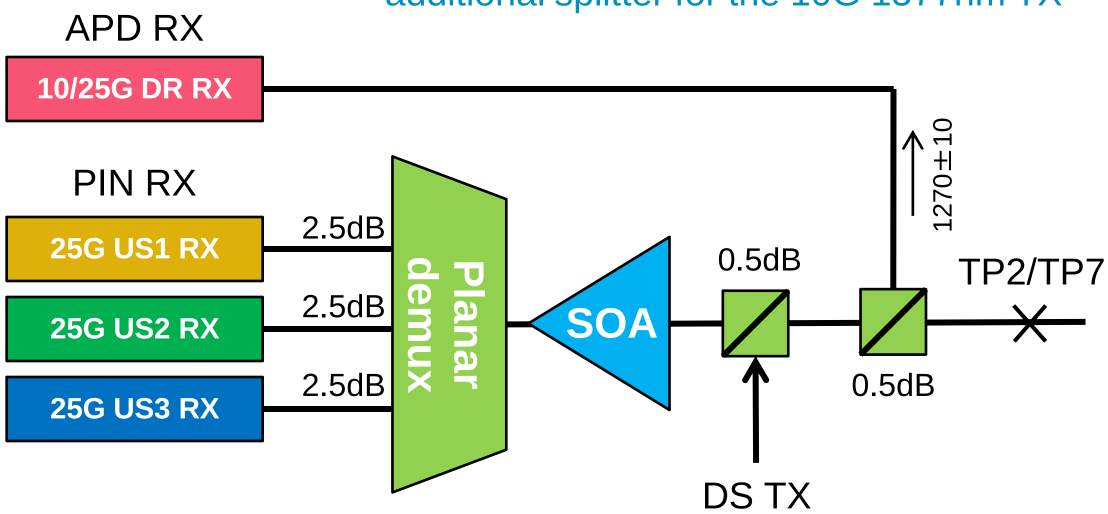
100G OLT RX configurations (greenfield)



Brownfield 10/10G ONU support requires an additional splitter for the 10G 1577nm TX



Dual-Rate SOA-PIN RX

- TFF demux filters can have arbitrary center frequencies and pass-band widths.
- First channel has lowest insertion loss, < 1dB.
- Last channel has < 2.5dB insertion loss.
- Compact ROSA integration

Dual-Rate APD RX

- Split off 1270nm signals before SOA.
- Low insertion loss to 10/25G dual-rate APD RX
- More difficult to integrate separate 1270nm splitter

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Straw-man power budget

- For all channels in O-band, the power budget is independent of details of the exact channel frequencies.
- Of interest for Plan B is how close are we to being able to implement 25/25G ONUs with uncooled DMLs.
- Only the 25G OLT case is analyzed here since optical amplification will be used with 100G OLTs to provided any needed gain.
- Transmitter assumptions (includes BOSA diplexer loss)
  - OLT cooled EML BOSA: Pavg > 5.5dBm, ER > 8dB, TDP < 1.5dB
  - ONU cooled DML BOSA: Pavg > 8dBm, ER > 6dB, TDP < 1.5dB
  - ONU uncooled DML BOSA: Pavg > 6dBm, ER > 5dB, TDP < 1.5dB
  - 100G mux loss = 2.5dB
- Receiver assumptions (includes BOSA diplexer loss)
  - No enhanced FEC
  - ONU BOSA: Sensitivity < -24 dBm
  - OLT BOSA: Sensitivity < -24dBm for APD or SOA-PIN
  - 100G demux loss = 1dB for US0(1270nm), 2.5dB for US1-3

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Power budget: 25G uncooled ONU – 25G OLT

Parameter	DOWN	UP	DOWN	UP	Unit
Insertion loss, max	24	24	29	29	dB
Transmitter - 25G	Cooled EML	Uncooled DML	Cooled EML	Uncooled DML	
ER, min	8	5	8	5	dB
AVP, min	5.50	6.00	5.50	6.00	dBm
OMA, min	7.12	6.17	7.12	6.17	dBm
Rx Stressed OMA, min	-16.88	-17.83	-21.88	-22.83	dBm
TDP, max	1.5	1.5	1.5	1.5	dB
Rx OMA, min	-18.38	-19.33	-23.38	-24.33	dBm
Receiver - 25G	DS0	US0	DS0	US0	
AVP Sensitivity, min	-24.00	-24.00	-24.00	-24.00	dBm
OMA Sensitivity, min	-22.38	-23.83	-22.38	-23.83	dBm
Margin: 25G - 25G	4.00	4.50	-1.00	-0.50	dB

- PR20 is no problem. There is a 1dB gap for PR30 downstream due to the limited output power of the EML TX.
  - This is a common issue for all wavelength plans, not specific to this one.
  - Lower EML ER can be traded off for higher OMA – topic for future study.
- There is a 0.5dB gap for PR30 upstream with uncooled DML which can be closed by a 0.5dB improvement in FEC gain.
- 0.5dB must be added for 10/10G ONU support (brownfield) to account for the additional 10G/25G TX splitter loss, so uncooled power needs 0.5dB improvement.

Summary

- Given previous arguments that having all channels in O-band is the best performing and lowest cost choice for NG-EPON wavelength plan (johnson_3ca_1_0117), the remaining choice is whether to implement 10G-EPON upstream coexistence with WDM or TDM.
- Based on the arguments given in this contribution, a TDM coexistence plan has significant cost advantages over WDM due to the limited usable spectrum between the 10G upstream and the zero dispersion window.
  - WDM coexistence dictates the use of 800GHz channel spacing with 2nm passband width which increases ONU optics cost starting with entry-level 25/25G ONUs.
  - TDM coexistence not only increases upstream channel spacing and passband width by 50% but enables the possibility of using uncooled DMLs which are the single most powerful tool for reducing ONU cost.
  - WDM coexistence should only be chosen if service providers consider it to be essential based on 10G and 25G service level requirements.
- The task force is urged to adopt TDM coexistence in the upstream direction as the baseline for the P802.3ca standard.
  - The revised Plan B shown on slide 7 is one proposed implementation that meets the necessary performance requirements.
  - Small changes to the center frequencies and passband widths can be discussed during the drafting process without affecting the overall benefits of the plan.

Proposed motion

- Motion #2: The P802.3ca standard shall specify that the first 25G upstream wavelength shall be 1270±10nm and shall coexist with 10G-EPON by time-division multiplexing (TDM).

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Thank You!