Security Level:

100G-EPON Wavelength Plan solution candidates

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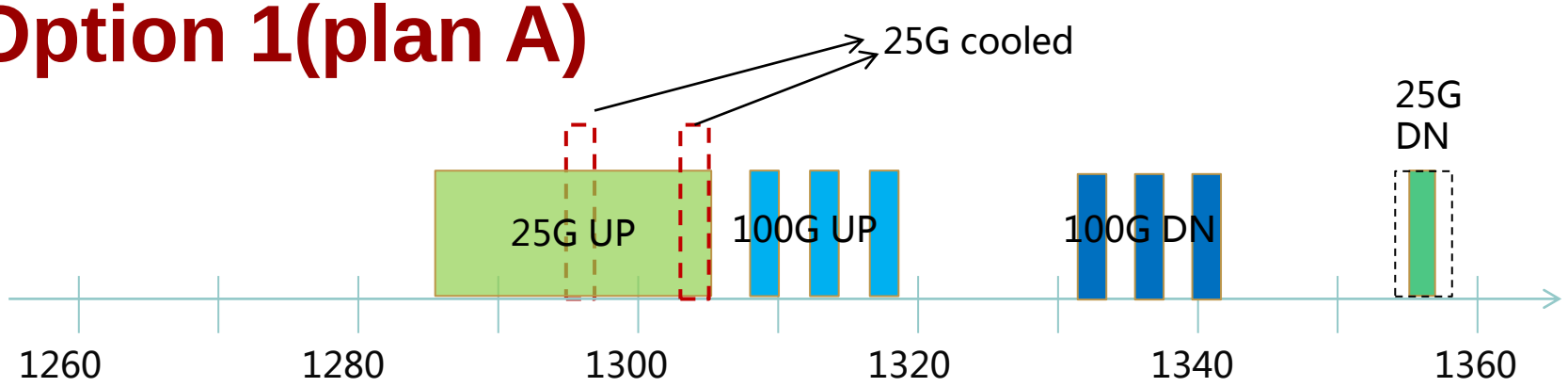
Wavelength plan consideration principle

- Meeting different operators' requirement as possible
  - 10G->25G->50G->100G are too small steps
  - Some operators may skip 25G PON OLT to 100G PON directly
  - Only 1+3 solution can support operators skipping previous generations OLT
- Low cost for both 25G and 100G EPON
  - The compromise of 25G and 100 EPON cost must be considered.
- Encourage the key optical component to share the industry chain with ITU , and re-use the existing industry chain as much as possible (such as the components in Date Center)

Low cost consideration factor

- Low cost of ONUs should be the first priority
  - If we must choose some thing expensive, it should be in the OLT
  - Uncooled ONUs are more promising (cooled transmitter is 50% more expensive) (he_3ca_1_0716.pdf)
  - Collimated beam in ONU should be avoided as possible
- The cost of 25G EPON should be close to 10G EPON
  - The bandwidth is just 2 times more of 10G EPON, the cost difference should be even smaller
  - More than 35nm DS/US gap, more than ~10nm gap for ONU receiver are preferred
- Solutions easy to cost down should be preferred
  - Cost due to complex technology is easier to reduce compared with due to long labor time
  - Solutions easy for optical integration will have more chance to cost reduction

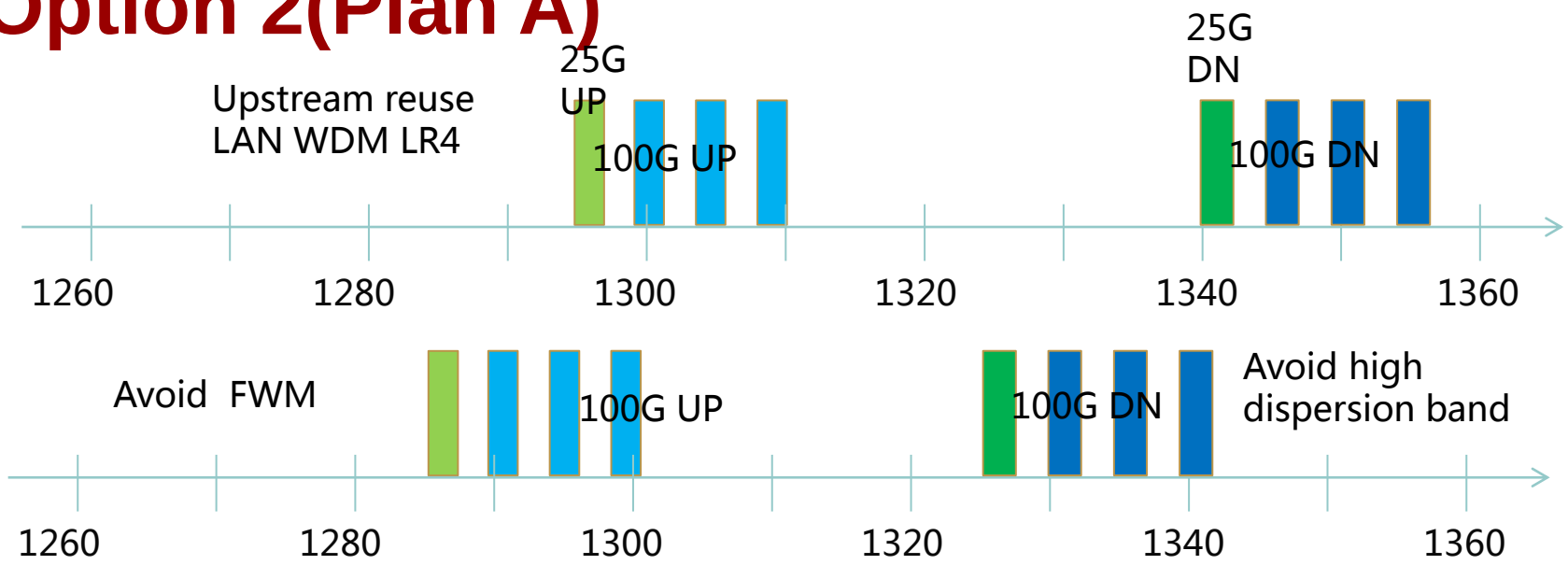
Option 1(plan A)



- 25G DS/US： 1356.5+/-2.5 ， 1295.5+/-10
- 100G DS/US： （ 1342.0,1337.2,1332.4 +/-1 ， ） ，
  （ 1309.1,1313.7, 1318.3 +/-1, ）
- Pros：
  - All wavelength in O-band, NRZ modulation for all channels
  - Upstream in O- band, enable DML modulation , enable uncooled ONU for 25G.
  - Coexists with 10G EPON by WDM, high upstream efficiency
  - 25G DS/US gap>50nm， 25G DS channel separation >10nm
- Cons：
  - 100G ONUs need a TEC for every channel
  - Non-equal channel spacing for 100G

	f(THz)	λ(nm)
25G UP	233	1286.663
	232.2	1291.096
	231.4	1295.559
	230.6	1300.054
	229.8	1304.58
100G UP	229	1309.137
	228.2	1313.727
	227.4	1318.349
	226.6	1323.003
	225.8	1327.69
100G DN	225	1332.411
	224.2	1337.165
	223.4	1341.954
	222.6	1346.777
	221.8	1351.634
25G DN	221	1356.527
	220.2	1361.455
	219.4	1366.42

Option 2(Plan A)



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	224.2	1337.165
100G DN	223.4	1341.954
	222.6	1346.777
	221.8	1351.634
	221	1356.527

- Pros :
  - 25G/100G equal channel spacing, all channel in O-band
  - Re-using existing LR4 transmitters
- Cons :
  - 25G ONU needs collimated beam, cooled transmitter, very difficult to block other channels
  - +/- 1nm operating wavelength range is relative tight for lasers.

Reuse LAN WDM LR4 vs FWM

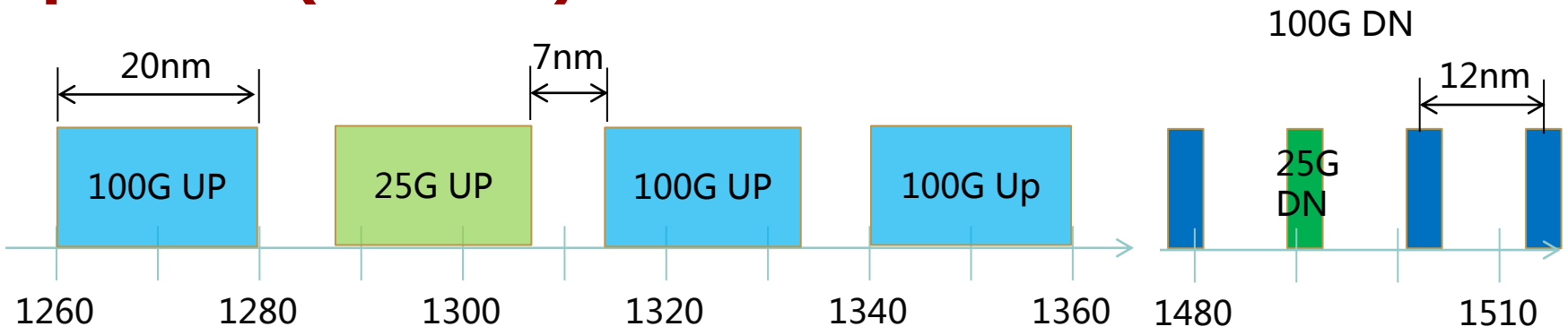
- Advantage of same wavelength grid with LR4:
  - Reusing the same platform and existing optics, less R&D cost
  - Larger volume , accelerating cost down process, lower price
  - Quicker industry chain availability
- FWM penalty is indeed possible to happen in theory , but only in extremely worst case:
  - Exactly equal channel spacing, zero dispersion wavelength coincides in the middle of 4 wavelength, the polarization are same for four channels, enough power and suitable fiber length
  - No FWM penalty has been observed nor published in LAN WDM products. Though they have been widely deployed for several years with enough big volume.
- FWM can be prevented even from the theory:
  - Slightly offset one of the middle wavelength
  - Rotating one polarization of one channels
- **Strongly suggest we do more investigation on FWM (including FWM preventing) before we make a decision if we use 800GHz channel spacing.**

Power levels of type A

	25G EPON	100G EPON
OLT Tx power (dBm)	6	7
ONU Rx sensitivity(dBm)	-25	-24
TDP (dB)	2	2
ONU Tx power (dBm)	6	4
OLT Rx sensitivity(dBm)	-25	-27
TDP (dB)	2	2

- Some suggested power levels for initial discussion

Option 3(Plan D)

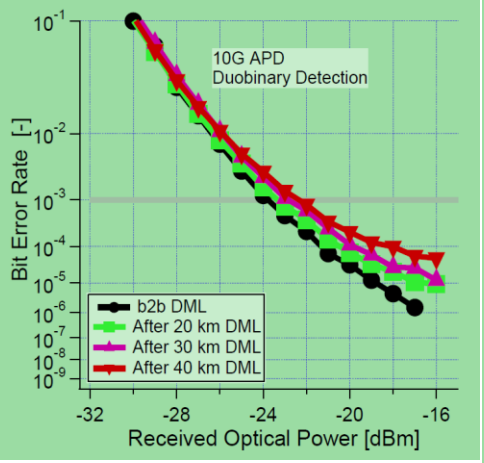


- 25G DS/US： 1491 +/-2 nm， ，1297+/-10nm
- 100G：（1479, 1503, 1515 +/-2）， （ 1350，1270，1323 +/-10）
- Pros：
  - Both 25G /100G ONUs can be uncooled.
  - 100G OLT can share one TEC for four channels, suitable for optics integration (Enable future cost down and high ports density)
  - 25G /100G equal channel spacing, sufficient channel spacing for all 100G channels, enough DS/US separation， no collimated beam, no challenging on ONU guard band requirement.
  - 25G PON coexists with 10G-EPON by WDM，The last channel of 100G coexists with 10G by TDM
- Cons：
  - Dispersion in downstream need to be migrated for 20km(such as ODB，EDB are need in DS)
- Plan D is one most suitable solution for 10km spec.

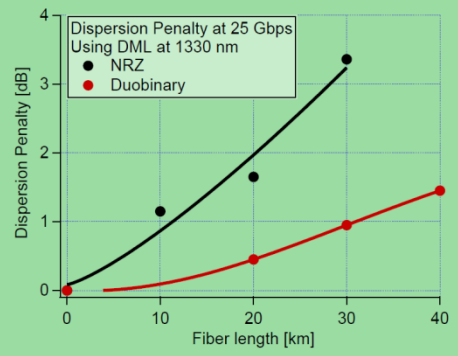
Small dispersion in O+ band for DML

Duobinary Detection Results

Dispersion (ps/nm)	Dispersion Penalty (dB)
+17.1 (20 km)	0.4
+34.2 (30 km)	0.9
+51.3 (40km)	1.4



Dispersion Tolerance NRZ versus Duobinary as function of fiber length for 25G DML at 1330 nm



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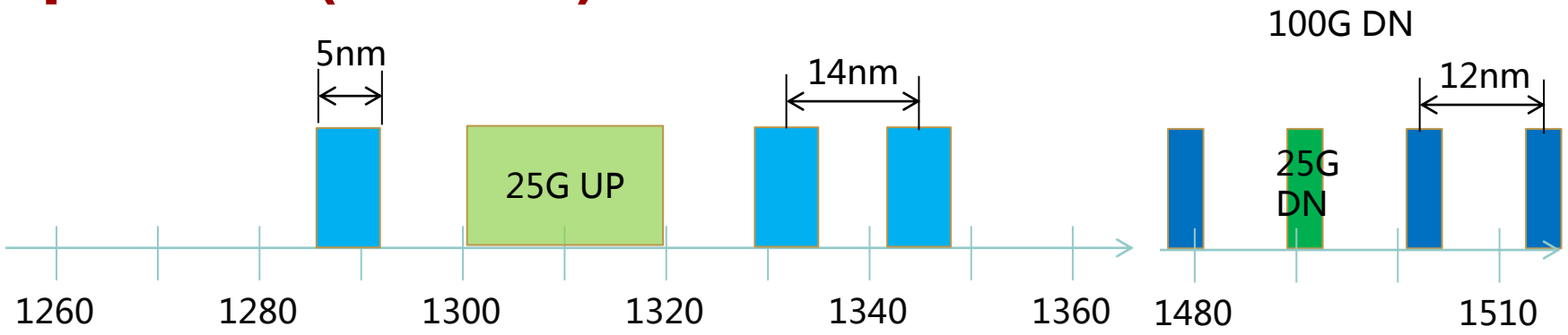
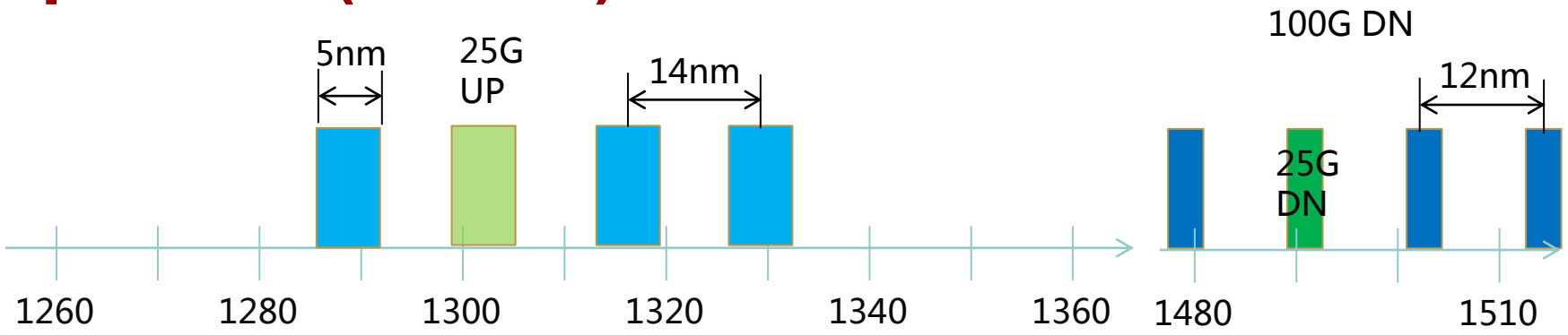
- There are some small dispersion issue for 25G DML laser in O+ band (above 1320nm) for 20km, Duo binary detection can help to overcome them.
- A light EDC also can help to overcome the small dispersion.
- For 10km scenario, NRZ detection can be used directly for 25G DML.

Option 3’(Plan D)



- 25G DS/US： 1491 +/-2 nm， 1310+/-10nm
- 100G： （1479, 1503, 1515 +/-2 nm） ，（ 1288.5，1331.5，1345.5 +/-2.5 nm ）
- This plan is similar with previous option 3, the advantage is that all 4 channels coexists with 10G EPON by WDM.
- 100G EPON ONU can be a shared TEC.
- 25G EPON re-use existing GPON/EPON wavelength (better laser gain material availability， utilizing existing deployed WDM1r.)

Option 3”(Plan D)



- 25G DS/US： 1491 +/-2 nm， 1301.5+/-2.5nm
- 100G： （1479, 1503, 1515 +/-2 nm） ，（ 1287.5，1315.5，1329.5 +/-2.5 nm）
- This plan is similar with previous option 3”, the only difference is that 25G ONU needs to be cooled and only 5nm operating wavelength range.
- The advantage is that all upstream wavelength are in very small dispersion range in O band.

Operating wavelength range 5nm VS 2nm

- 5nm transmitter operating wavelength range have a lot of advantage versus only +/-1 nm :
- The fabrication wavelength of laser chips distributes in +/- 3nm usually.
- 5nm will save the cooled transmitter cost by a lot

Type(10G)	DML	Cooled DML，5nm	Cooled DML，2nm	EML
Cost	1X	1.5X	2.5X	5.5X

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Ltd. Accelink

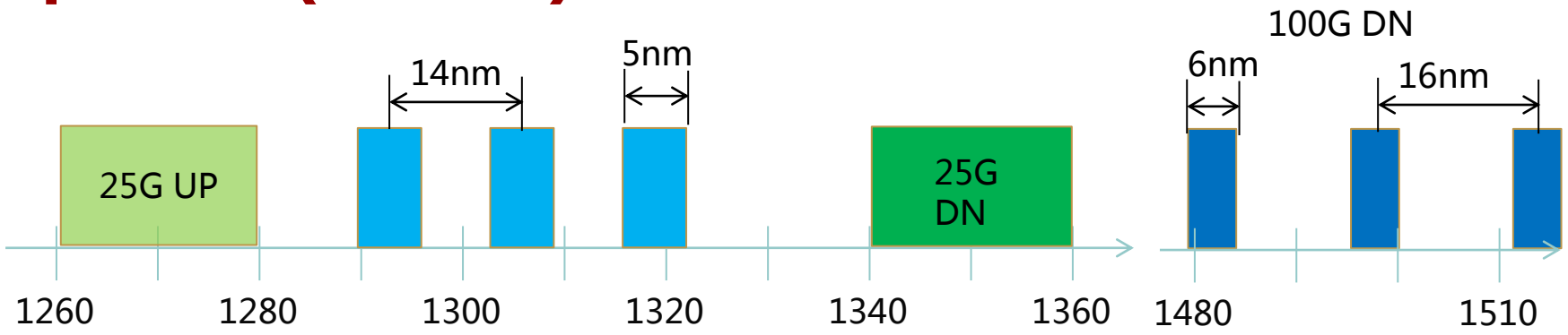
- The high yield of laser chips with 5nm wavelength range will enable a shared cooler for 4 channels, which is easy for optical integration.
  - The yield is much more important for integration due to the total yield is the multiplication of single channel.

Power levels of type D

	25G EPON	100G EPON
OLT Tx power (dBm)	7	8
ONU Rx sensitivity(dBm)	-24	-23
TDP (dB)	2	2
ONU Tx power (dBm)	6	4
OLT Rx sensitivity(dBm)	-25	-27
TDP (dB)	2	2

- Some suggested power levels for initial discussion

Option 4(Plan E)



- 25G DS/US： 1350 +/-10 nm， ，1270+/-10nm
- 100G：（1483, 1499, 1515 +/-3.0nm）， （ 1291.5，1305.5，1319.5 +/-2.5nm）
- Pros：
  - All 25G downstream and upstream are in O-band, 20nm for 25G downstream/upstream.
  - All 100G EPON upstream are in O- band which are suitable for DML laser.
  - Enough bandwidth and channel guard band for all 8 channels, which will relax the optics requirement by a lot .
- Cons：
  - For 100G downstream, 1 channel O band while 3 channels in S band looks quite ugly!
  - 25G upstream re-use the 10G upstream wavelength, which will result in low upstream efficiency and complex optics when coexists with previous 10G PON systems.
  - 3 downstream channels need dispersion migration .

Power levels of type E

	25G EPON	100G EPON
OLT Tx power (dBm)	6	8
ONU Rx sensitivity(dBm)	-25	-23
TDP (dB)	2	2
ONU Tx power (dBm)	6	4
OLT Rx sensitivity(dBm)	-25	-27
TDP (dB)	2	2

- Some suggested power levels for initial discussion

Wavelength plan summary(25G)

25G EPON								
	item	Transmitter operating bandwidth	channel guard band(Rx)	uncool or cool	Modulation Format	Need collimated beam or No?	Coexistence with 10G	Note
Option 1	OLT	+/-2.5 nm	5.5nm	cooled	NRZ	No	WDM	
	ONU	+/-10 nm	11 nm	uncool	NRZ	No		
Option 2	OLT	+/-1 nm	2.5 nm	cooled	NRZ	No	WDM	Upstream reusing existing LR4 wavelength
	ONU	+/-1 nm	2.5 nm	cooled	NRZ	Yes		
Option 3	OLT	+/-2 nm	7 nm	cooled	Duo Binary	No	WDM	NRZ for 10km
	ONU	+/-10 nm	8 nm	uncool	NRZ	No		
Option 4	OLT	+/-3 nm	9 nm	uncool	NRZ	No	TDM	
	ONU	+/-10 nm	10 nm	uncool	NRZ	No		

Wavelength plan summary(100G)

100G EPON								
	item	transmitter operating bandwidth	channel guard band(Rx)	uncool or cool	Modulation Format	Need collimated beam or No?	Coexistence with 10G	Note
Option 1	OLT	+/-1 nm	2.5nm	cooled (4 TECs)	NRZ	Yes	WDM	non-uniform grid
	ONU	+/-1 nm	2.5nm	cooled (4 TECs)	NRZ	Yes		
Option 2	OLT	+/-1 nm	2.5 nm	cooled (4 TECs)	NRZ	Yes	WDM	Upstream reusing existing LR4 wavelength
	ONU	+/-1 nm	2.5 nm	cooled (4 TECs)	NRZ	Yes		
Option 3	OLT	+/-2 nm	7 nm	cooled (1 share cooler)	Duo Binary	No	WDM & TDM	NRZ for 10km
	ONU	+/-10 nm	8 nm	uncooled	NRZ	No		
Option 4	OLT	+/-3 nm	9 nm	cooled (1 share cooler)	NRZ/Duo Binary	No	WDM & TDM	Downstream 1 in O band, 3 in S band, not suitable for integration
	ONU	+/-10 nm	10 nm	cooled (1 share cooler)	NRZ	No		

Summary

- Some candidate Wavelength plan for A, D, E are proposed.
- Based on the summary in previous tables, Option 1(plan A) and option 3 (plan D) are preferred.

Back up: LAN WDM Spec

Table 88–6—100GBASE-LR4 and 100GBASE-ER4 operating ranges

PMD type	Required operating range
100GBASE-LR4	2 m to 10 km
100GBASE-ER4	2 m to 30 km
	2 m to 40 km[a]

[a]Links longer than 30 km for the same link power budget are considered engineered links. Attenuation for such links needs to be less than the worst case specified for B1.1, B1.3, or B6_a single-mode fiber.

Table 88–7—100GBASE-LR4 and 100GBASE-ER4 transmit characteristics

Description	100GBASE-LR4	100GBASE-ER4	Unit
Signaling rate, each lane (range)	25.78125 ± 100 ppm		GBd
Lane wavelengths (range)	1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19		nm
Side-mode suppression ratio (SMSR), (min)	30		dB
Total average launch power (max)	10.5	8.9	dBm
Average launch power, each lane (max)	4.5	2.9	dBm
Average launch power, each lane[a] (min)	–4.3	–2.9	dBm
Optical Modulation Amplitude (OMA), each lane (max)	4.5		dBm

Thank you

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