Split-band Wavelength Plans for 100G EPON

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IEEE 802.3ca 100G EPON TF

September, 2016

Ft. Worth, Texas, USA

Outline

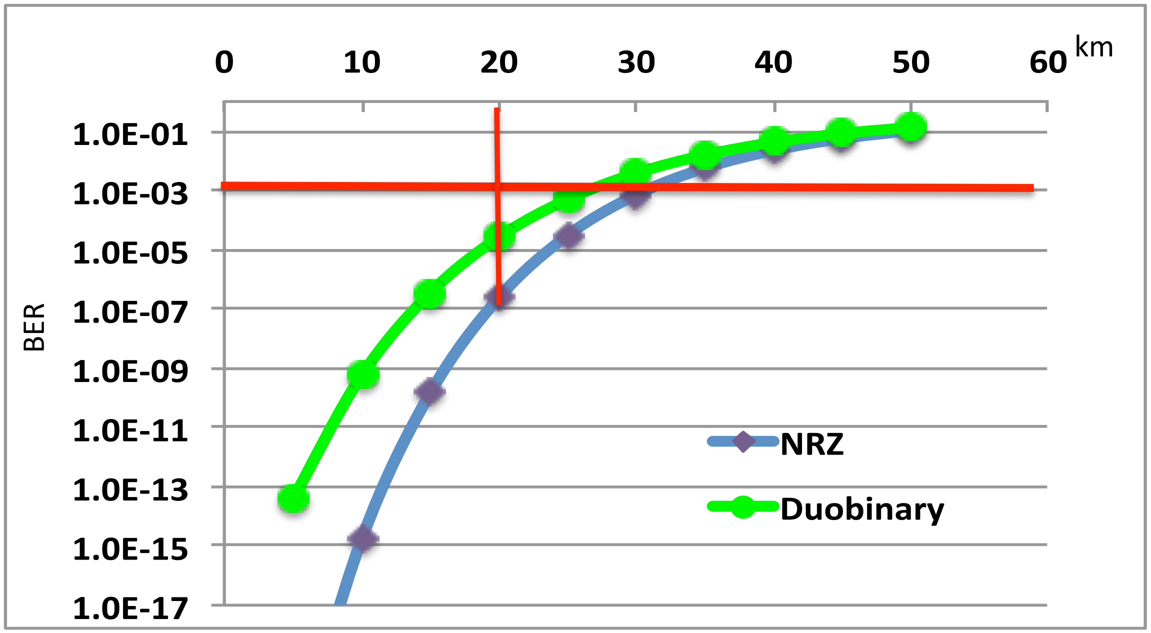
- **Wavelength plan and line code**
- **Split band wavelength plans**
- **Common or partial common wavelength plan with NGPON2**

Wavelength plan and line code

- Historically in PON, wavelength plan and line code have been considered independently
  - At rate ≤ 10 Gbps with 20km reach, dispersion can be tolerated
  - Wide upstream channel in the O band uses uncooled DFB lasers
  - NRZ is the default choice for line code
- When transmission rates > 10Gbps, dispersions may have to be compensated for. PMD effects will be noticeable
- Starting from NG-PON2, WDM is introduced in PON
  - May not be feasible to put all channels in O band due to wavelength resources limitations, FWM, and coexistence requirements
- Some line codes are more tolerant with dispersions. Therefore, the wavelength plan needs to be considered with line codes

Line code choice for O band*

O Band BER versus Fiber length (25Gbps, fixed TX power)

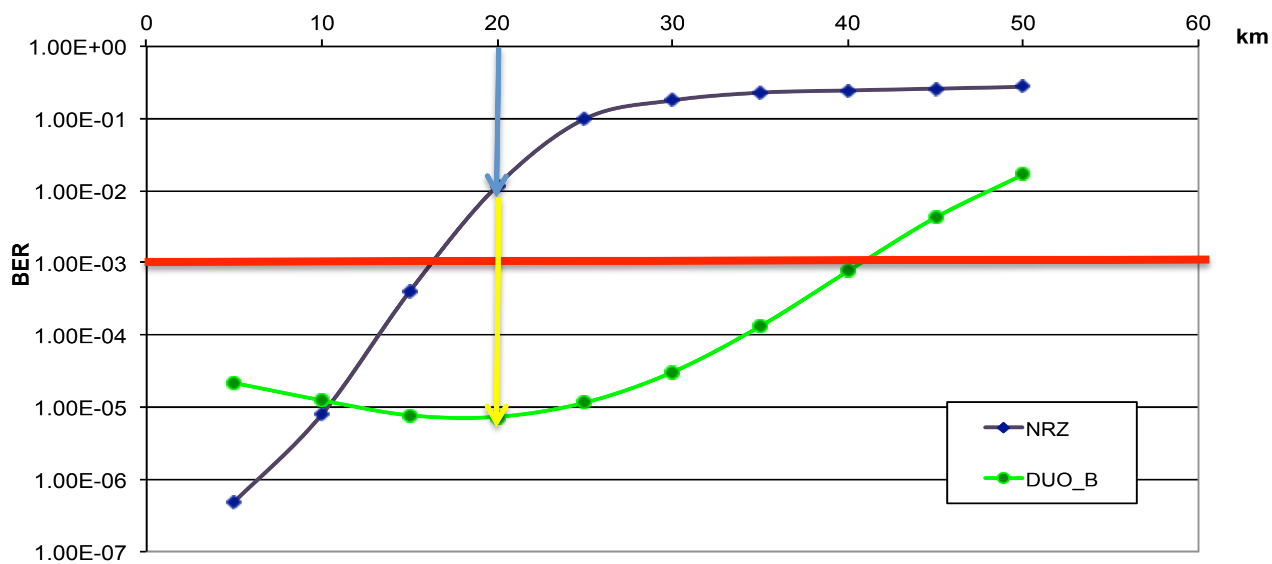


* Dispersion of 2ps/nm/km was used in the simulation

- **NRZ outperforms Duobinary at 25Gbps with 20km reach**
- **Optimum line code for O band is NRZ**

Line code choice for C*/L band

C band BER versus fiber length (25Gbps, fixed RX power)



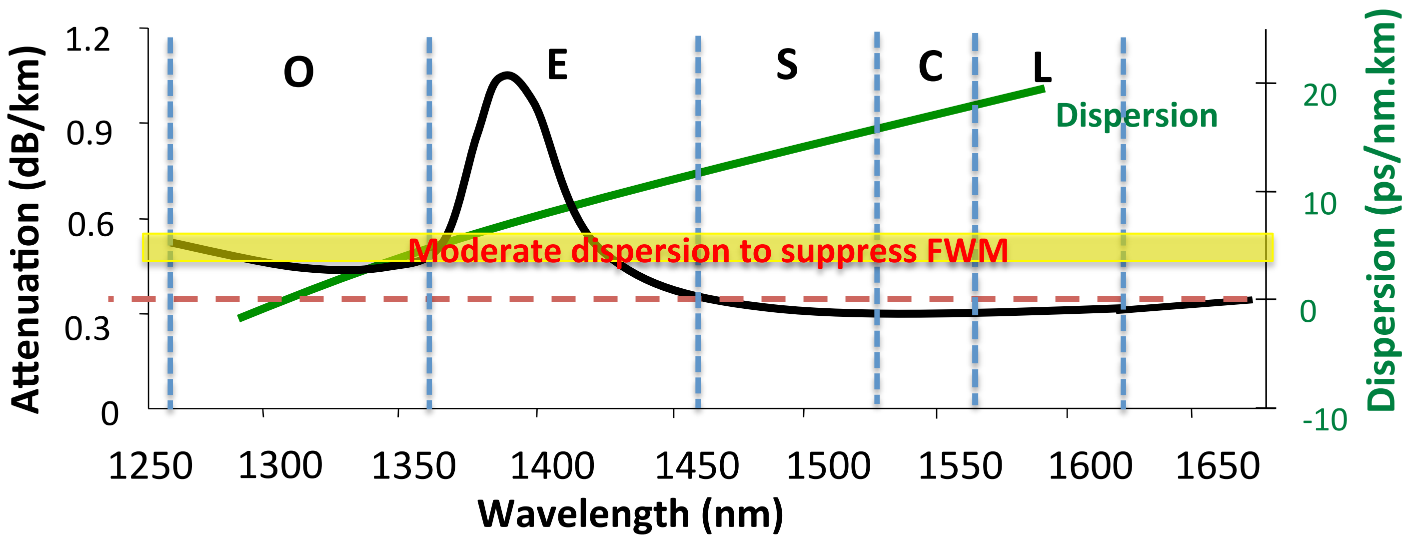
* Dispersion of 16ps/nm/km was used in the simulation

- **Needs dispersion compensation for 20km reach in C/L band for NRZ**
- **Dispersion compensation may be avoided by using Duobinary**
- **Optimized line code for C/L bands is Duobinary**

Advanced modulations or dispersion compensation?

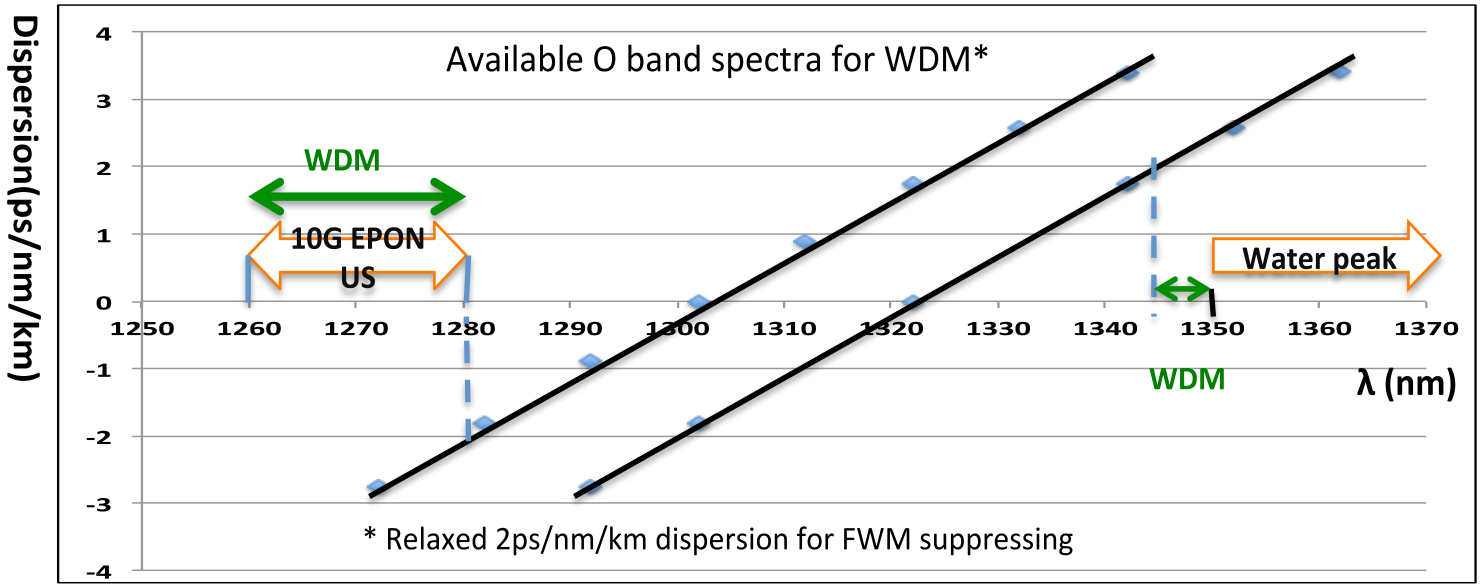
- Dispersion tolerant advanced modulations, such as Duobinary and PAM, will eventually be used for transmission rates ≥ 25Gbps
- At a 25Gbps rate, dispersion compensation can be avoided by using O band channels, however there may not be enough O band spectra for WDM channels
- In order to use C or L bands, either dispersion compensation or advanced modulation has to be considered
- The question is that should we consider advanced modulation or dispersion compensation with NRZ?
- At this moment, the main stream group seems to prefer NRZ, that puts dispersion compensation into the picture for C/L band

Choices of Wavelengths



- **O band is the best choice for single channel 25Gbps with NRZ**
- **Some O band spectra are not suitable for WDM because of low dispersion**
- **Moderate dispersions, for example ≥ 4ps/nm/km, are needed to suppress FWM for WDM**

How to use O band for 100G EPON? (1)



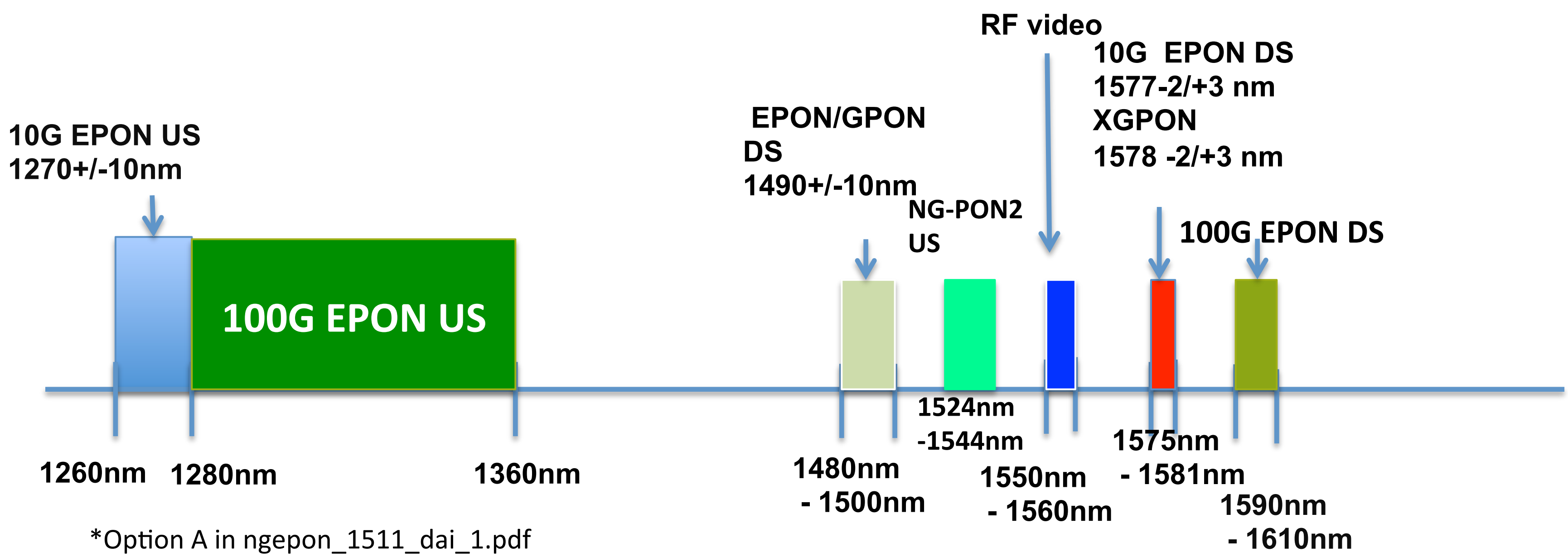
Available O band spectra for WDM:

- 20nm in negative dispersion region (1260nm to 1280nm) are available for WDM, but already used by 10G EPON
- ~5nm in positive dispersion region (1345nm to 1350nm)

How to use O band for 100G EPON? (2)

- 10G EPON US uncooled DFB lasers have 20nm spectra range.
- Even if tightening it to 8nm to a 10nm range and assuming using the 20nm 10G EPON spectra, there are still not enough WDM spectra to put all US channels in O band and using uncooled DFB lasers
- **If O band is used in some way, for example narrower WDM or single pair for 25Gbps channel, split band wavelength planes are needed**

Split-band wavelength plan* in general

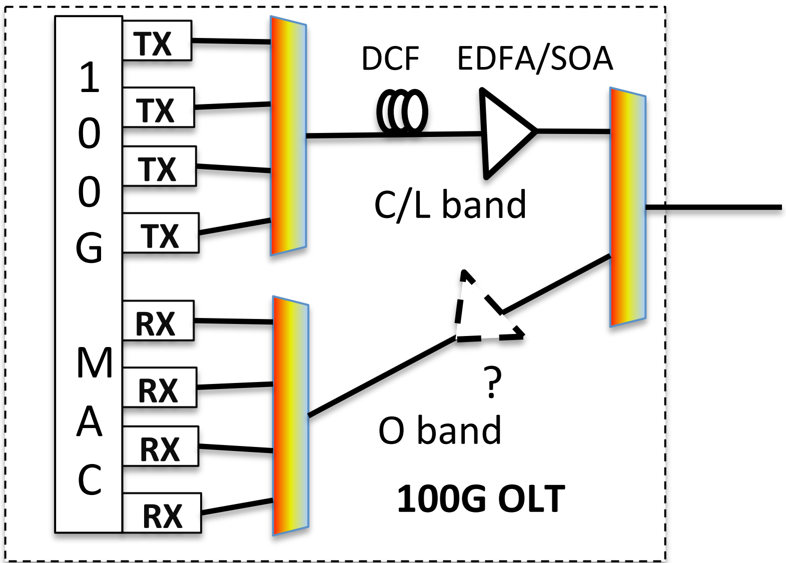


*Option A in ngepon_1511_dai_1.pdf

- US: 1280 nm to 1360 nm range, avoid zero dispersion region
- DS: L band in 1590nm to 1610 nm, or C band in 1524nm to 1544nm, reusing NG-PON2 spectrum allocations
- Coexists with 10G EPON
- There are several split-band architectures

Asymmetric Dispersion Compensation (1)

- **All upstream channels are in O band**
- **Asymmetric dispersion compensation (DC) is needed for DS in Split O/L band or O/C band wavelength plan**
- **Only need to compensate dispersions to the range needed for WDM**



DCF 38

Dispersion (ps/nm/km)	**-49.0 to -33.0**
Dispersion Slope (ps/nm^2/km)	-0.155
Effective Area (µm^2)	27
Attenuation(dB, at 1550nm))	0.256

- **5 km DCF is needed to compensate the dispersion of 20km SFM to ~6ps/nm/km**
- **An EDFA/SOA is needed to compensate additional losses of DCF and filters in DS**
- **In the US, an SOA may be needed to compensate for the loss of the additional filter**

Asymmetric Dispersion Compensation (2)

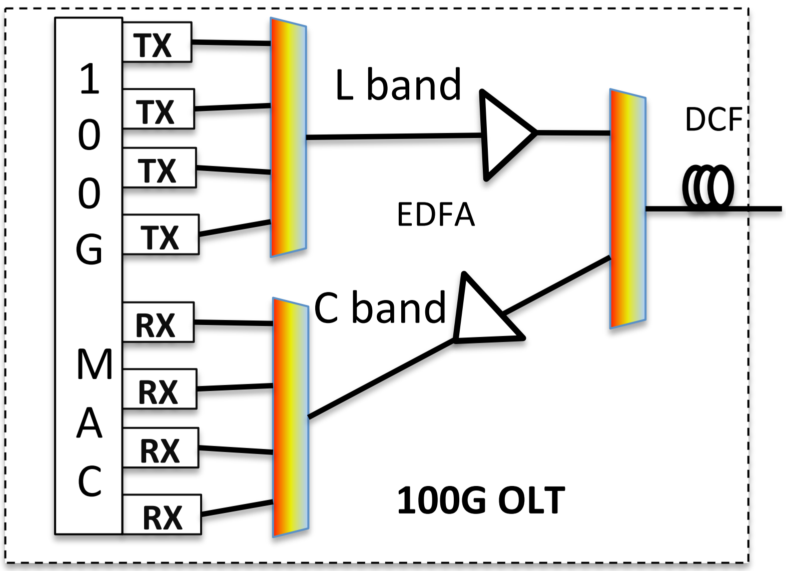
- **The benefit of the split O/L or O/C band wavelength plan is to keep all upstream channels in O band to avoid dispersion compensation in the upstream**
- **All US channels in O band is possible only if coexistence with 10G EPON is not required**
- **All upstream in O band may be possible if further relax dispersion criteria for suppressing FWM is feasible**

Asymmetric Dispersion Compensation (3)

- **The drawback of all upstream in O band is the "asymmetric" way to compensate dispersions**
- **The hidden assumption is that without US dispensation compensation the cost of an ONU will be lower**
  - **Uncooled DFB laser**
    - **Need large WDM spectra in O band**
  - **No SOA is need at ONU**
- **An OA may be needed at OLT as preamplifier and shared by all ONUs.**

Symmetric Dispersion Compensation (1)

- **All DS and US channels in the C and/or L band**
- **Symmetric dispersion compensation, the DFC is placed at the common part of the ODN**
- **It compensates the dispersions for both US and DS**



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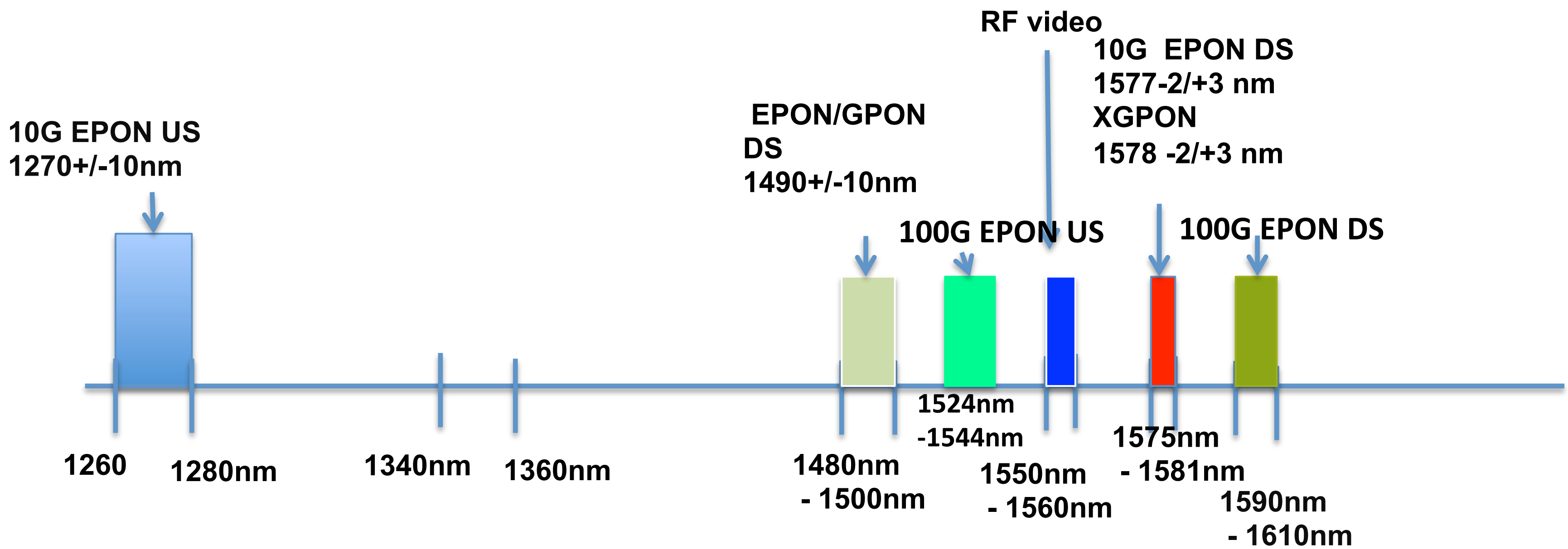
- **5 km DCF is needed to compensate the dispersion of 20km SFM to ~6ps/nm/km**

Symmetric Dispersion Compensation (2)

- **The benefit of symmetric dispersion compensation is that the US channels and DS stream channel are treated the same way**
- **Symmetric dispersion compensation requires allocation of US and DS channels in C band and/or L band**
- **It enables reuse of NG-PON2 spectra to conserve wavelength resources**
- **If US chooses C band and DS in L band as in NG-PON2, it is still considered as a split band wavelength plan**
- **The drawback is that cooled DFB lasers may be needed**
- **It may be accepted for 100G ONUs since they are considered business ONUs**
- **The cost of the 1st 25G channel will be higher**

Split band wavelength plan – reuse NG-PON2 wavelength plan

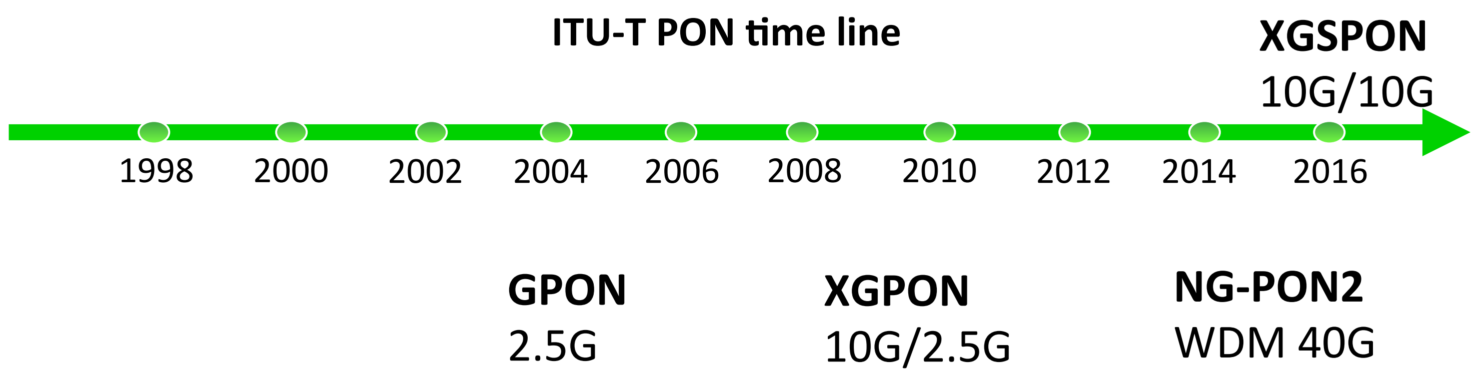


- 100G EPON US: C band 1524 nm to 1544 nm
- 100G EPON DS: L band 1590nm to 1603 nm
- 5 nm spectra per channel, cooled DFB lasers may be needed
- WDM coexists with 10G EPON

Common Wavelength Plan with NGPON2

- **A common or particle common wavelength plan with NGPON2 conserves wavelength resources**
- **A common wavelength plan in C/L bands facilitates migration to WDM PON in the future**
- **NGPON2 reserves C-band 1524nm to 1544nm for upstream and L-band 1596nm to 1603nm for downstream, 1610nm – 1625nm for P2P WDM**

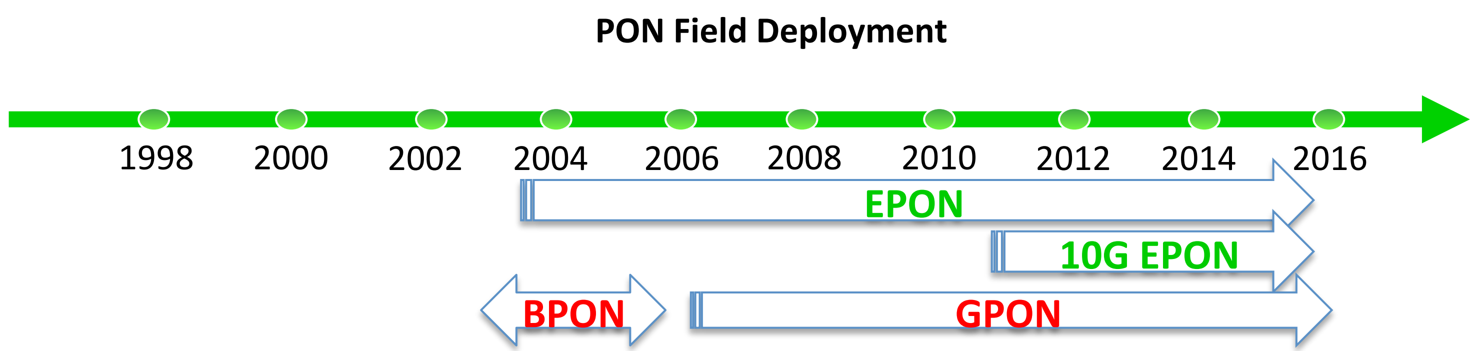
The 1st 25Gbps single channel



- FSAN/ITU-T completed 4 ch (4X10G) NG-PON2 (basic configuration) in 2015
- Realized the needs for single channel symmetric 10G rates, FSAN/ITU-T adds 10G/10G XGSPON in 2016

Although multi-channel PON is feasible/available, it cannot replace the needs of low cost single channel PON

A Historical view of PON deployment

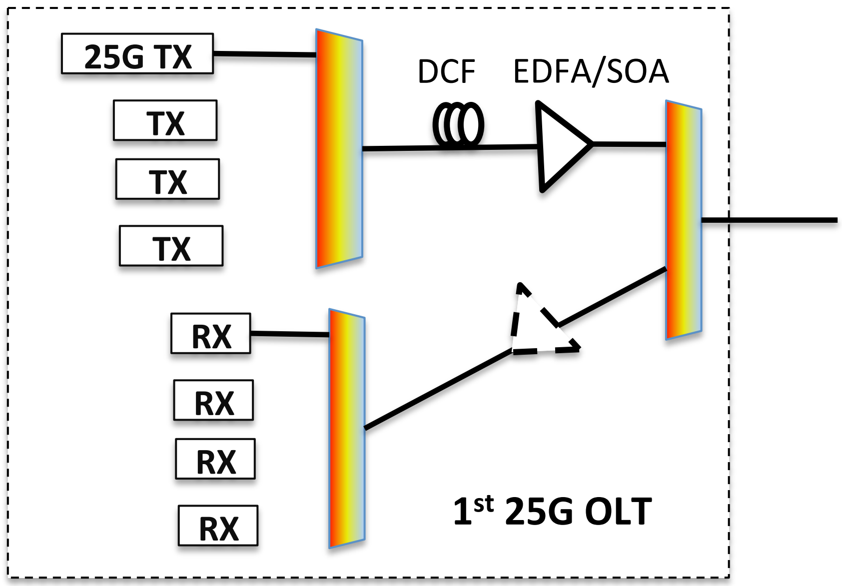


- An access network rate will last for many years.
- GPON has been deploying since 2006 (>16 years), and is still deploying today.
- 10G EPON has been deploying since 2010 (6 years), the volume is still small. Therefore, 10G EPON still has several years to reach its peak (another 10 years?)

- **When 25G PON starts to deploy, we expect that there will be many years (10?) for 25 Gb/s EPON reach its peak before the noticeable 100G EPON deployment begins (for business?)**
- **During this long time period low cost for 25G EPON is critical.**

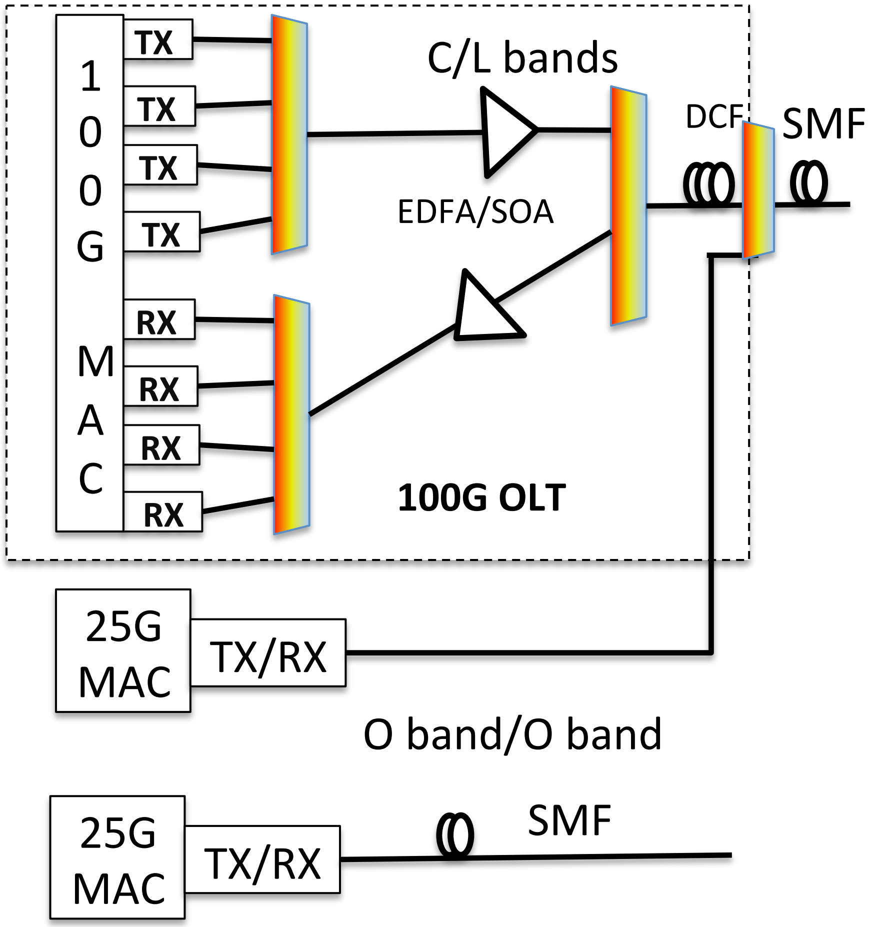
The economics of the 1st 25G EPON channel

- **In O/L , O/C or C/L, split-band architectures, the 1st 25G channels need dispensation compensation**
- **An EDFA/SOA is needed in the downstream**



- **The cost of the 1st 25G channel will be high**
- **Some 25G deployments may never upgrade to 100G**
- **Bearing the cost of 100G in those 25G deployment has no business value**

The balanced wavelength plan solution*

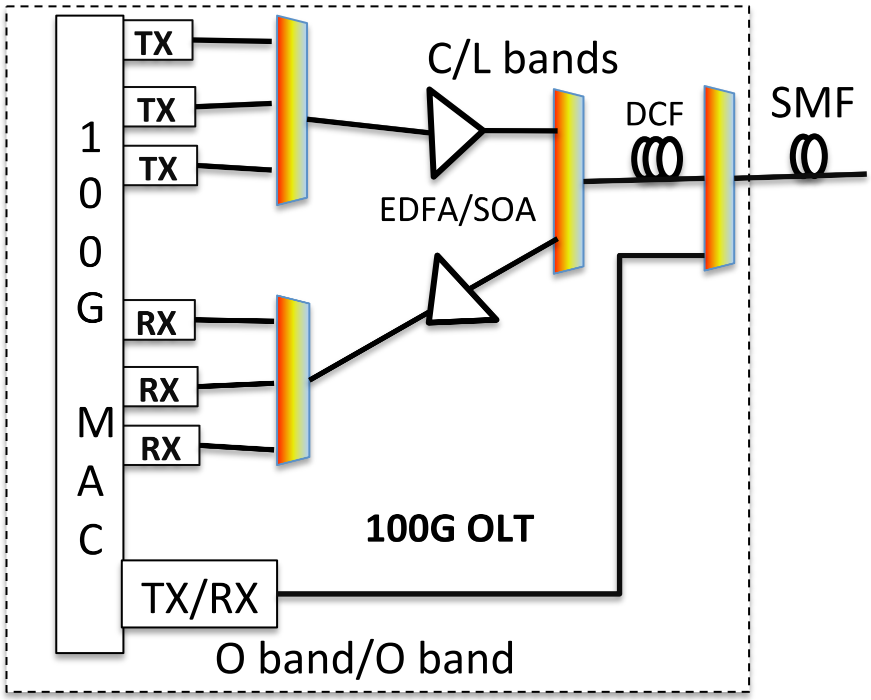


- **100G channels in C/L band align with NG-PON2 spectrum**
- **Standalone 25G channel in O/O band without OA**
- **There are enough spectra for O/O band 25G channel**
- **The 1st 25G channel uses uncooled DBF laser**
- **The standalone 25G channel WDM overlay with 100G channels for migration in the future, if needed.**
- **NG-PON2 spectra are reused to conserve wavelength resources**

* Also called 1+4

25G channel and 100G channels can scale separately for economic and growth together if needed

Split O/O and C/L band wavelength plan*



* Also referred as 1+3

A slight variation of the previous architecture:

- **3 channels are in C/L band and align with NG-PON2 spectra**
- **The 25G channel is in O/O band**
- **The 25G channel uses uncooled DBF laser**
- **The drawback is additional OA is needed for the 25G channel**
- **The wavelength filtering scheme is more complicated, which could increase the cost of ONUs**

Split-band wavelength plans

1st 25G Channel	Wavelngth band	Centrer wavelength	Dispersion distribution
Upstream	O band, 20nm	1310 nm +/- 10nm	0.6 to -2/ps/nm/km
Downstream	O band, 5nm	1335 nm +/- 2.5nm	0 to 2.4 ps/nm/km

3 C/L band Channels	Wavelngth band	Centrer wavelength	Dispersion
Upstream	C band, 5 nm spacing	1526.5 nm +/- 2.5 nm, 1531.5 nm+/- 2.5 nm, 1536.5 nm +/- 2.5 nm	~16/ps/nm/km
Downstream	L band, 2 nm spacing	1597 nm +/-1 nm, 1599 nm +/- 1 nm, 1601 nm +/- 1 nm	~18 ps/nm/km

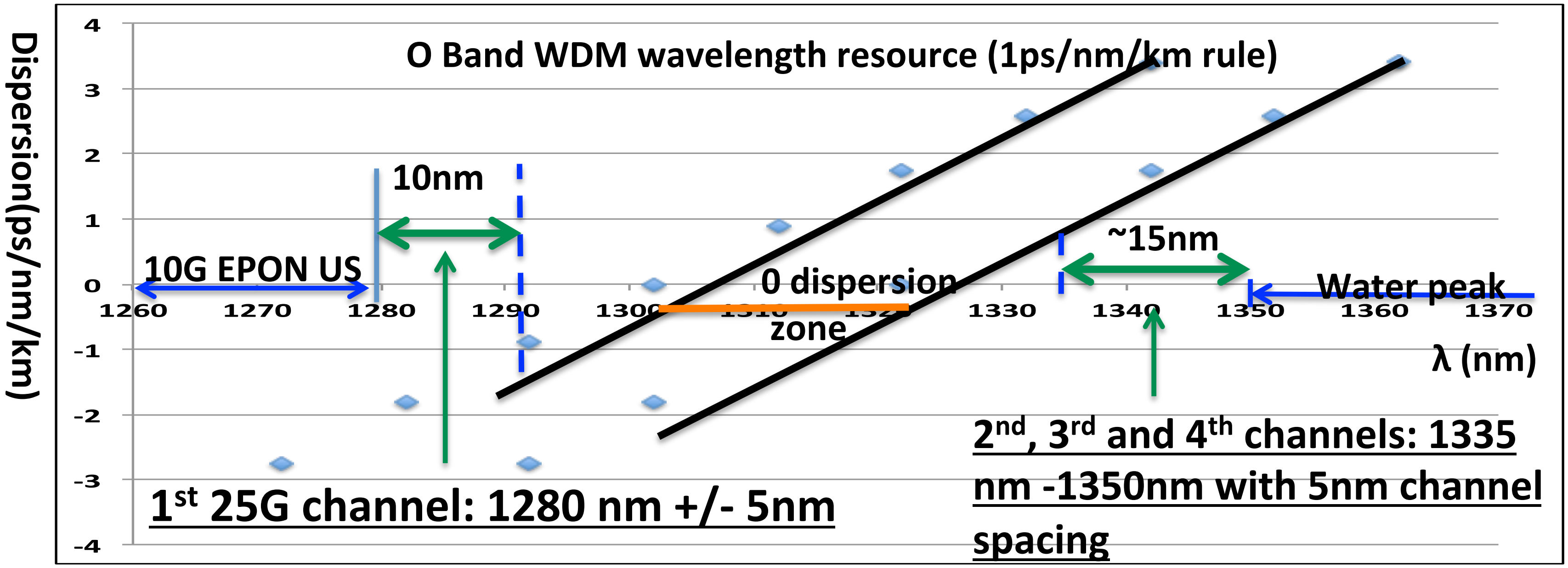
4 C/L band Channels	Wavelngth band	Centrer wavelength	Dispersion
Upstream	C band, 5 nm spacing	1526.5 nm +/- 2.5 nm, 1531.5 nm+/- 2.5 nm, 1536.5 nm +/- 2.5 nm, 1541.5 nm +/- 2.5 nm	~16/ps/nm/km
Downstream	L band, 2 nm spacing	1597 nm +/-1 nm, 1599 nm +/- 1 nm, 1601 nm +/- 1 nm, 1603 nm +/- 1 nm	~18 ps/nm/km

Center wavelength and range are for the purpose of channel resources estimate

“1+3” or “1+4”?

- There are some commonalities and differences in “1+3” and “1+4” under the split-band architectures been discussed
- The “1+4” under the split-band architecture has lowest cost for the 1st 25G channel
- The “1+3” under the split-band architecture need an additional OA for the 1st 25G upstream channel
- The cost of C/L band channels in “1+3” and “1+4” are similar
- The “1+4” split-band architecture allows 25G and 100G channels scale separately

All O band US WDM wavelength plan



Upstream channel	Centrer wavelength/range
Channel 1	1280 nm +/- 5nm
Channel 2	1337 nm +/- 2.5nm
Channel 3	1342 nm +/- 2.5 nm
Channel 4	1347 nm +/- 2.5 nm

Center wavelength and range are for the purpose of channel resources estimate

Advanced modulations

- Dispersion tolerant advanced modulations, such as Duobinary, could be used to avoid the needs for dispersion compensations at 25Gbps with 20km reach
- The overall architectures of the above discussed split-band solutions will not be affected by using advanced modulations, except the filter arrangement may be different.
- The split-band wavelength plans remain unchanged if advanced modulations are used.

Conclusions

- A common (or partial common) wavelength plan with NG-PON2 conserves wavelength resources
- The proposed split band architectures place the 1st 25G in O/O band wide channels resulting lower cost for the 25G channel
- Other 3 (in “1+3”) or 4 (in “1+4”) channels are in C/L band and have similar cost structures
- The “1+4” in split-band architecture has lowest cost for the 1st 25G channel
- Advanced modulations could be used to avoid DCF. The split-band architectures will not be affected by using advanced modulations

Thanks

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