NG-EPON
Wavelength Planning Considerations

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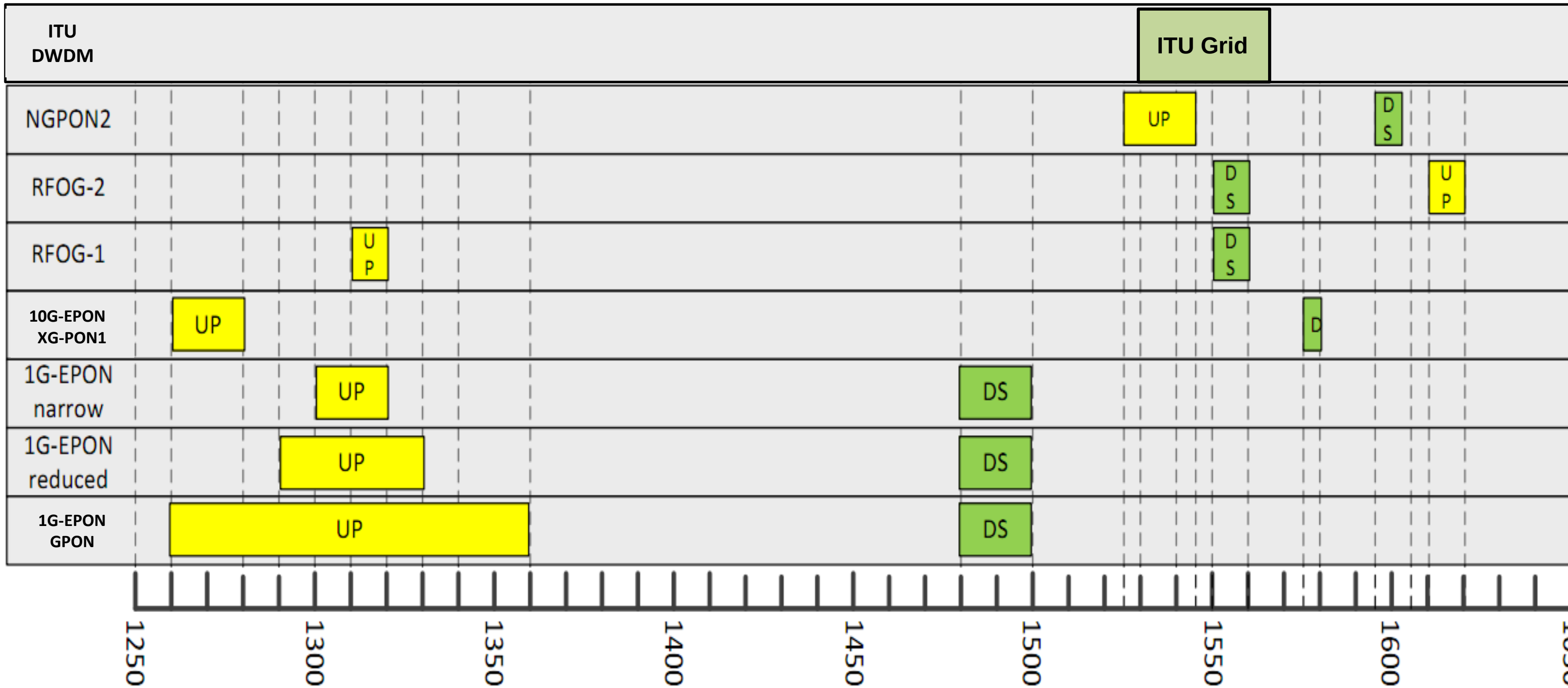
September 14, 2015

NG-EPON Wavelength Planning Goals

- Maintain coexistence with legacy FTTP services
  - RFoG
  - EPON / GPON
  - 10G EPON / XG-PON1
- Allow multi-service capability over a single fiber
  - Commercial services DWDM
  - Distributed access architecture HFC and PON
- Define NG-EPON wavelength allocations for DS/US that optimize link reach, data capacity, and device economics
  - Select BW that minimizes fiber impairments with TDM multi-wavelength
  - Maintain compatibility with existing hardware and volume services

Current Optical Spectrum Allocations[1]



- Current allocations support coexistence by providing non blocking optical BW plus adequate guard band separation
- Use of discrete channelized lasers allows multi-service harmony

Laser Technology Impact on BW Allocations

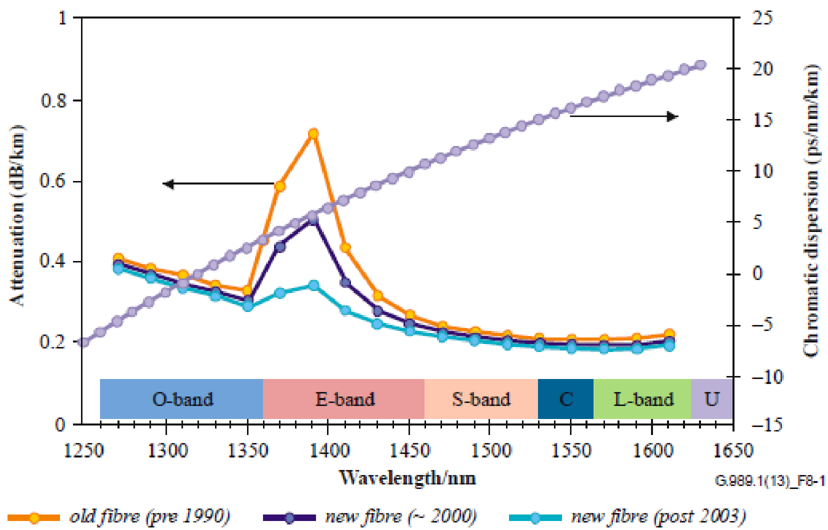
- Optical BW allocations tend to be conservative based on worst case assumptions for laser technology, manufacturing yield distribution, temperature effects, and intended application
- To achieve the lowest cost early PON deployments used Fabry Perot (FP) lasers which have a large wavelength distribution
- Early DFB laser manufacturing distribution was a significant improvement but still resulted in +/- 20 nm BW allocations
- Current laser manufacturing has made dramatic advances
  - Typical wavelength distribution of +/- 2 nm

Laser Technology Physical Layer Limits to BW

- Uncooled laser over-temperature variation
  - Wavelength change is predictable at 0.1 nm/deg C
    - Laser wavelength typical reference temperature is 25 deg C
    - Requires 8 degree change to move one DWDM grid channel (100 GHz)
    - 10 nm total variation for OSP range of -40 to +60 deg C
    - 5 nm total variation for ISP range of 0 to +50 deg C
- Channelized lasers use TE coolers to maintain set wavelength
- Channelized laser BW allocation is primarily determined by the optical passive filter BW
  - Optical passive cost versus performance is the main factor
  - Multiple laser channel (WDM) systems create unique challenges

NG-EPON BW Allocation Coexistence Factors

- Fiber distortion impacts are a significant determining factor for optimum BW spectrum location
- Optical multi-wavelength solutions to achieve 40Gb or 100Gb require at least 8 to 10 nm BW for a (maximum) 4 ch system



- Fiber Wavelength Attenuation
- SMF Water Peak Attenuation
- Dispersion characteristics
- Dispersion power penalty
- Four Wave Mixing (FWM)

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Fiber Distortion Factors

- O-Band / E-Band limitations (1260 to 1460 nm)
  - Higher attenuation (0.4 to 0.3 dB/km) reduces link reach
  - Older deployed fiber has a large water peak loss
  - Wavelength channel grid standards do not exist in these bands
  - Low dispersion range is a major disadvantage for multi-wavelength systems due to higher FWM impacts. Channel spacing to limit FWM will create potential coexistence conflicts with existing 1G and 10G US BW
- O-Band / E-Band wavelengths present considerable hurdles for NG-EPON TDM DS/US channel allocations
- C-Band / L-Band advantages (1520 to 1625 nm)
  - Lower attenuation (0.25 to 0.22 dB/km)
  - Higher dispersion reduces impact of FWM
  - Channelized allocations are widely established

Fiber Distortion Factors - Dispersion

NRZ Single Carrier Usable Spectrum for SMF28 Fiber [2]

NRZ bit rate	Dispersion tolerance (EML)	Usable spectrum (20 km, no DC)
10 Gb/s	1000 ps/nm	All of O-, E-, S, C, and L bands
25 Gb/s	190 ps/nm	1260–1410 nm
40 Gb/s	75 ps/nm	1290–1340 nm

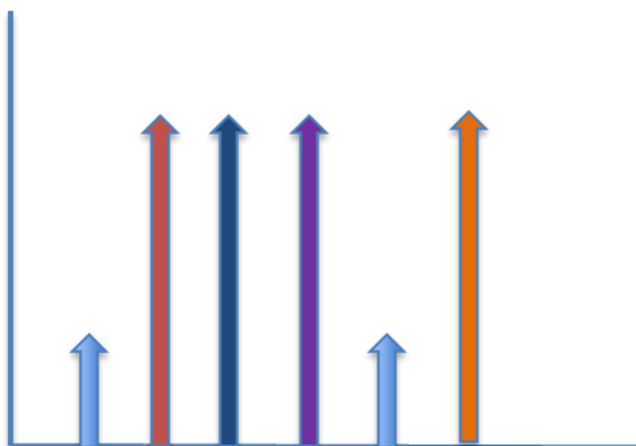
NRZ Single Carrier Dispersion Power Penalty [2]

NRZ bit rate [Gb/s]	Rx sensitivity, downstream [dBm]	Required transmit power, PR30 [dBm]
10	-29.5	1
25	-25.5	5
40	-22.5	8

- Dispersion increases challenges with high bit rate modulation
  - Dispersion correction required to extend usable spectrum
  - Dispersion penalty reduces link reach, increases laser cost

Fiber Distortion Factors – Four Wave Mixing

- Multi-wavelength systems are subject to FWM distortion
  - Generation of harmonic tones that coincide with other channels
  - Creates cross talk that imparts noise to the desired signal channel
  - Magnified by long reach, low dispersion, high density WDM systems



FWM Illustration

- FWM mitigation solutions
  - Careful wavelength spacing to avoid harmonic beat relationships
  - Spectrum location (Dispersion is your friend)
  - Optical launch power reduction
  - Reduced number of WDM channels

NG-EPON Compatibility

- Promoting development at the lowest cost requires multiplying potential volumes from both EPON and GPON or another commercially viable service
  - 1G/2.5G and 10G optical devices have successfully followed this path
- NGPON2 wavelength allocation or a closely aligned variation should be the first to be considered for selection
  - Maintains coexistence with legacy services
  - BW aligns with spectrum beneficial to TDM multi-wavelength systems
  - Potential to drive cost curve lower with shared BW allocation plan
- NGPON2 TWDM devices do not directly align with TDM devices but base laser chips and device packaging may be compatible

Summary

- Optical devices needed for NG-EPON will require significant development to achieve the proposed long term goal of 40Gb or higher data rates
- Early decisions on modulation technology and multiplexing will require careful alignment of the optical channels selected
- Maintaining coexistence with legacy services allows a non-disruptive path to introducing higher data rate services with NG-EPON
- Selecting optical spectrum compatible with NGPON2 provides a possible path to volume availability and implied lower cost

Thank You

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Footnotes - Credits

1. *Wavelength allocation plans for 1G-EPON, 10G-EPON, ITU-T PON, SCTE RFOG, and NGPON2; adapted from slide 4 from Wavelength Plan Analysis, Minghui Tao and Quian Liu, November 2014.*
2. *IEEE 802.3 Industry Connections Feasibility Assessment for the Next Generation of EPON, March 2015.*
3. *40 Gigabit capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification, ITU-T G.989.2, December 2014.*

NG-PON2 Wavelength Bands (ITU-T G.989.2)[3]

Wavelength compatible systems	TWDM PON		PtP WDM PON
	Downstream	Upstream	Upstream/downstream
GPON, RF video, XG-PON1	1596-1603 nm	Wideband option 1524-1544 nm Reduced band option 1528-1540 nm Narrow band option 1532-1540 nm	Expanded spectrum 1524-1625 nm (Note 1) Shared spectrum 1603-1625 nm (Note 2)

NOTE 1 – This Recommendation specifies PtP WDM PON anywhere in the spectrum identified in Table 9-1, subject to spectrum otherwise being used. Whenever a particular subset of the spectrum in either band is unused by TWDM PON and/or legacy systems, PtP WDM PON is permitted to make use of that particular sub-band in upstream and/or downstream direction. However, the isolation requirements to the TWDM PON and/or legacy systems must be considered when determining the expanded spectrum wavelengths to be occupied by PtP WDM PON.

NOTE 2 – When TWDM PON and PtP WDM PON are both present, wavelength channels of both technologies may occupy adjacent wavelength bands; however, TWDM and PtP WDM channels must not be interleaved. The required guard band between TWDM PON and PtP WDM PON is a minimum of 3 nm when using separate mux/demux devices. In the shared spectrum case, the PtP WDM PON upstream channels use the shorter wavelengths in the shared spectrum. When a single device is used to multiplex PtP WDM PON and TWDM PON, the required guard band is a minimum of 100 GHz.