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Potential Ways to Use the ITU-T SG15 Liaison for the 800G-LR4 Baseline

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Background

- In the November 2023 IEEE 802 plenary meeting, the baseline proposal for 800GBASE-LR4 (rodes_3dj_01a_2311) was approved, with the chromatic dispersion (CD) values of its four wavelength channels “to be specified once ITU-T statistical data gets available”.

Transmitter compliance channel specifications

Dispersion								Max mean DGD
Lane0		Lane1		Lane2		Lane3		
Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	
TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	0.8 ps

CD values to be specified once ITU-T statistical data gets available

- In December 2023, IEEE 802.3 WG received the liaison from ITU-T SG15 regarding the statistical CD properties of G.652 / G.657 fiber, which was posted at: https://www.ieee802.org/3/minutes/jan24/incoming/SG15-LS86_Redacted.pdf
  Additional attachments were also posted at: https://www.ieee802.org/3/minutes/jan24/index.html.

Key takeaway messages from the ITU-T liaison

1) It is good that the ITU-T SG15 is using the statistical methodology for assessing the fiber CD properties.
2) It is very valuable to have the initial CD measurement results from ITU-T, which can help us refine the CD channel model.
3) It is also good that ITU-T looks forward to "continued communications to align our work as much as possible". "Specifically, any comments on the initial results, as well as suggestions on how to improve them would be most welcome. "
4) The ITU-T SG15 liaison only provided the worst-case CD values of eight fiber vendors at a confidence level of 99.99% without providing much information on the zero-dispersion wavelength (ZDW) distribution and dispersion slope (S) distribution.

Potential Way #1: using the example ZDW distribution in the ITU-T appendix

- ZDW=N(1312, 3.5) is adopted in a numerical example in the appendix of TD-GEN-0248.
- Together with the statistical distribution of S_0 described in Johnson_3dj_2307, we can derive the CD values for 800G-LR4 using M=4 and Q=1E-4, as done in liu_3dj_optx_01_231214:

Channel 1		Channel 2		Channel 3		Channel 4	
$CD_{min,Q}$ @1294.53 nm	$CD_{max,Q}$ @1296.59 nm	$CD_{min,Q}$ @1299.02 nm	$CD_{max,Q}$ @1301.09 nm	$CD_{min,Q}$ @1303.54 nm	$CD_{max,Q}$ @1305.63 nm	$CD_{min,Q}$ @1308.09 nm	$CD_{max,Q}$ @1310.19 nm
-20.34	-7.49	-16.42	-3.73	-12.52	0.03	-8.64	3.78

Potential Way #2: Deriving the ZDW and S_0 Distributions from the main ITU results (1)

- The primary numerical results presented by ITU is a table showing coefficients B and C for maximum and minimum CD with confidence level of 99.99%.

- With coefficients B and C, we could approximate dispersion with the given formula:

$$D(\lambda) = 2(B\lambda - C\lambda^{-3})$$

- According to a Corning paper [Corning 2001], ZDW and S_0 can be obtained as:

$$ZDW \equiv \left[\frac{C}{B}\right]^{1/4} \quad S_0 \equiv 8B$$

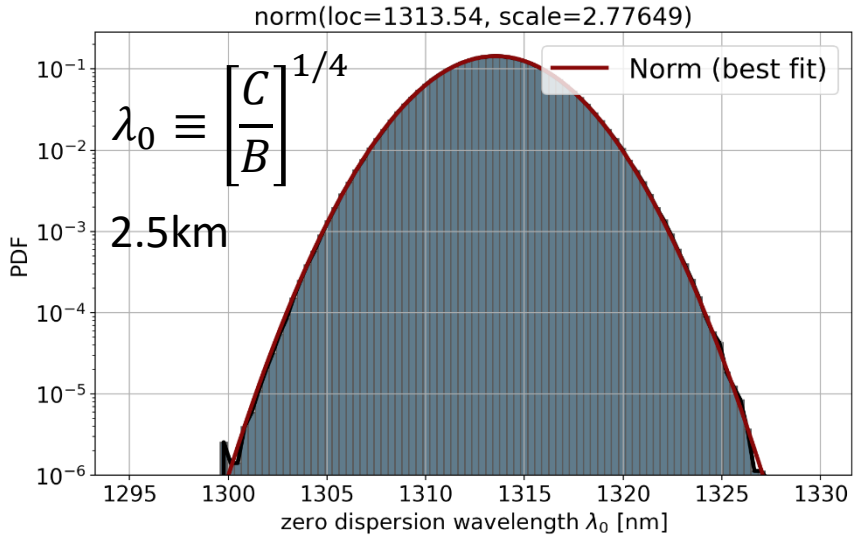
- Looking from the general curves pattern, ZDW and S_0 for the 2km link case are not consistent with results for links of longer lengths.
  - First, the zero dispersion slope S_0 does not have a range for the 2km case.
  - In addition, the limits of ZDW for the 2km case violate the [1300, 1324]nm maximum range defined by ITU-T.

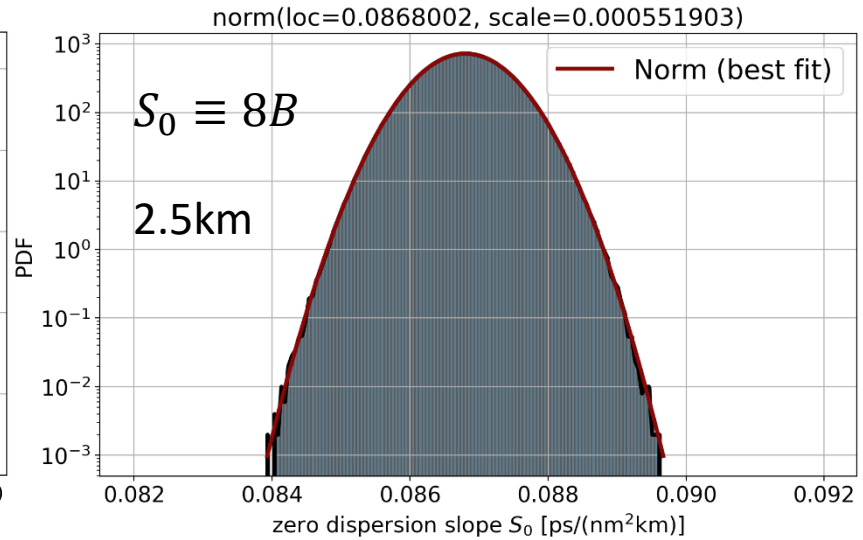
- We can obtain reasonable parameters for 2.5-km link from the data at 10, 20, 30 and 40 km.

Potential Way #2: Deriving the ZDW and S_0 Distributions from the main ITU results (2)

- Using the limits of the B and C parameters for 2.5-km, we can obtain the $D(\lambda)$ limits as CD_{min}=-2.592ps/nm/km@1294.56nm and CD_{max}=0.6ps/nm/km@1310.19nm with 99.99% confidence for the 2.5km-link, and the distributions of B and C as:

  B=N(2.7125E-2, 0.01725E-2); C=N(8.075E10, 0.045E10).





Correlation between λ_0 and S_0 are measured from Monte Carlo simulations:

	λ_0	S_0
λ_0	1.0	-0.75
S_0	-0.75	1.0

- We can then simulate the distributions of λ_0 and S_0, whose histograms can be very well fitted by Normal distributions:

  λ_0~N(1313.54nm, 2.78nm); S_0~N(0.0868, 0.00055)

Potential Way #2: The CD limits for 800G-LR4

Finally, we obtain the CD limits for 800G-LR4 through Monte Carlo simulations with the ZDW and S_0 distributions of the 2.5-km fiber segment as follows:

Channel 1		Channel 2		Channel 3		Channel 4	
$CD_{min,Q}$ @1294.53 nm	$CD_{max,Q}$ @1296.59 nm	$CD_{min,Q}$ @1299.02 nm	$CD_{max,Q}$ @1301.09 nm	$CD_{min,Q}$ @1303.54 nm	$CD_{max,Q}$ @1305.63 nm	$CD_{min,Q}$ @1308.09 nm	$CD_{max,Q}$ @1310.19 nm
-21.38	-10.48	-17.34	-6.45	-13.28	-2.44	-9.26	1.57

Potential Way #3: Reading directly from the ITU-T values for 99.9%* confidence level (1)

(*: Here the 99.9% confidence level is w.r.t. the worst vendor's data, so the overall confidence level can be much higher)

- Given that we got the CD values at the 99.99% confidence level (or Q=1E-4) from the ITU-T liaison, we can figure out what the CD values at the 99.9% confidence level (or Q=1E-3)
- We can use the Q function (Q_f): $Q_f(3.72)$=1E-4 and $Q_f(3.09)$=1E-3.
- When a single Gaussian distribution is assumed, we can get:

$$\text{sigma}(\lambda)=[CD_{max}(\lambda,99.99\%)-CD_{min}(\lambda,99.99\%)]/(2*3.72) \quad (1)$$

- In real-world applications, there are multiple Gaussian distributions for difference fiber vendors, so the sigma value is reduced. As the most conservative case is likely the 6-sigma case, we can obtain the smallest sigma value in practice as:

$$\text{sigma}(\lambda)=[CD_{max}(\lambda,99.99\%)-CD_{min}(\lambda,99.99\%)]/[2*(3.72+1.5)] \quad (2)$$

where the constant 1.5 is for 6-sigma rule's mean shift range of [-1.5 1.5]sigma.

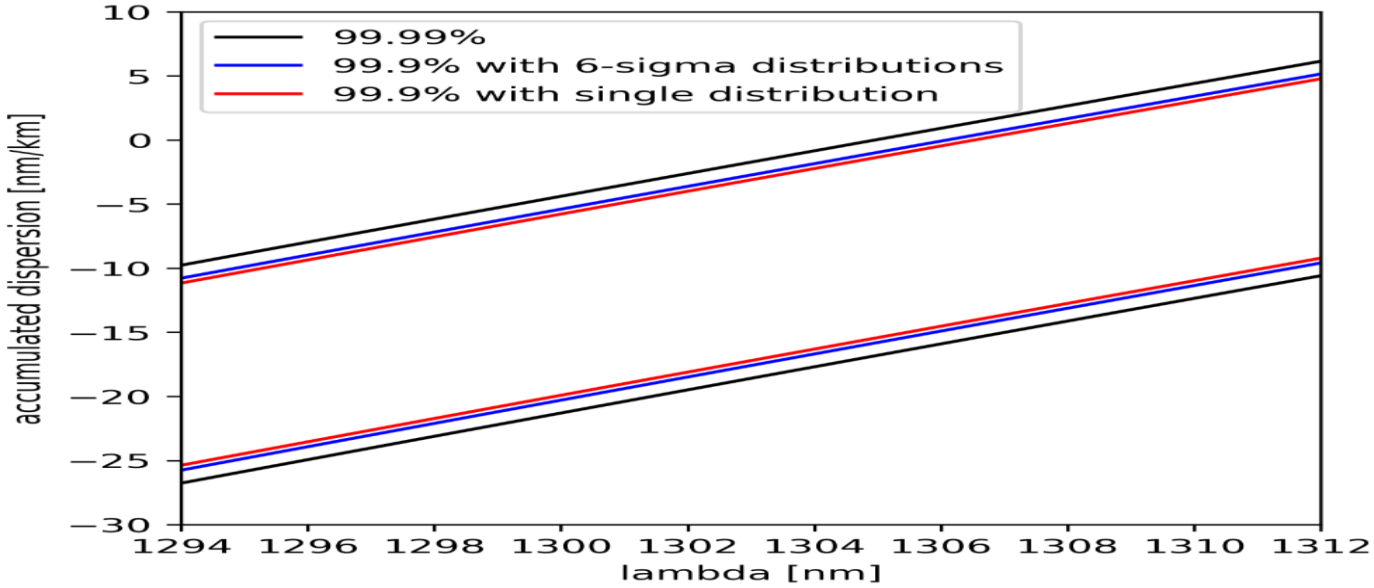
- With the above two formulas, we can readily calculate the CD_{min} and CD_{max} boundaries for 99.9% confidence level based on the ITU-T liaison values for the 99.99% level as:

$$CD_{min}(\lambda,99.9\%)=CD_{mean}(\lambda,99.99\%)-(3.09+1.5)*\text{sigma} \quad (3)$$

$$CD_{max}(\lambda,99.9\%)=CD_{mean}(\lambda,99.99\%)+(3.09+1.5)*\text{sigma} \quad (4)$$

Potential Way #3: Reading directly from the ITU-T values for 99.9% confidence level (2)

- With the formulas in the last slide and the ITU-T liaison, we obtain the following results for LR4:



- For the case with a single Gaussian distribution, sigma≈2.3 ps/nm
- For the case with 6-sigma distributions, sigma≈1.6 ps/nm.

Channel	Channel 1		Channel 2		Channel 3		Channel 4	
CD boundaries	$CD_{min,Q}$ @1294.53 nm	$CD_{max,Q}$ @1296.59 nm	$CD_{min,Q}$ @1299.02 nm	$CD_{max,Q}$ @1301.09 nm	$CD_{min,Q}$ @1303.54 nm	$CD_{max,Q}$ @1305.63 nm	$CD_{min,Q}$ @1308.09 nm	$CD_{max,Q}$ @1310.19 nm
99.99%	-26.28	-7.44	-22.19	-3.43	-18.11	0.58	-14.05	4.57
99.9% with a single Gaussian	-24.89	-8.83	-20.8	-4.81	-16.73	-0.8	-12.67	3.2
99.9% 6-sigma distributions	-25.27	-8.45	-21.18	-4.43	-17.11	-0.42	-13.05	3.57

Comparing the CD Limits Obtained by Different Methods

We compare the 800G-LR4 CD limits obtained by the four different methods discussed:

Method	**Potential Way #1:** ZDW~N(1312, 3.5) S_0~ N(0.0825, 0.001) with 99.99% confidence		**Potential Way #2:** ZDW~N(1313.54, 2.78) S_0~N(0.0868, 5.5E-4) with 99.99% confidence		**Potential Way #3:** From the ITU-T Liaison with 99.9% confidence (using 6-sigma distributions)		**From the ITU-T Liaison:** From the worst vendor data with 99.99% confidence		**ITU-T Worst-Case:** ZDW_{min}=1300 nm, ZDW_{max}=1324 nm, S_0=0.092.	
CD limits (ps/nm)	min	max	min	max	min	max	min	max	min	max
	-20.34	3.78	-21.38	1.57	-25.27	3.57	-26.3	4.57	-28.05	9.27

- The CD reductions obtained from the three "Potential Ways" are sufficient for 800G-LR4.
- The mean ZDW's of the Method #2 and Method #3 are shifted towards longer wavelength (~1314 nm), which is in agreement with other recent studies. This is reasonable as the bend-insensitive G.657 fibers tend to have longer ZDW.
- Among the three potential methods, Method #3 is based on the commonly accepted 6-sigma rule for multiple Gaussian distributions and is conservative and realistic.

Summary

1) It is good that the ITU-T SG15 is using the statistical methodology for assessing the fiber CD properties.
2) After a careful review of the ITU-T SG15 liaison results, we present three potential methods to use these results for deriving the CD values in the 800G-LR4 baseline.
   - Method #3 accommodates multiple Gaussian distributions and is conservative and realistic.
3) As suggested in the ITU-T liaison letter, we can provide our study on their initial results, and ask their opinion on the most suitable CD calculation method to use.

Thank you!