

TO INFINITY AND BEYOND!

Ethernet and optics on the road to 800GE and 1.6TE

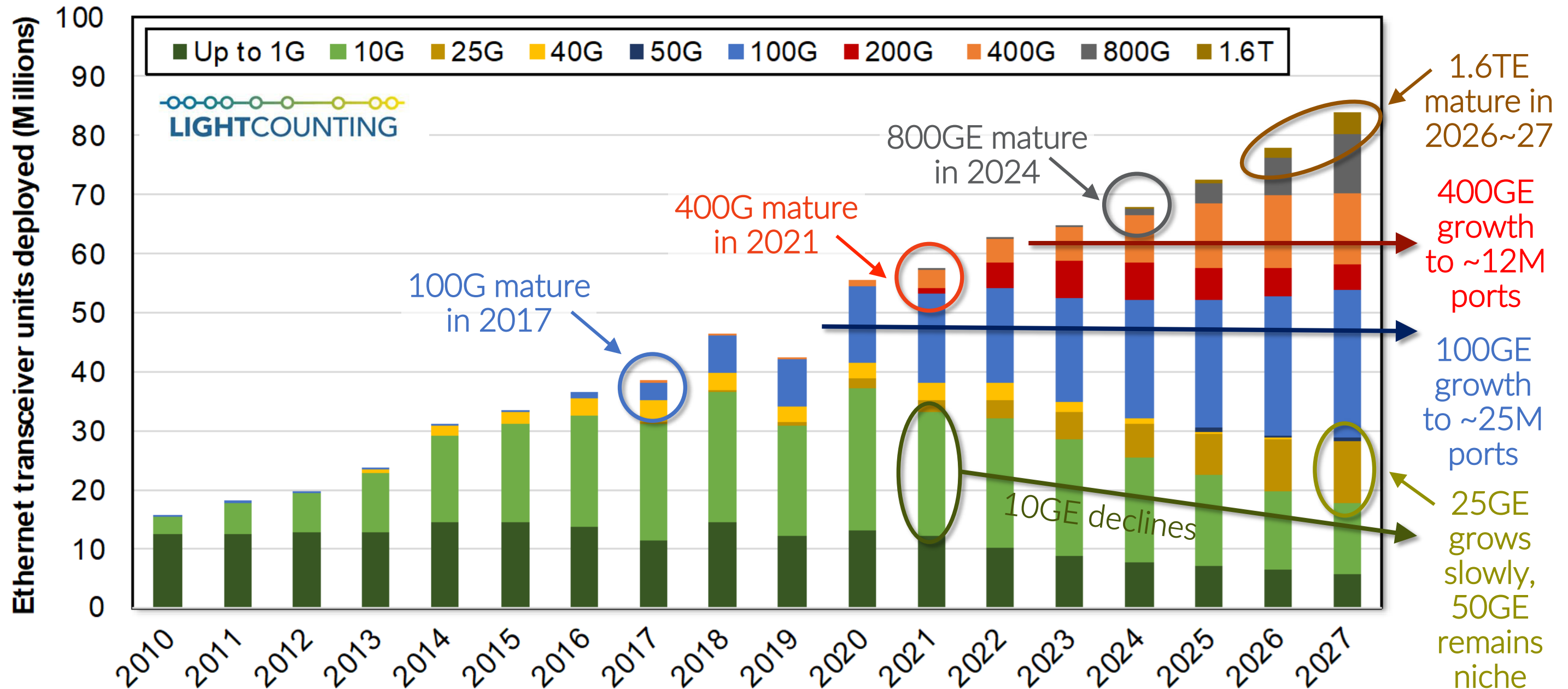
Netnod Meeting 2023, Stockholm, 15th March 2023

JUNIPER
NETWORKS®

Driven by
Experience™

THE ETHERNET (R)EVOLUTION

Past, present and future of ethernet transceiver sales across the industry

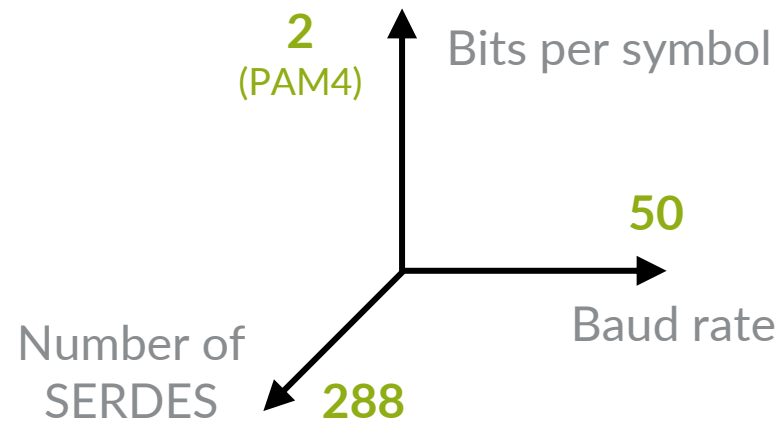


Adapted from Lightcounting, September 2022 High Speed Ethernet Optics Report

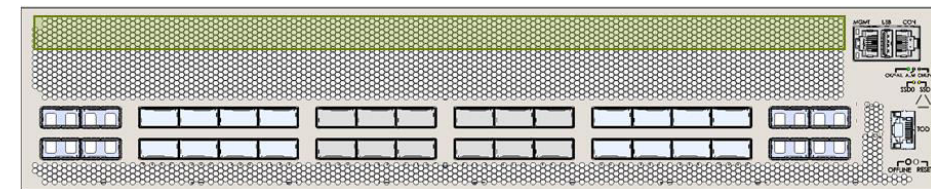
800G ADOPTION ON ROUTERS AND SWITCHES

Evolution to 100G Electrical I/O

Industry is evolving from 50G to 100G electrical I/O, and number of SERDES per PFE increases:



PTX10001-36MR
24 x 400GE



NG compact PTX
36 x 800G



Juniper
Express 4 (BT)
72 x 50G



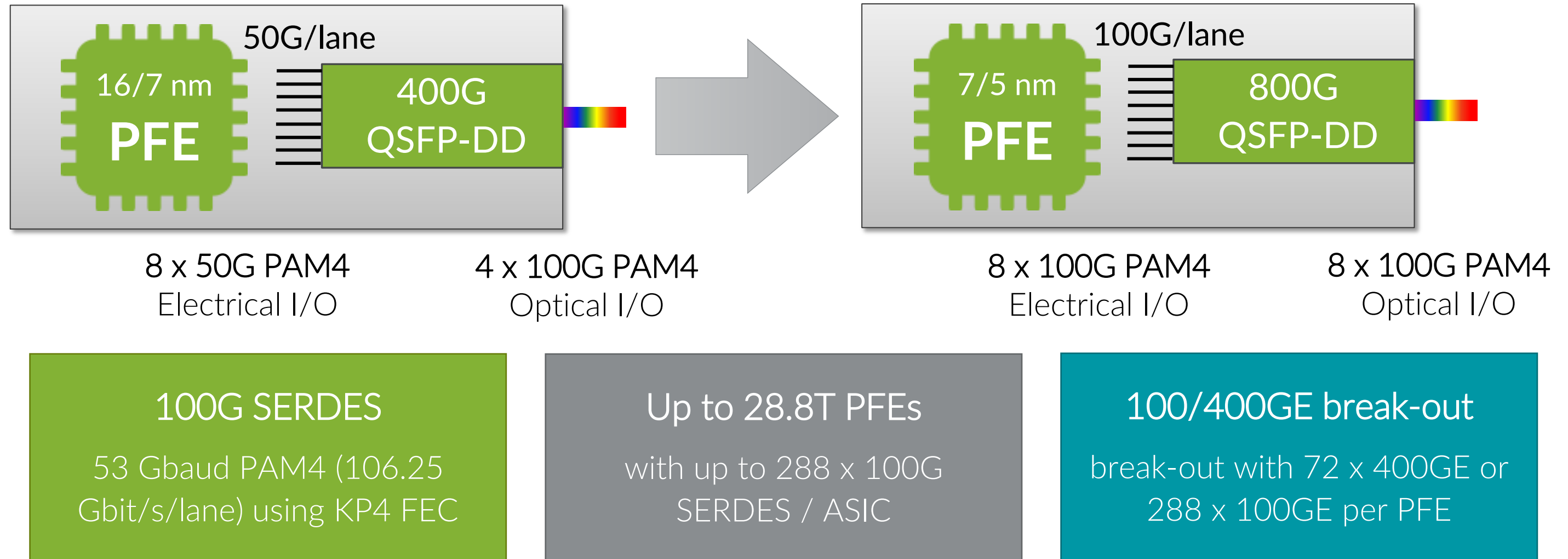
Juniper
Express 5 (BX)
288 x 100G

118 billion transistors

For more details: Chang-Hong Wu, "Juniper's Express 5: A 28.8Tbps Network Routing ASIC and Variations", <https://hc34.hotchips.org>

800G ADOPTION ON ROUTERS AND SWITCHES

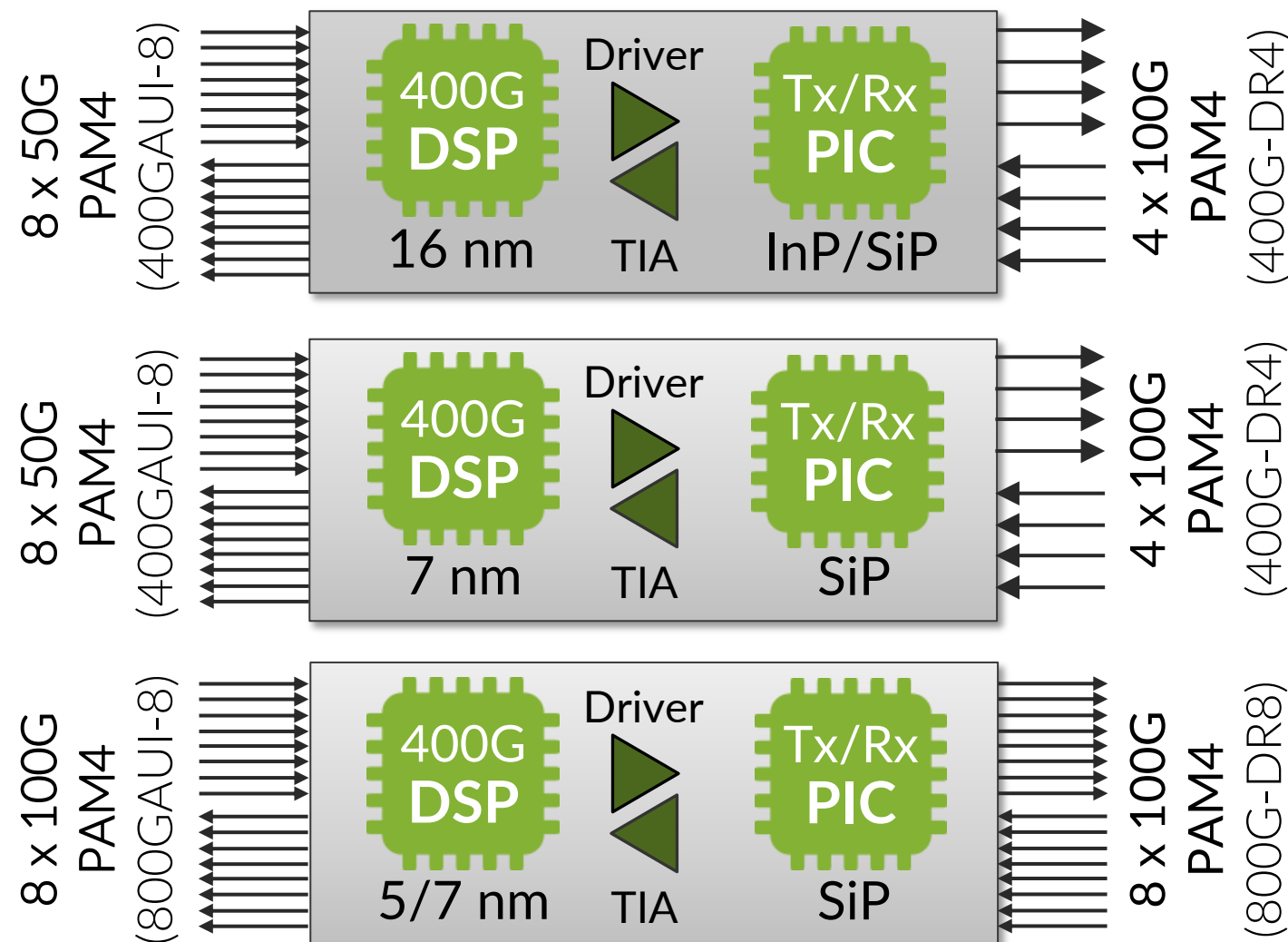
Evolution to 100G Electrical I/O



The adoption of 100G serial electrical I/O is the key building block for high-density 100GE/400GE-optimized routing and switching platforms

800G OPTICAL CLIENT INTERFACES

Power consumption evolution



400G "Gen-1"

16 nm CMOS, EML-based Tx
Typically 10~12 W

400G "Gen-2"

7 nm CMOS, SiP-based Tx,
more optimized DSP
Typically 8~10 W

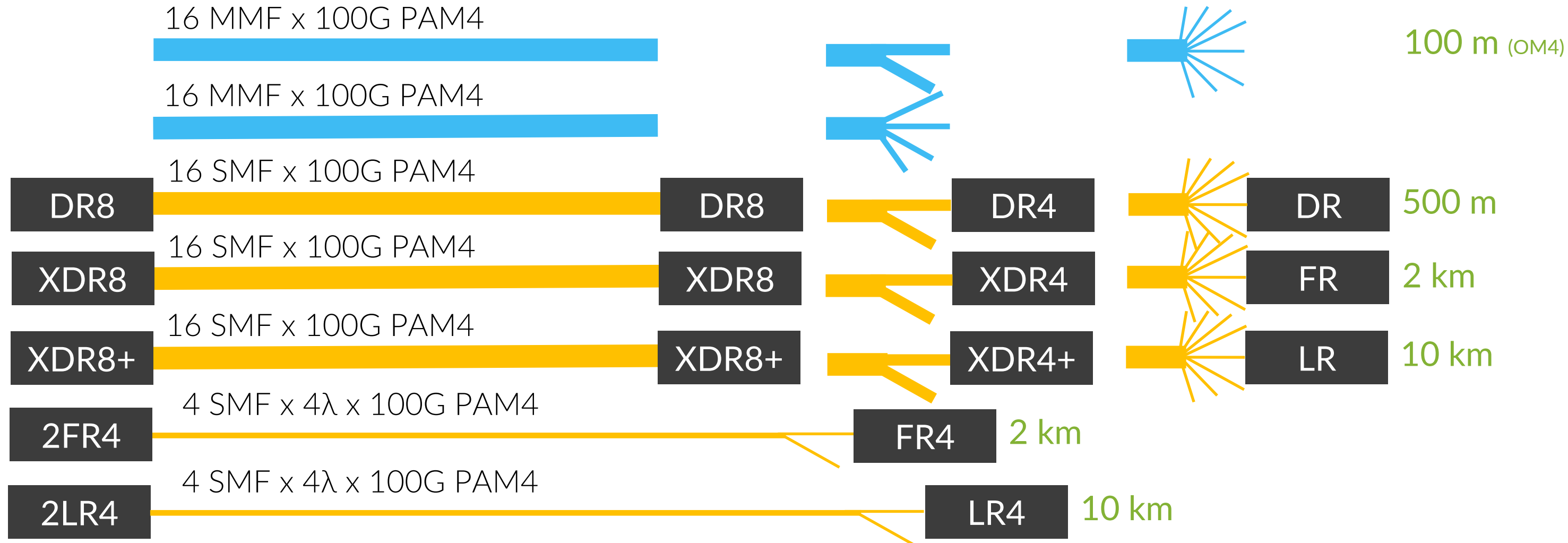
800G "Gen-1"

5/7 nm CMOS, no gearbox
Typically 16~18 W, 14~16 W with 5 nm

Photonic integration and more advanced DSP reduces power consumption over time, but optics remains a significant part of the total power consumption.

800GE OPTICAL CLIENT INTERFACES

100G optical I/O extends the life cycle of 100GE & 400GE



* XDR8 is also known as DR8+ or 8x100G-FR, and XDR8+ as DR8++ or 8x100G-LR

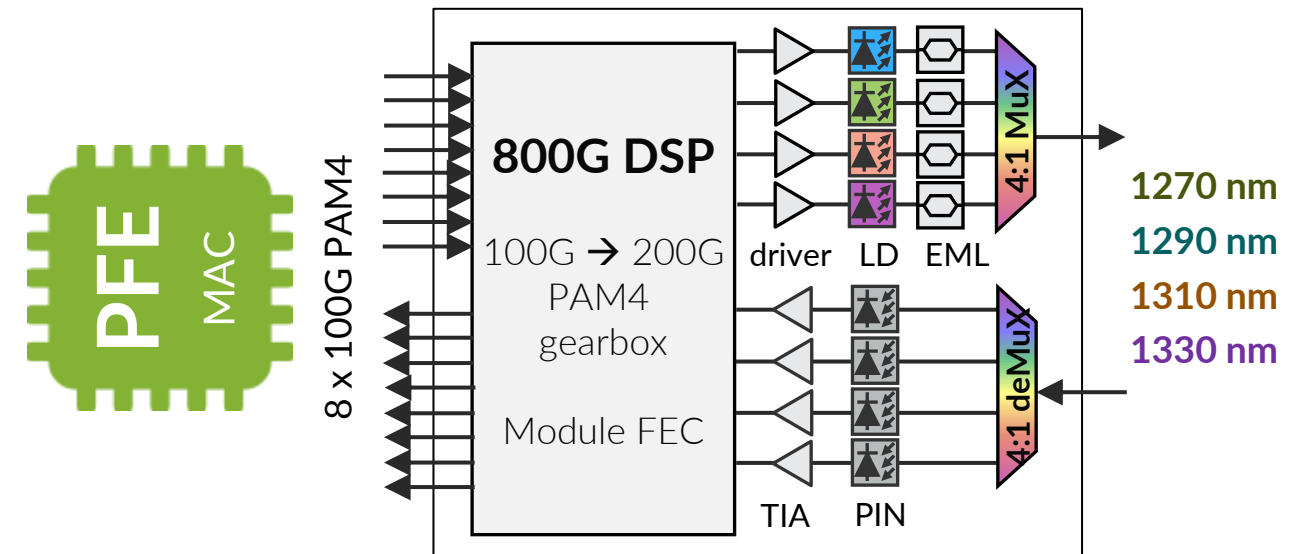
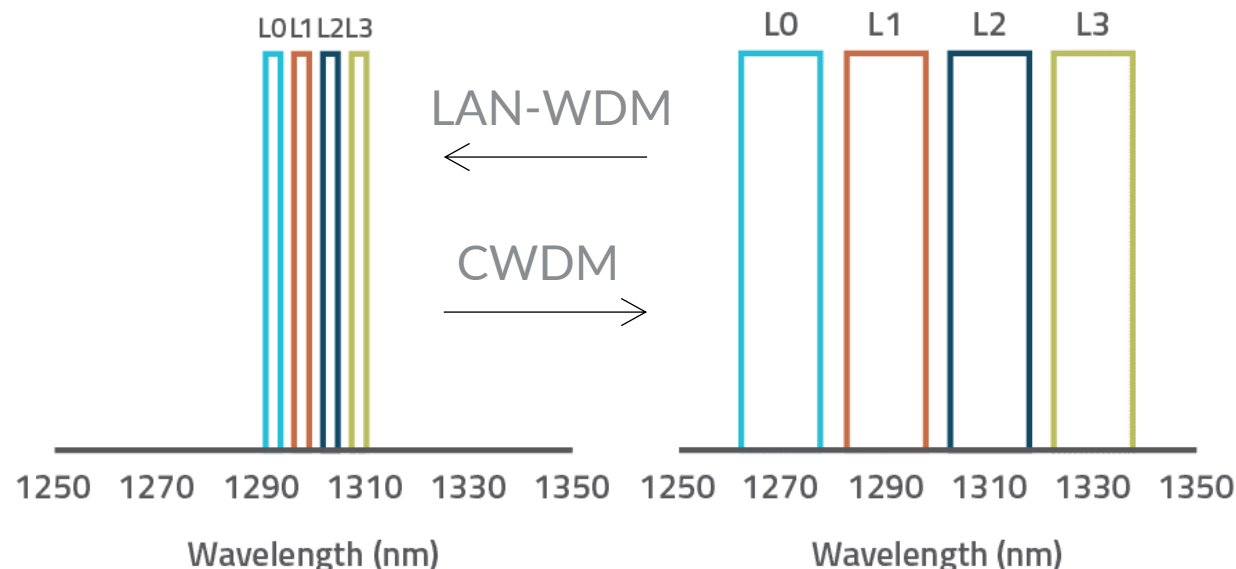
Today's mainstream 100G/400G optics, i.e. 100G DR/FR/LR and 400G DR4/FR4/LR4 are forward compatible with 800G break-out

800G OPTICAL CLIENT INTERFACES

Towards 200G optical I/O for duplex SMF optics

800G LR8 over duplex SMF based on 100G optical I/O is challenging:

- 8ch CWDM grid → Too high chromatic dispersion penalties for 10 km reach.
- 8ch LAN-WDM grid → Too high FWM penalties [1]
- ... and 8λ optics are not cost effective.



800G LR4 based on 200G optical I/O in exploration:

- 4-lane optics using 200G PAM4 modulation.
- 200G EML, driver and TIA have been successfully demonstrated for 1 or 2 km transmission
- Low chromatic dispersion tolerance requires careful chirp control and strong FEC

[1] X. Zhou et al., https://www.ieee802.org/3/df/public/22_05/22_0524/lam_3df_01a_220524.pdf, May 2022

800G OPTICAL CLIENT INTERFACES

Towards 200G optical I/O for duplex SMF optics

200G optical I/O needs stronger equalization and FEC inside the modules:

- Concatenated or segmented FEC scheme

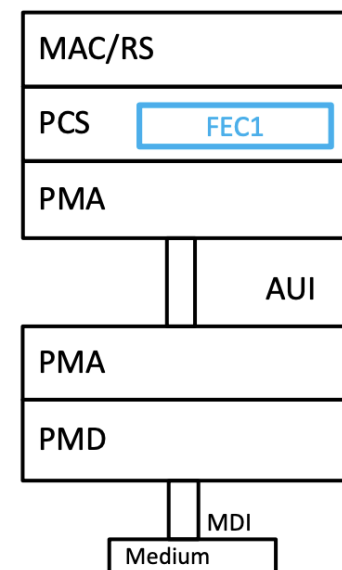
Current proposal in 802.3bj standardization:

- Outer KP4 code in the host
- (128,120) inner Hamming code in the module
- $4.85e-3$ pre-FEC BER threshold

From: https://www.ieee802.org/3/df/public/22_07/shrikhande_3df_01b_2207.pdf
https://www.ieee802.org/3/dj/public/23_01/23_0206/farhood_3dj_01a_230206.pdf

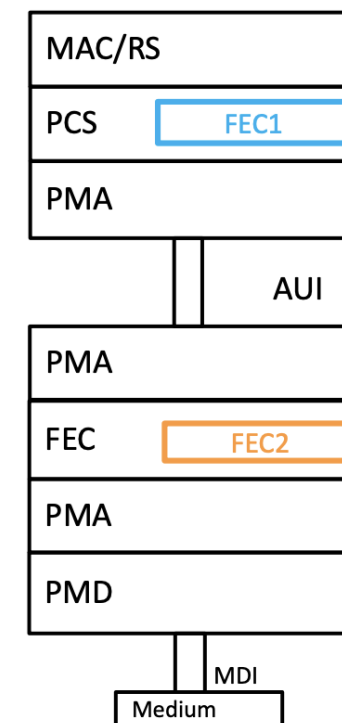
End-to-End FEC scheme

(FEC1 used for AUIs and PMD)



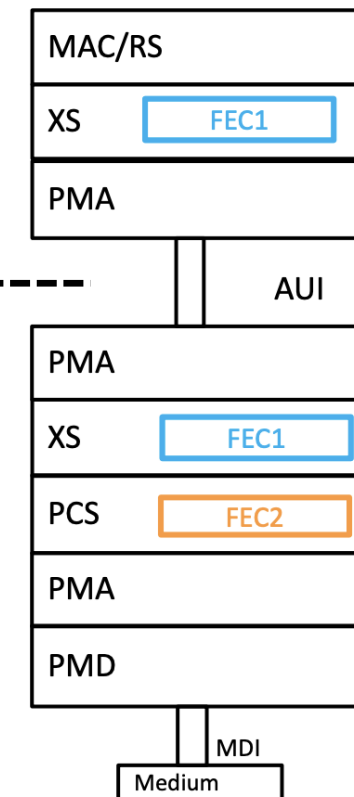
Concatenated FEC scheme

(FEC2 is added on top of FEC1.
FEC 1 for AUIs, FEC1+FEC2 for PMD)



Segmented FEC scheme

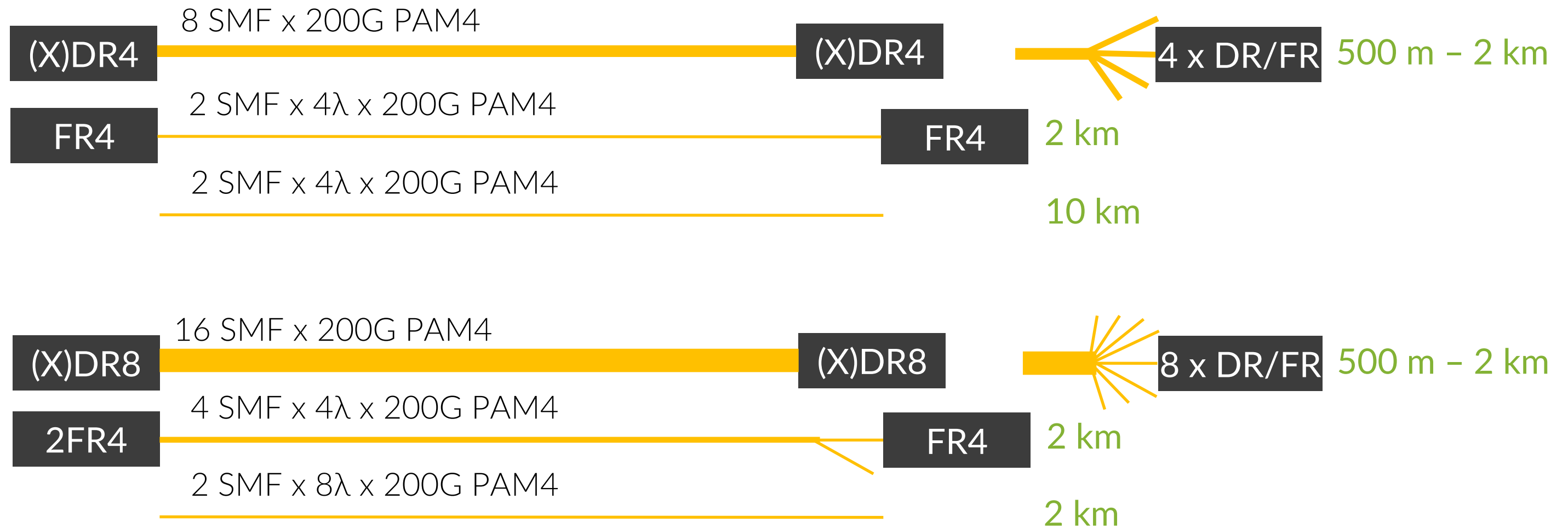
(FEC2 replaces FEC1. FEC1 used for local AUI only. FEC2 for PMD only)



KP4 FEC in the host combined with low-latency (soft-decision) FEC in the module ensures backwards compatibility of future optics with today's routers

800GE & 1.6TE OPTICAL CLIENT INTERFACES

200G optical I/O



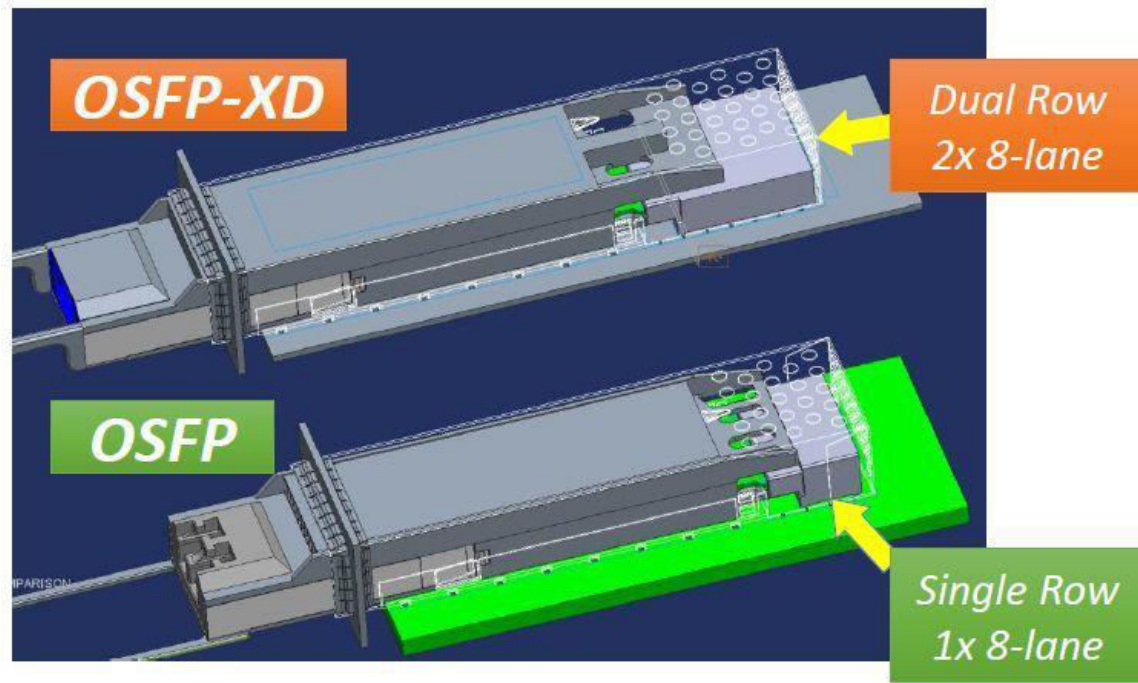
200G PAM4 electrical and optical I/O will be the main building for “gen-2” 800GE and 1.6TE optical interfaces

BEYOND 800G

Next-generation pluggable form factors



<https://osfpmsa.org/>



From: OSFP MSA

QSFP-DD
connector

+

OSFP*
Integrated
heatsink

=

OSFP-XD

OSFP-XD as next-generation pluggable form factor:

- 16-lane electrical I/O
- Combining denser (.6 mm) pitch of OSFP with DD design of QSFP-DD connector.
- Target is to support up to 40 W module power consumption.

OSFP-XD will support 1.6T with 100G electrical I/O:

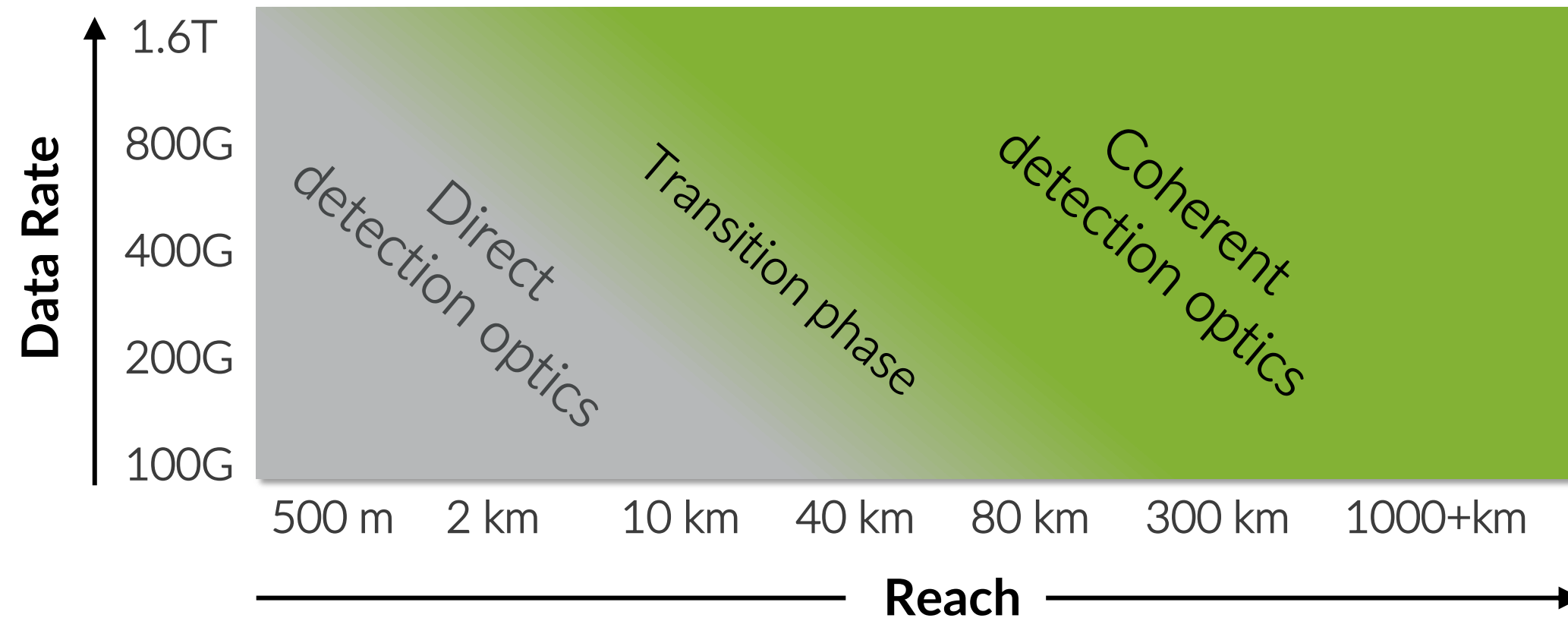
- Future evolution to 3.2T per pluggable optic with 200G electrical I/O.

*OSFP-XD is not backwards compatible to OSFP

OSFP-XD potentially enables the evolution of pluggable optics to support up to 102.4T switches in 1RU with 32 x 3.2T ports

COHERENT vs. DIRECT-DETECTION OPTICS

Technology evolution



Direct-detect and coherent optics are converging more and more with increasing data rates, as both need similar DSP functions and therefore approach similar complexity

COHERENT GOES (QSFP) PLUGGABLE

The (big) promise of IP-Optical integration

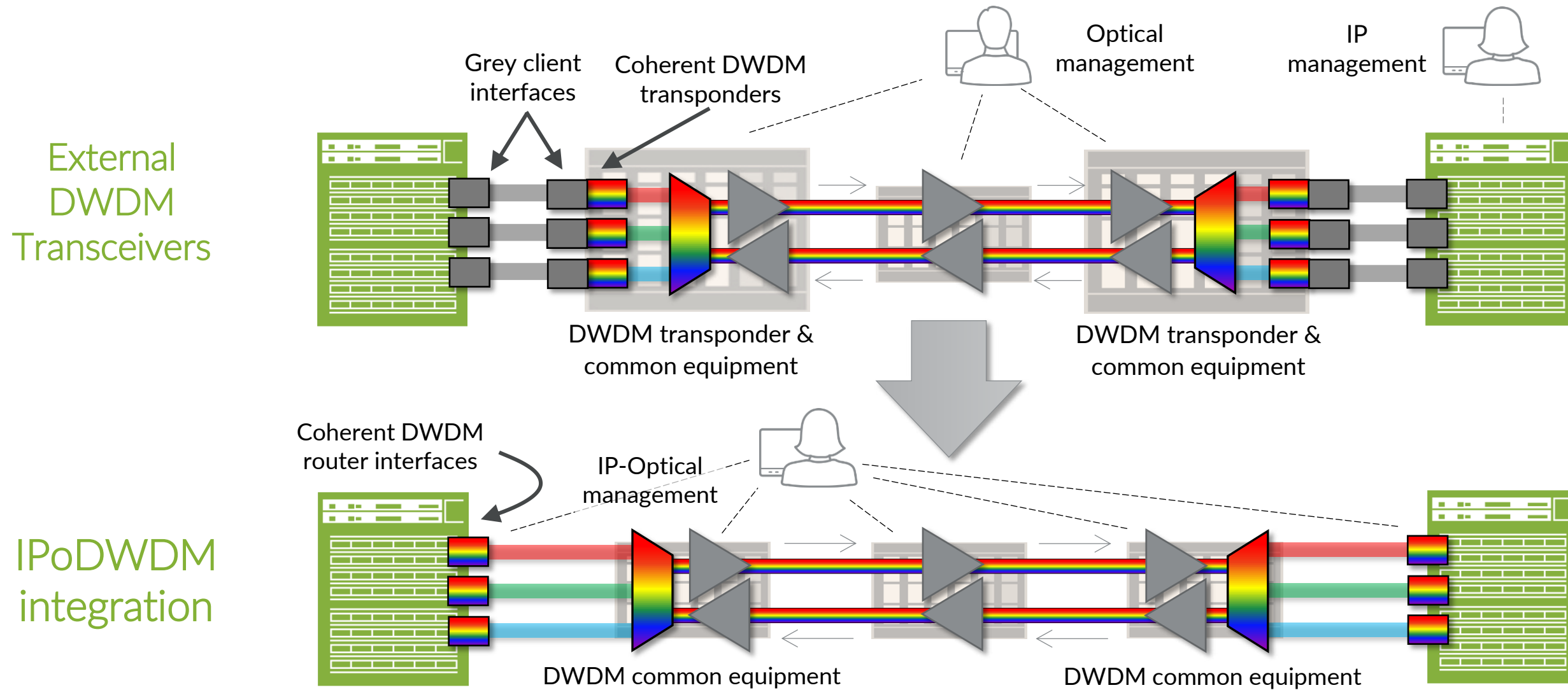


“Innovation does not entail having new ideas, but rather getting rid of old believes”

– Jacques Piccard

COHERENT GOES (QSFP) PLUGGABLE

The (big) promise of IP-Optical integration

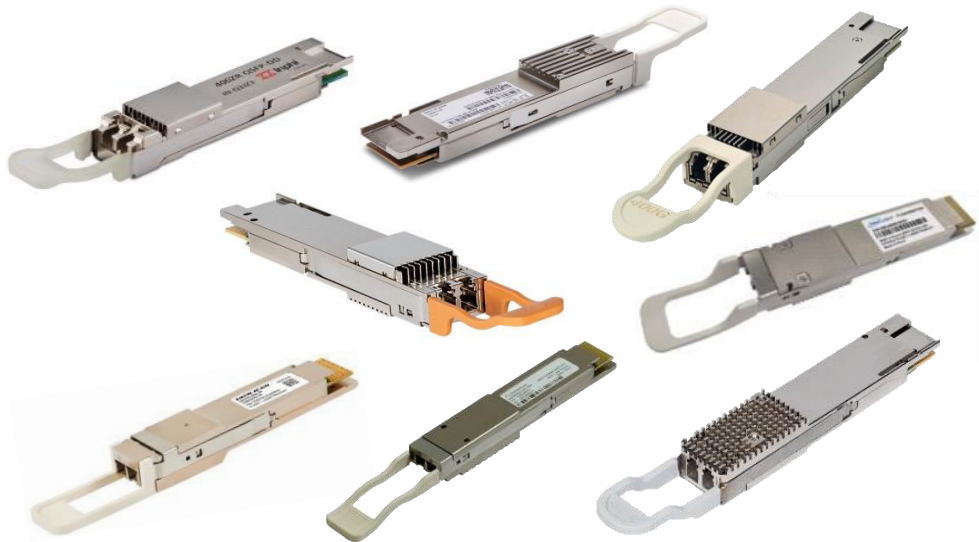


IP-optical integration eliminates hardware components, which in turn increases reliability, lowers cost, reduces power, and minimizes footprint

COHERENT GOES (QSFP) PLUGGABLE

The (big) promise of IP-Optical integration

2023: Healthy ecosystem of 400G coherent pluggable optics



0 dBm

2022: QSFP-DD with high Tx output power

75-GHz

2022: OIF and OpenZR+ add 75-GHz support

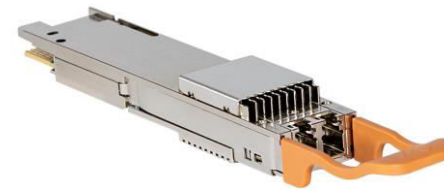
2020: OpenZR+ MSA



2020: OIF releases 400ZR IAs



2020: First 400ZR pluggables



Early proprietary ACO/DCO pluggables



Project Start: 400ZR Interop

OIF2016.400.04



2016: OIF starts working on 400ZR IA



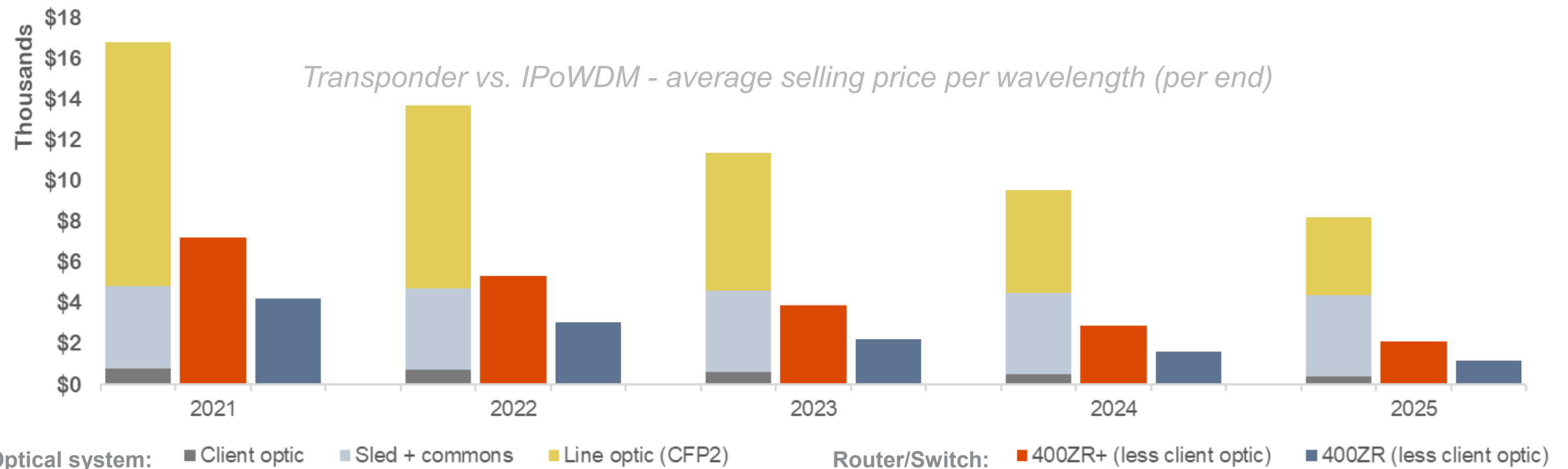
2020: OIF starts working on 800G coherent (LR/ZR)

2023: OIF releases 800LR/ZR IAs (???)

To Infinity and Beyond!, Ethernet and optics on the road to 800GE and 1.6TE, March 2023

COHERENT 400ZR/ZR+ OPTICS

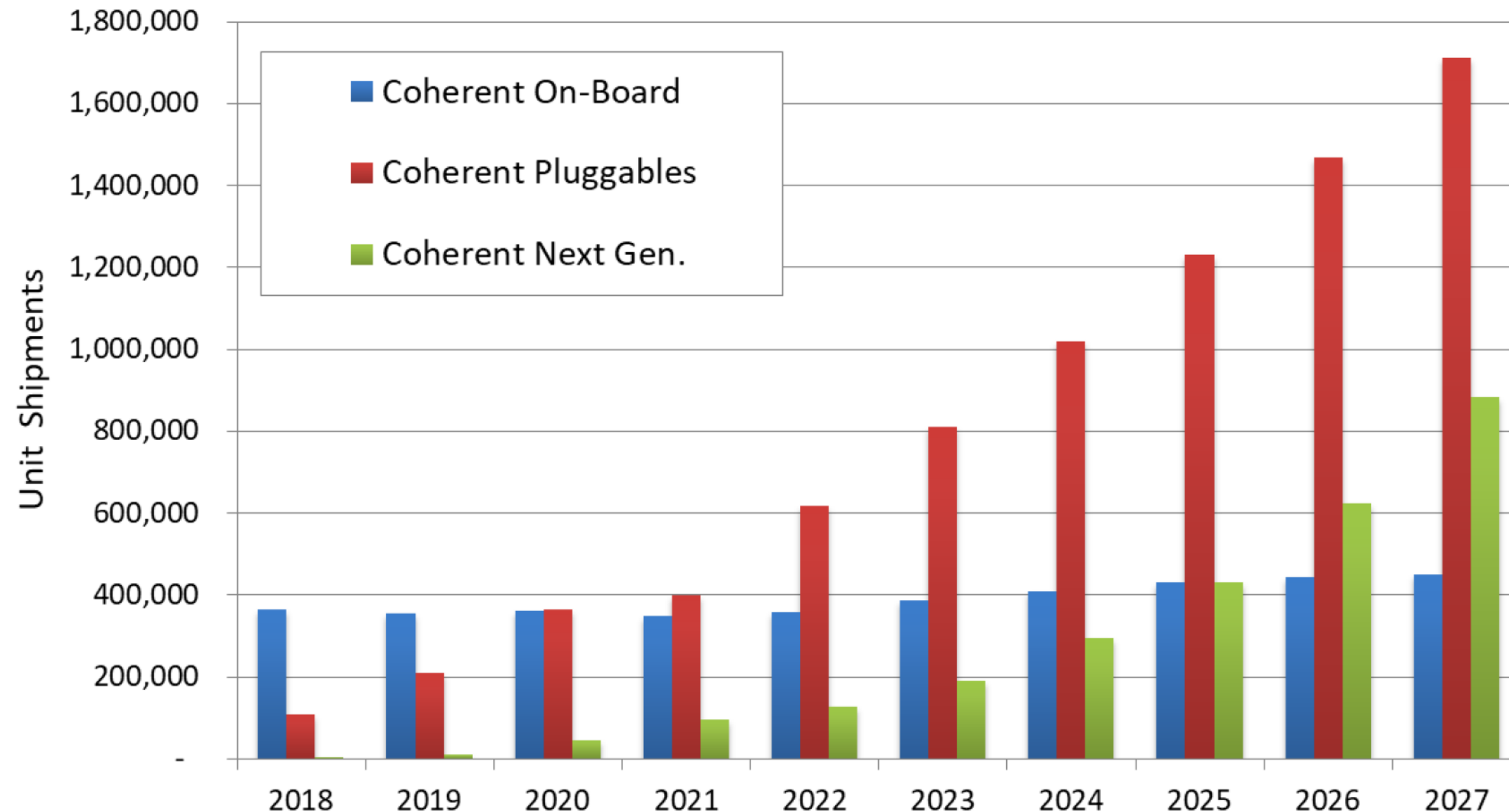
CAPEX comparison with external transponders



From: Signal AI, 400ZR/ZR+ IPoDWDM Market Impact and Forecast, November 2021

COHERENT 400ZR/ZR+ OPTICS

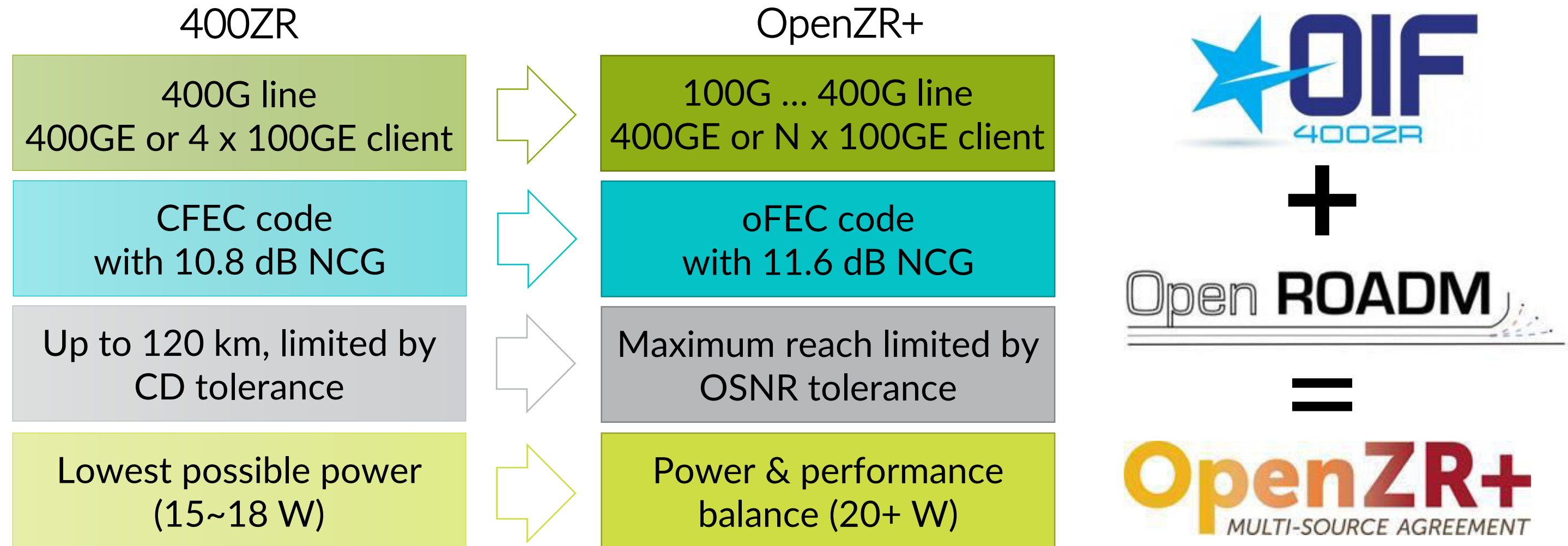
Not an evolution, but a revolution!



From Lightcounting, October 2022 Market Forecast Report

OIF 400ZR & OpenZR+ MSA

Coherent DWDM pluggables for DCI, metro, regional & long-haul



https://www.oiforum.com/wp-content/uploads/OIF-400ZR-01.0_reduced2.pdf

http://www.openzrplus.org/site/assets/files/1075/openzrplus_1p0.pdf

400G coherent DWDM pluggable are quickly becoming the de-facto standard deployment model for DCI, metro and regional applications

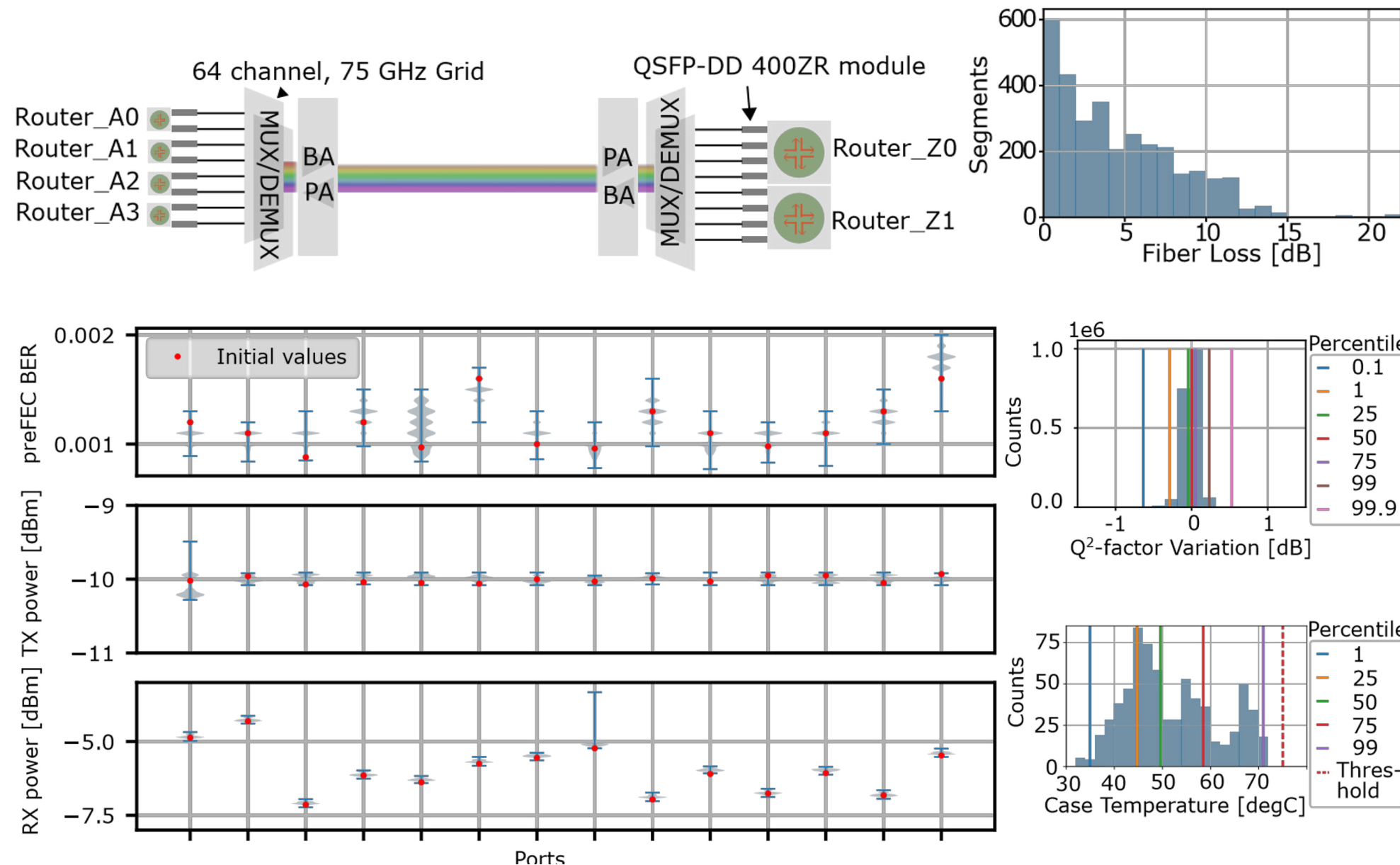
OIF 400ZR PLUGFEST

at OFC 2023 conference



400ZR FIELD DATA

Statistics from Microsoft's first ~700 deployed modules

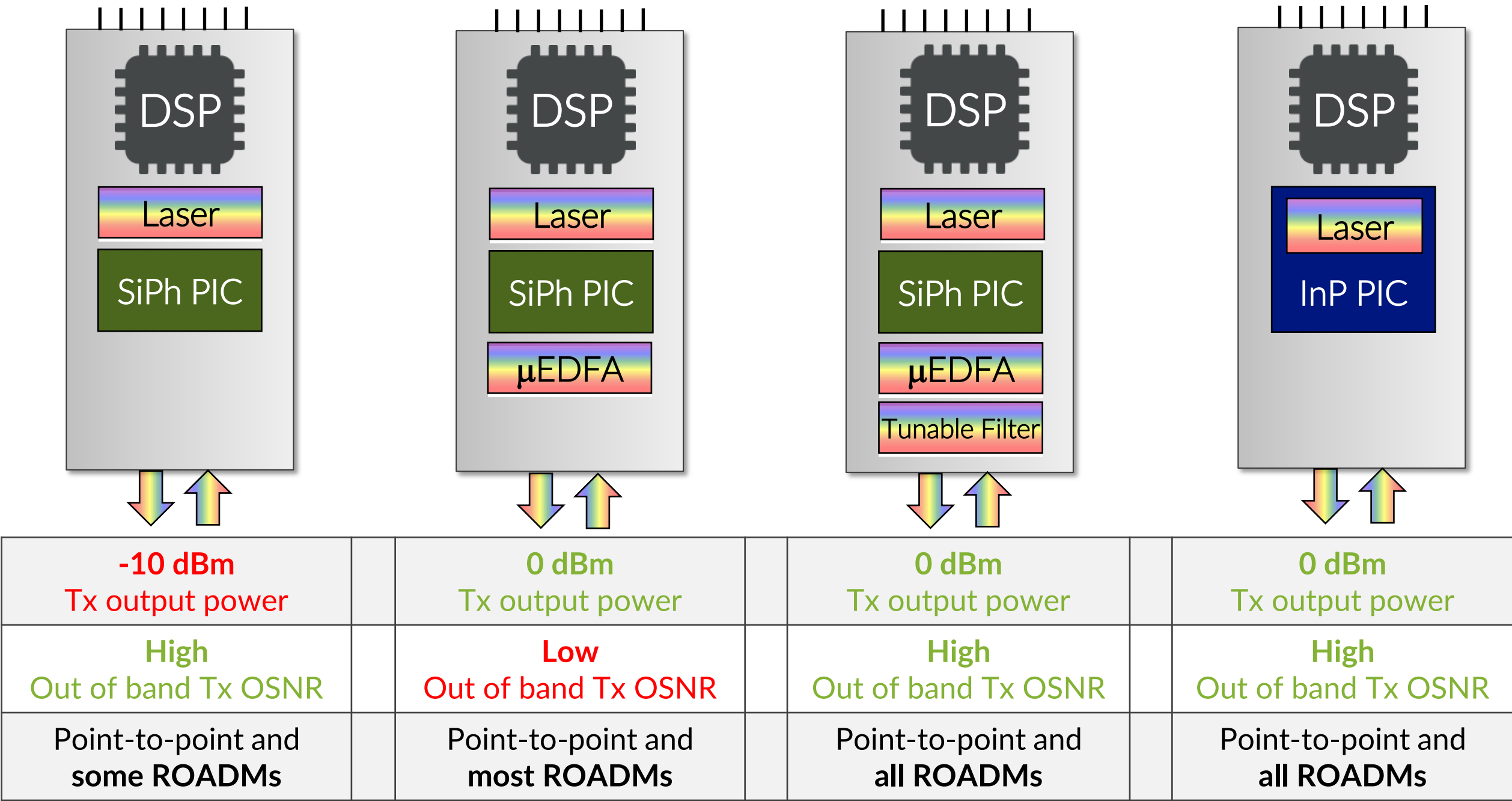


- Statistics from Microsoft's first ~700 deployed modules
- Metro fiber loss distributions well-confined < 20 dB
- Ultra-stable performance over time (Q std dev ± 0.06 dB for 1.5 months)
- Case temp < 72 C across all module suppliers, router HW platforms, operating environments

Source: C. Qin et al., "Interoperable 400ZR Deployment at Cloud Scale" OFC 2023, paper W3H.2

COHERENT GOES (QSFP) PLUGGABLE

How to achieve a higher transmit output power



800G COHERENT FOR DCI

Coherent DWDM OIF 800ZR preliminary specifications

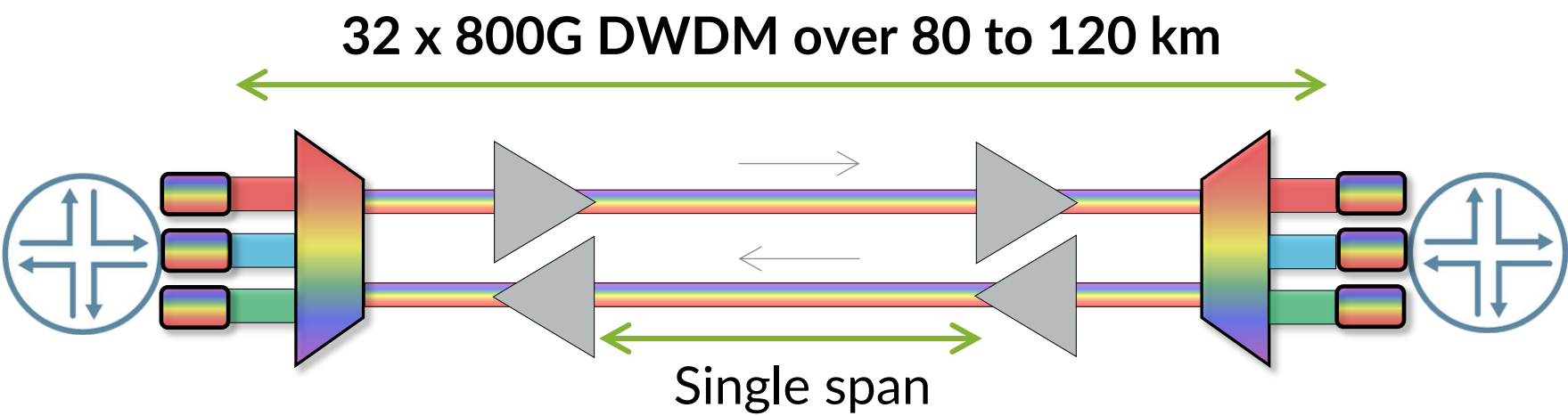
1 x 800GE/ETC, 2 x 400GE, 4 x 200GE, 8 x 100GE clients

DP-16QAM modulation with 118.2 Gbaud symbol rate

Standardized FEC with 15.3% OFEC code and 11.6 dB NCG

C-band tunable DWDM with 150 GHz channel spacing

QSFP-DD and OSFP form factors



	400ZR	800ZR
Target reach	Up to 120 km	Up to 120 km
Link Loss (minimum)	24 dB	24 dB
Tx output power range	-10 dBm (0x03)	-7 dBm
Rx input power range	-12 to 0 dBm	-9 to 0 dBm
Rx received OSNR	26.0 dB/0.1 nm	27.0 dB/0.1 nm

400G OpenZR+ IN THE WILD

Trial at SUNET

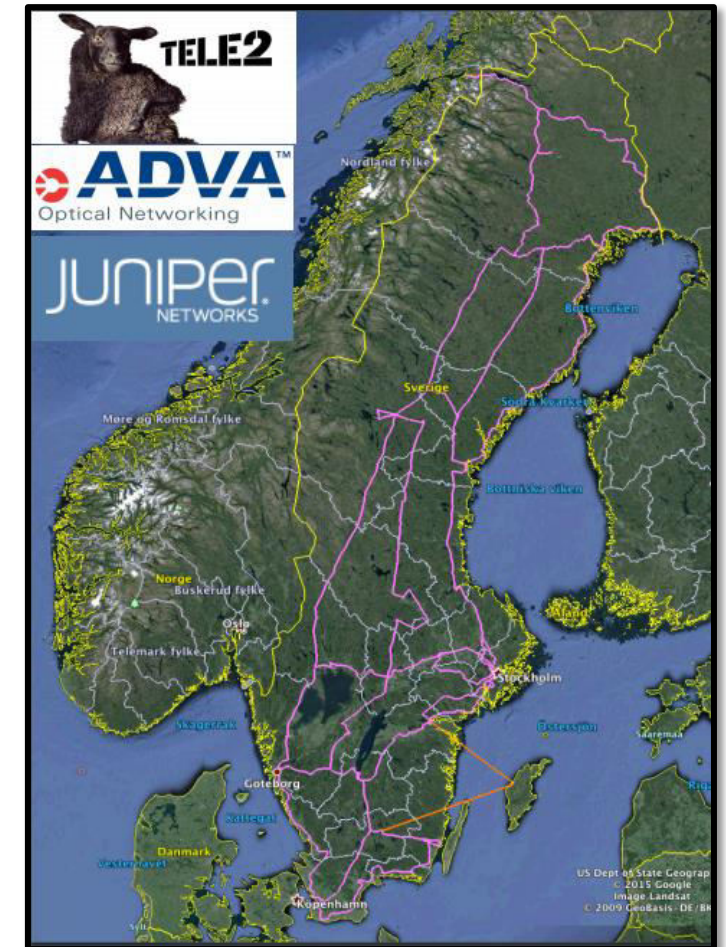
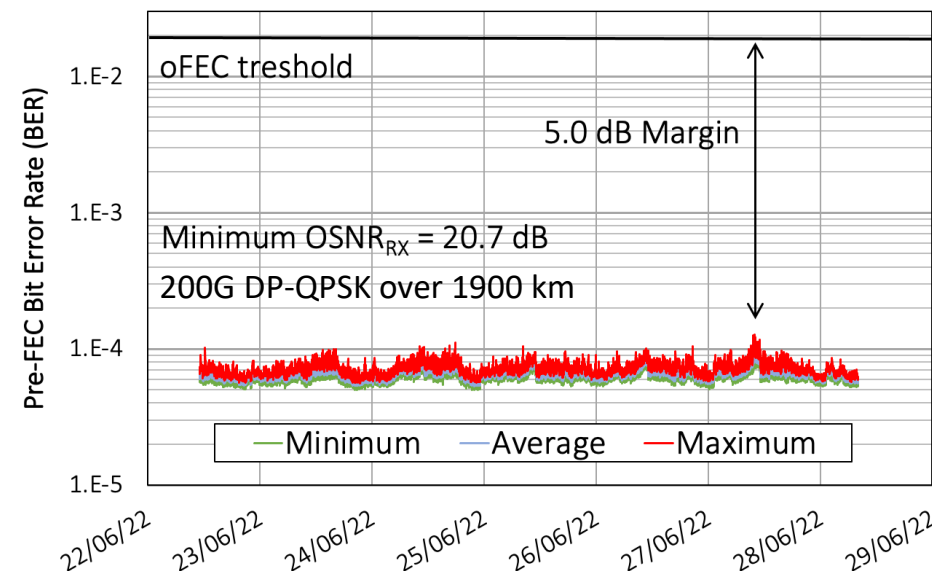
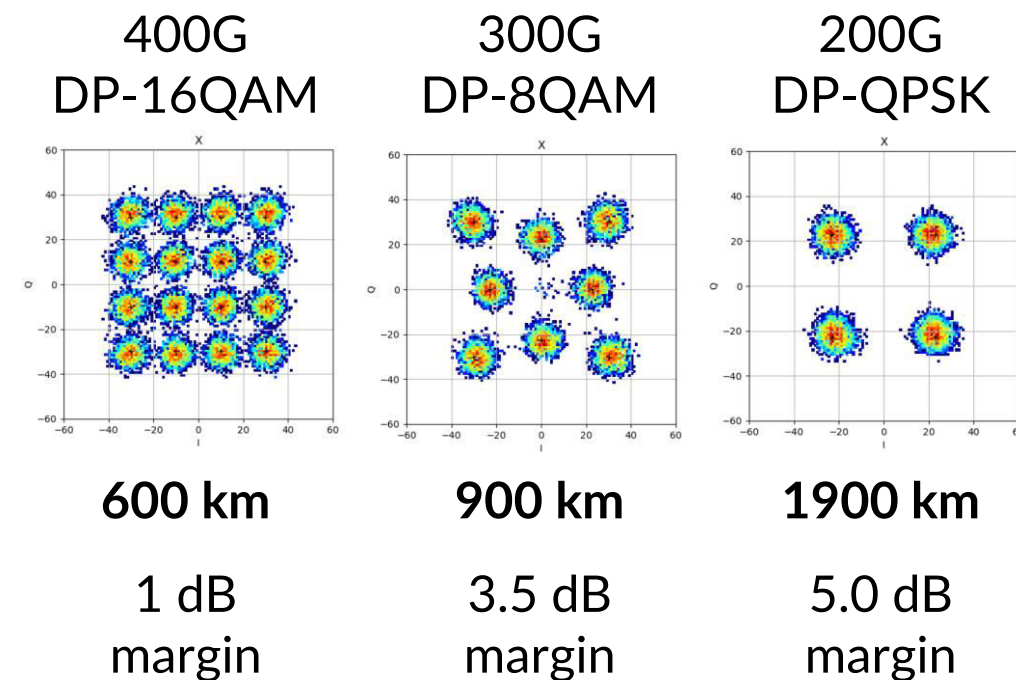


400G ZR+ trial result over SUNET's national fiber backbone:

- PTX10001-36MR with 400G ZR+
- 22.3 beta code for Openconfig telemetry.

```
root@ptx-1> show interfaces transport pm optics current et-0/0/0
Physical interface: et-0/0/0, SNMP ifIndex 512
2022-04-13,23:00:00 - current
Suspect Flag:False
Reason:Not Applicable
```

PM	CURRENT	MIN	MAX	AVG
Module temperature(Celsius)	48	48	48	48
Pre-FEC BER	8.01e-3	7.71e-3	8.18e-3	7.97e-3
Uncorrected FER	0.00e+0	0.00e+0	0.00e+0	0.00e+0
SNR (dB)	15.4	15.0	15.9	15.3
Tx power (dBm)	-11.1	-11.1	-11.0	-11.1
Rx total power (dBm)	-9.4	-9.5	-9.3	-9.4
Carrier frequency offset (MHz)	0	0	1	0
Chromatic dispersion (ps/nm)	10554	10553	10555	10553
Differential group delay (ps)	4.00	3.00	4.00	3.68
SOPMD (ps^2)	37	8.00	103	42
PDL (dB)	0.6	0.5	0.6	0.6
OSNR (dB)	24.7	24.4	24.8	24.6



Sunet national fiber network

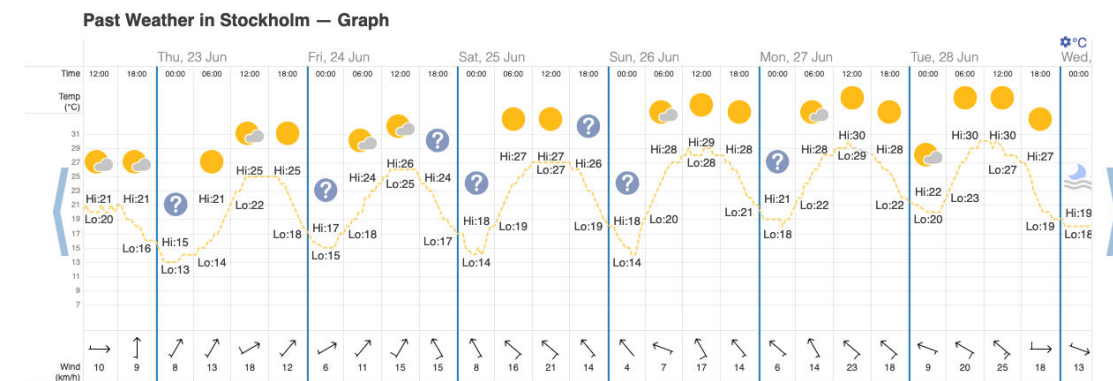
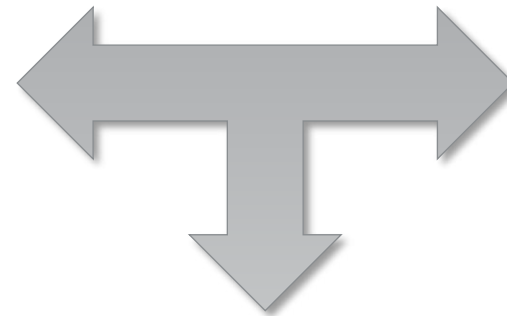
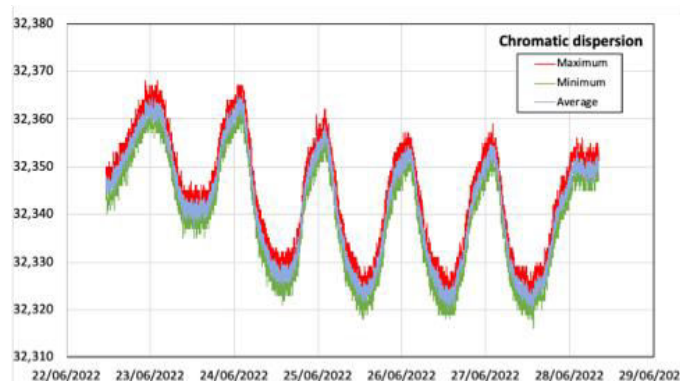
400G ZR+ trial on SUNET's national fiber backbone shows 400G coherent pluggables are a viable option even for regional and long-haul distances

400G OpenZR+ IN THE WILD

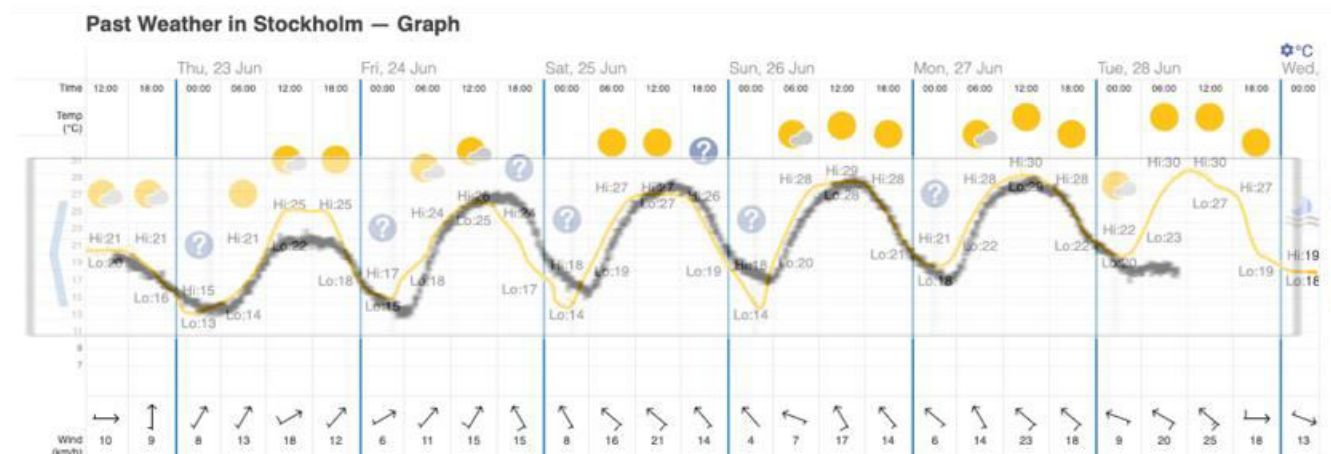
Trial at SUNET



400G ZR+ coherent pluggable optics allow for the export of detailed optical performance monitoring statistics for more insight into the transport layer:



Now you can even use a Juniper PTX to predict the weather 😊



IPoDWDM now (finally) is a mature and mainstream technology

Q & A



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