DENOG 14

400G-ZR(+) Real World Examples

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Optics Overview

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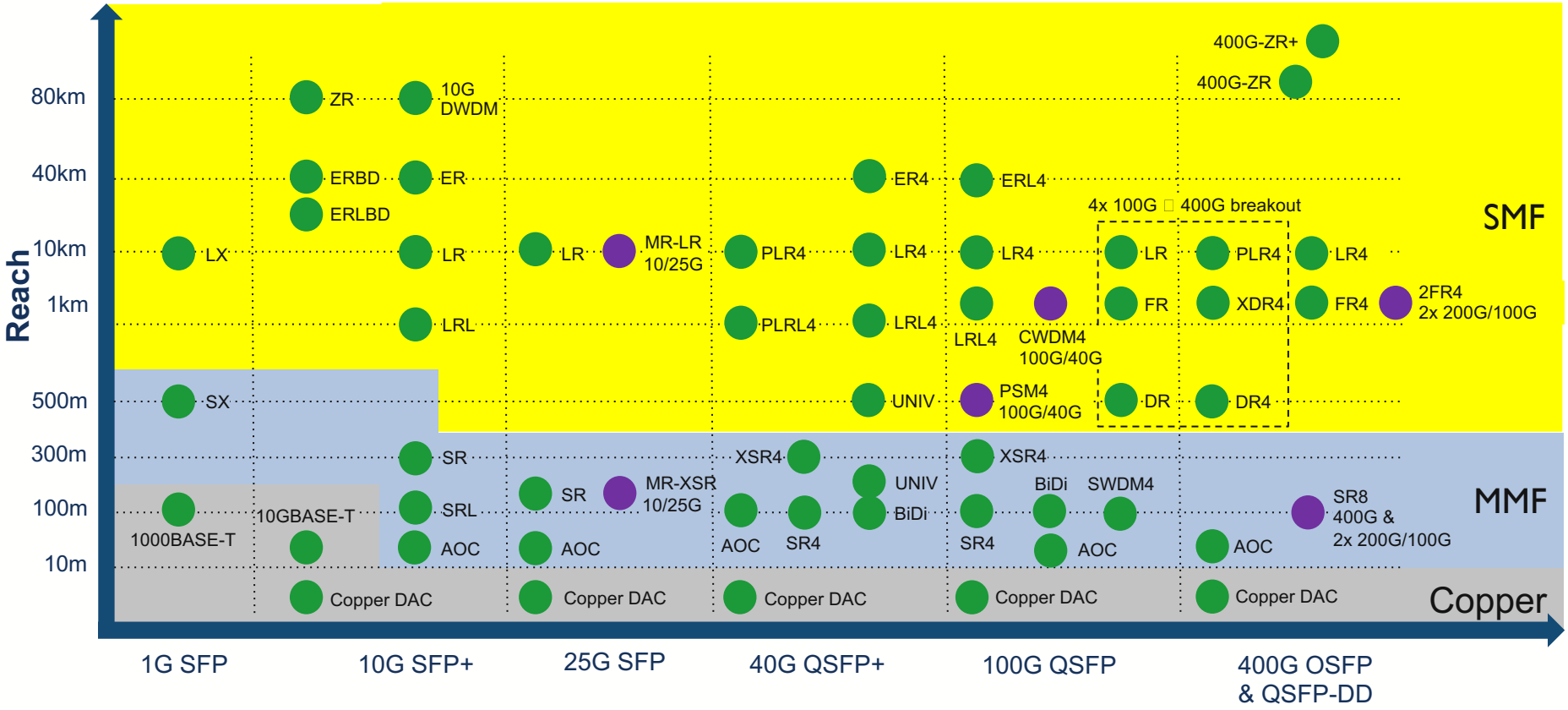
Optics & Cables: Broad Portfolio from 1G to 400G



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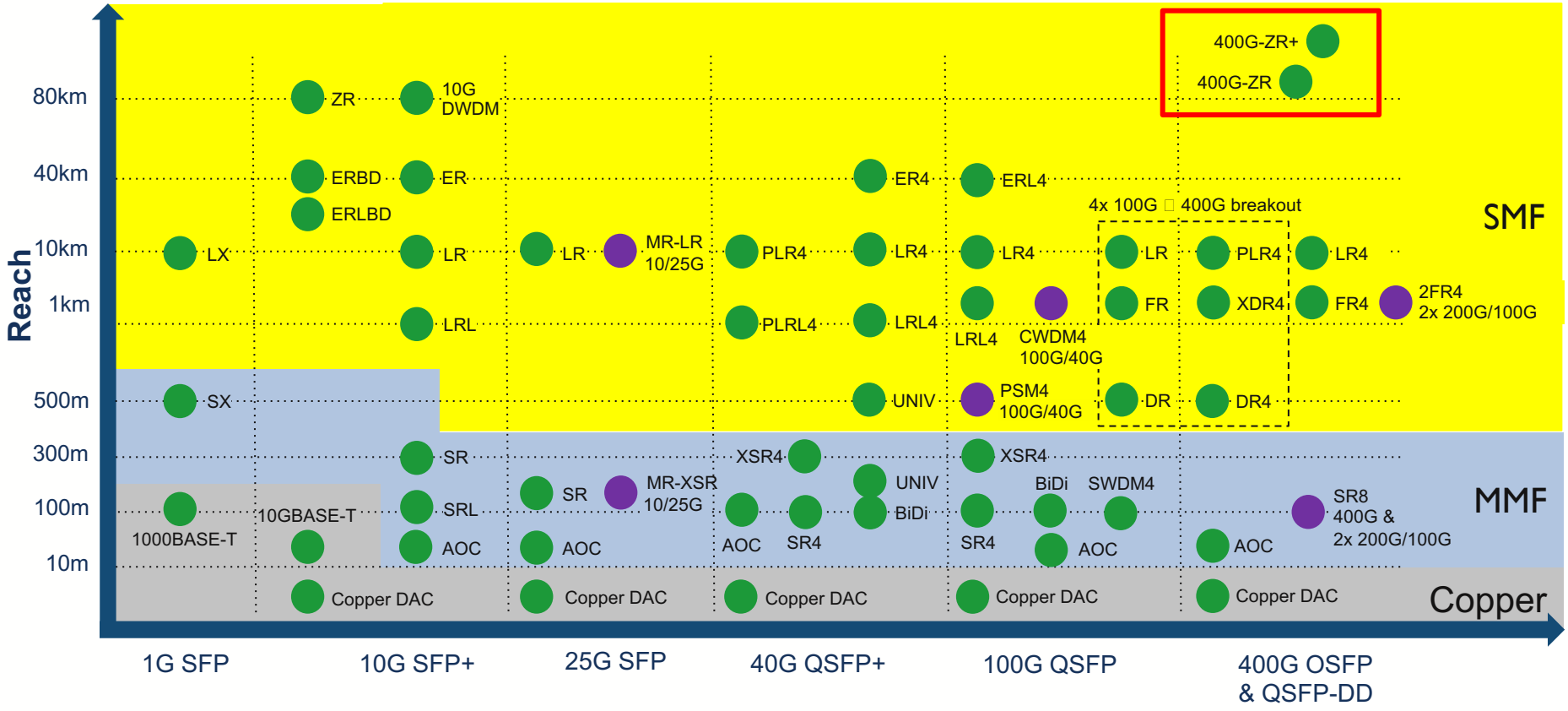
Optics & Cables: Broad Portfolio from 1G to 400G



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400G ZR
Metro

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400G-ZR Transceiver Specifications

Channel Range (Tunable)	191.375 to 196.100 THz
Channel Grid	100GHz & 75GHz
Optical Connector Type	Duplex LC
Tx output power	> -10 dBm*
Min Tx OSNR	45 dB
Rx input power	-16 dBm to 0 dBm
Min Rx OSNR	> 26 dB
Pre-FEC BER threshold	1.0E-02
Forward Error Correction (FEC)	C-FEC
Max amplified reach **	120km
Max span loss **	25 dB
Min span loss	2 dB
Max chromatic dispersion	2400 ps/nm
Power consumption	16 W Typ, 20 W max
Max case temperature	75C

Frequency and Grid Spacing

Low Launch Power Amplification needed

Critical value to ensure error free signal

Critical value to ensure link stability

Data based upon Arista 400G-ZR Datasheet

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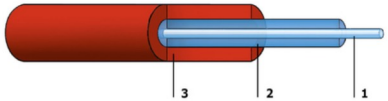
Typical Fiber Specifications

Single-mode fibre, E9/125/250, OS2 / G.652.D

low attenuation

in accordance with ITU-T G.652.D, IEC 60793-2-50 Type B1.3, equates to EN 50173:2011 OS2



1 Core
2 Cladding
3 Coating

OPTICAL PROPERTIES

Transmission characteristics

Wavelength	**[nm]**	**1310**	**1383**	**1550**	**1625**
Maximum attenuation (cabled)	[dB/km]	0.34	0.34*	0.21	0.23
		*post hydrogen aging performance			
Maximum Chromatic Dispersion	[ps/(nm x km)]	3,5		18	23
Zero Dispersion Wavelength λ_0	[nm]	$1304 \leq \lambda_0 \leq 1324$			
Maximim Zero Dispersion Slope So	[ps/(nm^2 x km)]	0.092			
Mode-Filed Diameter	[µm]	9.2 +/- 0.4		10.4 +/- 0.5	
Maximum Cable Cut-off Wavelength λ_{CC}	[nm]	1260			
Polarisation Mode Dispersion					
PMD Link Design Value	[ps/√km]	≤ 0.04			
Max. individual fibre PMD	[ps/√km]	≤ 0.1			
Max. individual cable PMD	[ps/√km]	≤ 0.2			
Refractive Index		1.4676		1.4682	

<0.25 dB/km required for ideal range

Typical value is around 17 ps/nm

Data based upon Datwyler Datasheet Single Mode Fiber OS2/G.652.D

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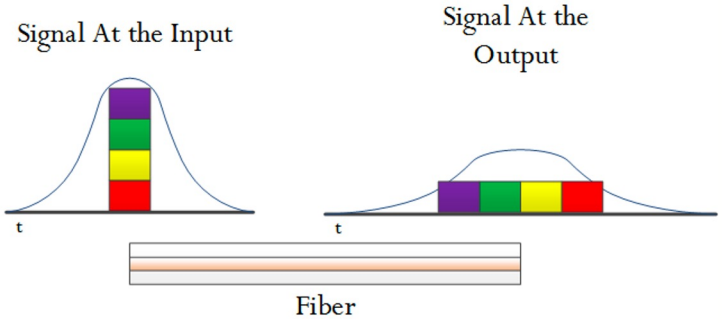
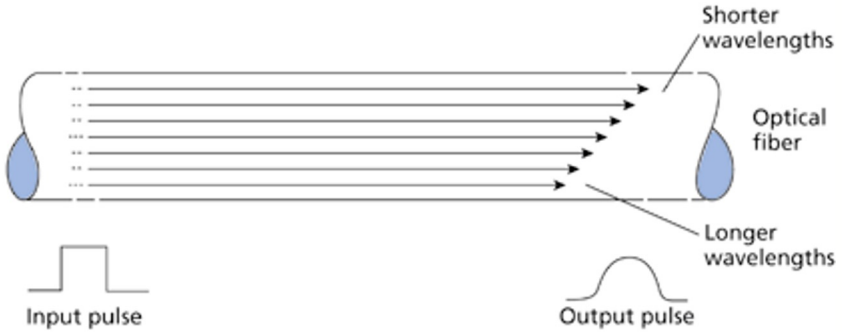
Optical Networking 101: Chromatic Dispersion

- Chromatic Dispersion is the phenomenon in which the phase velocity of a wave depends on its frequency
  - Different wavelength will travel at different speeds and hence broaden the overall signal





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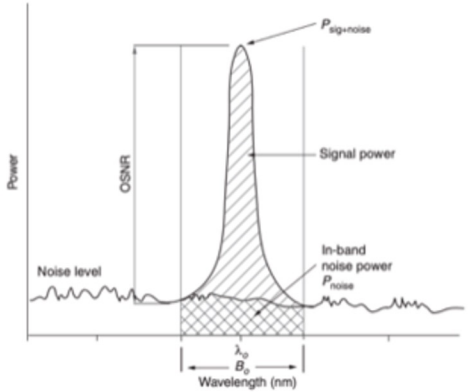
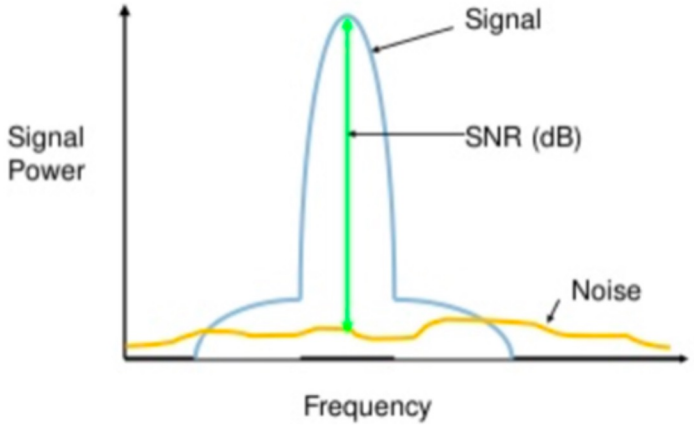
Optical Networking 101: OSNR

- Optical signal-to-noise ratio (OSNR) is used to quantify the degree of optical noise interference on optical signals
  - Direct relationship between OSNR and bit error rate (BER)





$$\text{BER} = \frac{\text{no. of incorrect received bits}}{\text{no. of transmitted bits}}$$

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400G-ZR / Point-to-Point for Metro Connections

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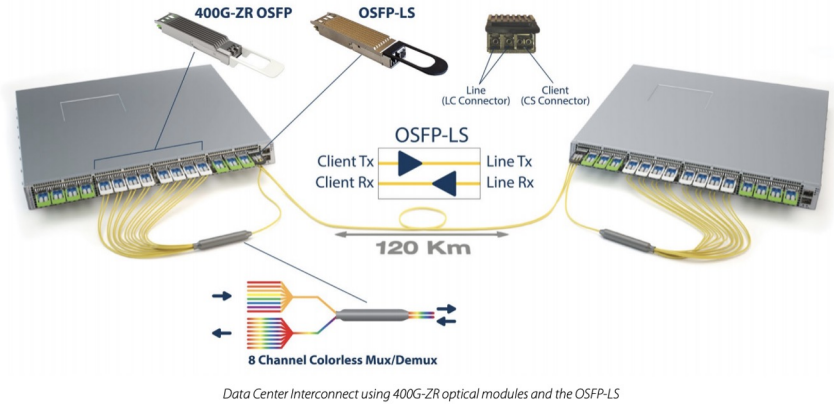
400G-ZR / Configuration

```
SiteA# show interface status | grep ZR
Et34/1            connected    routed    full    400G    400GBASE-ZR
Et35/1            connected    trunk     full    400G    400GBASE-ZR
Et36/1            errdisabled  1         full    400G    AMP-ZR
```

```
interface Ethernet34/1
   description To_SiteB
   no switchport
   ip address 10.1.34.1/24
   transceiver frequency 193100.000
   transceiver transmitter signal-power -10.00
!

interface Ethernet35/1
   description To_SiteB
   switchport mode trunk
   transceiver frequency 193300.000
   transceiver transmitter signal-power -10.00
```



Data Center Interconnect using 400G-ZR optical modules and the OSFP-LS

400G-ZR optics are tunable (coherent)
You define the frequency per optic

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400G-ZR / **80 km** / Transceiver

```
SiteB# sh int et 34/1 transceiver dom
Ch: Channel, N/A: not applicable, TX: transmit, RX: receive
mA: milliamperes, dBm: decibels (milliwatts), C: Celsius, V: Volts
Port 34
Last update: 0:00:05 ago
                                        Value
                                      ----------------
   Case temperature                     58.00 C
   Voltage                               3.30 V
   TX power                             -9.94 dBm
   RX total power                       -1.75 dBm
   RX channel power                     -8.90 dBm
   Pre-FEC BER                       4.28e-03
   Post-FEC errored frames ratio     0.00e+00
   Chromatic dispersion (short link)   -1384.00 ps/nm
   Differential group delay              4.00 ps
   SOPMD                                43.00 ps^2
   Polarization dependent loss           0.70 dB
   Received OSNR estimate               26.70 dB
   Received ESNR estimate               15.80 dB
   Carrier frequency offset            112.00 MHz
   SOP rate of change                    0.00 krad/s
   Laser temperature                    49.21 C
   Laser frequency                   193100.00 GHz
```

Post-FEC errored frames ratio is very important

Same calculation as for the previous link

1384/17=81.41 km

Configured laser frequency

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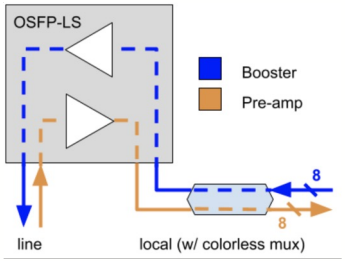
400G-ZR / **80 km** / Line System DOM

```
SiteB# show line system port 36 dom thresholds
                                        High Alarm  High Warn   Low Warn  Low Alarm
                                  Value  Threshold  Threshold  Threshold  Threshold  Unit  Indicator
                                -------------------------------------------------------------------
   Temperature                    37.59      70.00      65.00       0.00      -5.00     C
   Voltage                         3.28       3.47       3.37       3.23       3.14     V
Booster
   Optical TX power (line)         9.46      16.99      16.53      -0.00      -6.03   dBm
   Optical RX power (local)      -16.50      -7.20      -8.23     -20.97     -23.98   dBm
Pre-amp
   Optical TX power (local)        8.56      16.99      16.53      -0.00      -6.03   dBm
   Optical RX power (line)       -18.93      14.80      13.80     -19.21     -21.94   dBm
```

```
SiteC# show line system port 36 dom thresholds
                                        High Alarm  High Warn   Low Warn  Low Alarm
                                  Value  Threshold  Threshold  Threshold  Threshold  Unit  Indicator
                                -------------------------------------------------------------------
   Temperature                    34.00      70.00      65.00       0.00      -5.00     C
   Voltage                         3.31       3.47       3.37       3.23       3.14     V
Booster
   Optical TX power (line)         9.10      16.99      16.53      -0.00      -6.03   dBm
   Optical RX power (local)      -16.99      -7.20      -8.23     -20.97     -23.98   dBm
Pre-amp
   Optical TX power (local)        7.29      16.99      16.53      -0.00      -6.03   dBm
   Optical RX power (line)       -20.47      14.80      13.80     -19.21     -21.94   dBm       WARN
```



High attenuation on fiber in one direction

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400G-ZR / FEC

- dB Loss Margin
  - C-FEC: 25 dB -> 100 km at 0.25 dB/km
  - O-FEC: 30 dB -> 120 km at 0.25 dB/km

- TX/RX dB loss of our 80 km fiber is 29.93 dB
  - 29.93 dB / 81.41 km -> **0.37 dB/km loss**

```
SiteB# show interfaces ethernet 34/1 error-correction
Interface          Configured          Available                                              Operational
---------------    ----------------    -----------------------------------------------------  -----------
Ethernet34/1       Default             C-FEC, O-FEC                                           O-FEC
```


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Summary - 400G-ZR

400G-ZR

- 400G-ZR is a point-to-point <120km ONLY solution
  - No ROADMs or in-line amps
- Preamplification/booster available in Transceiver Form Factor
  - Extremely simple & cost effective, but cannot mix with other line systems
- 400G-ZR can work with external line systems, but customer needs to test & validate 3rd party line systems with their optical vendors

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400G ZR+
Longhaul / Global

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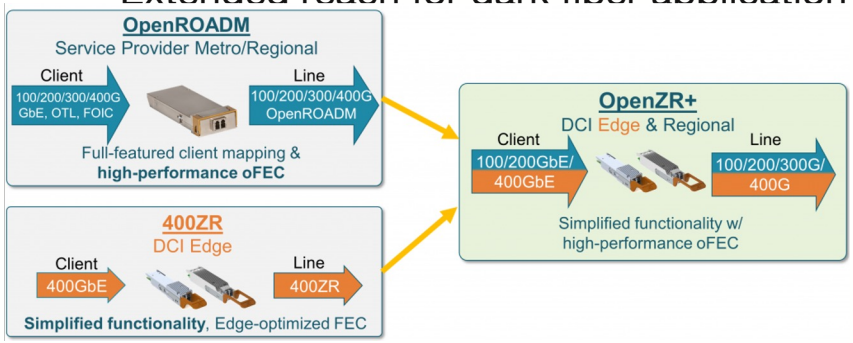
OpenZR+ MSA

- Open Industry standard for Long-haul Connections
- Key benefits of the 400G OpenZR+ MSA specification relative to 400-ZR are
  - 4x100GE multiplexing mode
  - Long-haul performance modes
  - Extended reach for dark fiber application



	400ZR	OpenROADM	OpenZR+
Target Application	Edge DCI	Carrier Metro/LH	Regional DCI
Client Traffic	400GbE only	100-400GbE & OTN	100-400GbE Multirate
Reach	<120km	>120km*	>120km*
Form Factor	QSFP-DD/OSFP	CFP2 or other	QSFP-DD/OSFP
SD-FEC	CFEC	oFEC	oFEC
Max Pwr Consumption	15W	Not Defined	20W*
Standards	OIF	OpenROADM	Leverages other standards work

OpenZR+ specifications are publicly available

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OpenZR+ Application Modes

OpenZR+ MULTI-SOURCE AGREEMENT

- ZR+ transceiver supports multiple ‘application modes’ based upon the CMIS specification. Those INCLUDE 400ZR modes!

CMIS Application Code	Host format	Electrical interface	Payload	FEC	Modulation	Operating reach	MSA format
1	400GBASE-R	1x 400GAUI-8 (8x 50G)	400G	CFEC	DP-16QAM	80km	OIF 400ZR app code 0x01
2	400GBASE-R	1x 400GAUI-8 (8x 50G)	400G	CFEC	DP-16QAM	25km	OIF 400ZR app code 0x02
3	4 × 100GBASE-R	4x 100GAUI-2 (2x 50G)	400G	CFEC	DP-16QAM	80km	OIF 400ZR extension
4	400GBASE-R	1x 400GAUI-8 (8x 50G)	400G	oFEC	DP-16QAM	120km	OpenZR+ MSA (small PMD)
5	400GBASE-R	1x 400GAUI-8 (8x 50G)	400G	oFEC	DP-16QAM	450km	OpenZR+ MSA
6	4 × 100GBASE-R	4x 100GAUI-2 (2x 50G)	400G	oFEC	DP-16QAM	450km	OpenZR+ MSA
7	3 × 100GBASE-R	3x 100GAUI-2 (2x 50G)	300G	oFEC	DP-8QAM	600km	OpenZR+ MSA
8	400GBASE-R	1x 400GAUI-8 (8x 50G)	400G	oFEC	DP-16QAM	450km	OpenZR+ MSA
9	4 × 100GBASE-R	4x 100GAUI-2 (2x 50G)	400G	oFEC	DP-16QAM	450km	OpenZR+ MSA
10	3 × 100GBASE-R	3x 100GAUI-2 (2x 50G)	300G	oFEC	DP-8QAM	600km	OpenZR+ MSA
11	2x 100GBASE-R	2x 100GAUI-2 (2x 50G)	200G	oFEC	DP-QPSK	1000km	OpenZR+ MSA
12	2x 100GBASE-R	2 x CAUI4 (4x 25G) w/o FEC	200G	oFEC	DP-QPSK	1000km	OpenZR+ MSA
13	1x 100GBASE-R	1x 100GAUI-2 (2x 50G)	100G	oFEC	DP-QPSK	2000km	OpenZR+ MSA
14	1x 100GBASE-R	1 x CAUI4 (4x 25G) w/o FEC	100G	oFEC	DP-QPSK	2000km	OpenZR+ MSA

400G-ZR modes

OpenZR+ modes

Data based upon Smartoptics Datasheet SO-TQSFPDD4CCZRP

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OpenZR+ Link Characteristics

OpenZR+ MULTI-SOURCE AGREEMENT

- Each application mode depends on certain link characteristics.

Appl mode	Line rate	Host format	Tx Power [1]	Rx sens @ high OSNR	Rx @ OSNR	Rx OSNR @0.5dB penalty	Rx OSNR @1dB penalty	CDC range
4	400G	1x 400GAUI-8	-10dBm to -6dBm	-20dBm	23.9dB@-12dBm	24.2dB@-14dBm	24.7dB@-16dBm	13 000ps/nm
5	400G	1x 400GAUI-8	-13dBm to -9dBm	-21dBm	23.4dB@-12dBm	23.9dB@-14dBm	24.4dB@-16dBm	13 000ps/nm
6	400G	4x 100GAUI-2	-13dBm to -9dBm	-21dBm	23.4dB@-12dBm	23.9dB@-14dBm	24.4dB@-16dBm	13 000ps/nm
7	300G	3x 100GAUI-2	-12dBm to -8dBm	-22dBm	20.3dB@-15dBm	20.8dB@-17dBm	21.3dB@-19dBm	26 000ps/nm
8	400G	1x 400GAUI-8	-13dBm to -9dBm	-21dBm	23.1dB@-12dBm	23.6dB@-14dBm	24.1dB@-16dBm	13 000ps/nm
9	400G	4x 100GAUI-2	-13dBm to -9dBm	-21dBm	23.1dB@-12dBm	23.6dB@-14dBm	24.1dB@-16dBm	13 000ps/nm
10	300G	3x 100GAUI-2	-12dBm to -8dBm	-23dBm	19.5dB@-15dBm	20.0dB@-17dBm	20.5dB@-19dBm	26 000ps/nm
11	200G	2x 100GAUI-2	-10.5dBm to -6.5dBm	-29dBm	15dB@-18dBm	15.5dB@-20dBm	16dB@-22dBm	50 000ps/nm
12	200G	2x CAUI4 w/o FEC	-10.5dBm to -6.5dBm	-29dBm	15dB@-18dBm	15.5dB@-20dBm	16dB@-22dBm	50 000ps/nm
13	100G	1x 100GAUI-2	-6dBm to -2dBm	-32dBm	11.8dB@-20dBm	12.3dB@-23dBm	12.8dB@-25dBm	50 000ps/nm
14	100G	1x CAUI4 w/o FEC	-6dBm to -2dBm	-32dBm	11.8dB@-20dBm	12.3dB@-23dBm	12.8dB@-25dBm	80 000ps/nm

1) The module transmit power can be provisioned up to the maximum available TX power. If the TX power is not provisioned by the host, the module TX power will default to the maximum available power, which can be any power level in the specified 4dB range.

Data based upon Smartoptics Datasheet SO-TQSFPDD4CCZRP

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OpenZR+ Reach

- Reach is achieved by reducing line side speed and modulation
  - The values below are specified by OpenZR+, but might vary between transceiver vendors
- Type of amplification is crucial for 400G and 300G modes

OpenZR+ modes	EDFA-only (km)	EDFA and Raman amplifier (km)
400ZR+ (ZR400-OFEC-16QAM)	480	1040
300ZR+ (ZR300-OFEC-8QAM)	1600	2320
200ZR+ (ZR200-OFEC-QPSK)	2880	2880
100ZR+ (ZR100-OFEC-QPSK)	5840	5840

Remember - the line side mode has impact on how the service is presented to the switch (*CMIS application modes*)

OpenZR+ specifications are publicly available

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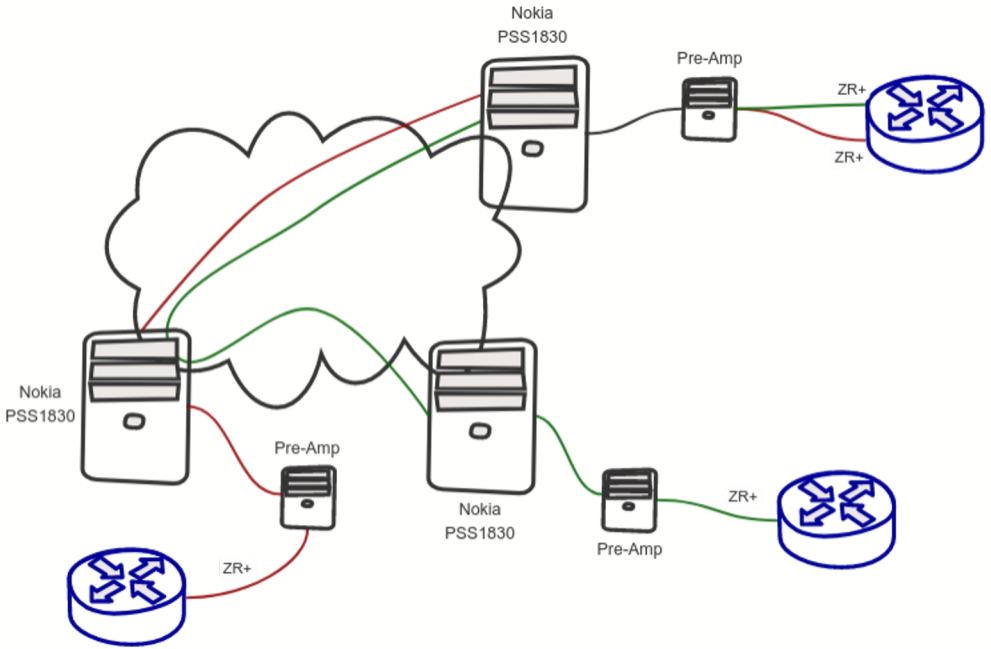
400G-ZR+ / Point-to-Point for Longhaul Connections

- Brownfield deployment
  - Existing Nokia WDM
  - Pre-Amp(!) required
  - Arista 7280CR3-32D4
- ZR+ optics
  - SmartOptics ZR+ QSFP-DD (OEM from Acacia)
- 2 different links from the same switch
  - 40 km on red link
  - 750 km on green link



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400G-ZR+ / **40 km** / Interface configuration

```
SiteA# sh run int et 35/1
interface Ethernet35/1
   no switchport
   ip address 10.0.0.2/24
   transceiver power ignore
   transceiver application override 5
   transceiver frequency 193400.000
   transceiver transmitter signal-power -10.00
```

```
SiteA# sh int et 35/1 transceiver hardware
Name: Et35/1
Media type: 400GBASE-ZR
Maximum module power (W): 23.75 (Power limit check disabled)
Maximum slot power (W): 20.0
Configured frequency (GHz): 193400.0
Computed wavelength (nm): 1550.12
Operational frequency (GHz): 193,400.0
Operational wavelength (nm): 1550.12
Configured TX power (dBm): -10.0
Operational TX power (dBm): -10.0
```

Appl mode	Line rate	Host format	Tx Power [1]	Rx sens @ high OSNR	Rx @ OSNR	Rx OSNR @0.5dB penalty	Rx OSNR @1dB penalty	CDC range
4	400G	1x 400GAUI-8	-10dBm to -6dBm	-20dBm	23.9dB@-12dBm	24.2dB@-14dBm	24.7dB@-16dBm	13 000ps/nm
5	400G	1x 400GAUI-8	-13dBm to -9dBm	-21dBm	23.4dB@-12dBm	23.9dB@-14dBm	24.4dB@-16dBm	13 000ps/nm
6	400G	4x 100GAUI-2	-13dBm to -9dBm	-21dBm	23.4dB@-12dBm	23.9dB@-14dBm	24.4dB@-16dBm	13 000ps/nm
7	300G	3x 100GAUI-2	-12dBm to -8dBm	-22dBm	20.3dB@-15dBm	20.8dB@-17dBm	21.3dB@-19dBm	26 000ps/nm
8	400G	1x 400GAUI-8	-13dBm to -9dBm	-21dBm	23.1dB@-12dBm	23.6dB@-14dBm	24.1dB@-16dBm	13 000ps/nm
9	400G	4x 100GAUI-2	-13dBm to -9dBm	-21dBm	23.1dB@-12dBm	23.6dB@-14dBm	24.1dB@-16dBm	13 000ps/nm
10	300G	3x 100GAUI-2	-12dBm to -8dBm	-23dBm	19.5dB@-15dBm	20.0dB@-17dBm	20.5dB@-19dBm	26 000ps/nm

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400G-ZR+ / **40 km** / Link status

```
SiteA# sh int et 35/1 transceiver dom
                                          Value
                                  ---------------
   Case temperature                    54.00 C
   Voltage                              3.19 V
   TX power                           -10.65 dBm
   RX total power                     -11.84 dBm
   RX channel power                   -11.27 dBm
   Pre-FEC BER                      2.12e-03
   Post-FEC errored frames ratio    0.00e+00
   Chromatic dispersion (short link)    624.00 ps/nm
   Chromatic dispersion (long link)     620.00 ps/nm
   Differential group delay             1.00 ps
   SOPMD                               32.00 ps^2
   Polarization dependent loss          0.90 dB
   Received OSNR estimate              27.90 dB
   Received ESNR estimate              16.80 dB
   Carrier frequency offset            -8.00 MHz
   SOP rate of change                   0.00 krad/s
   Laser temperature                   50.85 C
   Laser frequency                  193400.00 GHz
```

```
SiteA# sh transceiver status interface et 35/1 | grep Oper
  Operational speed             400Gbps
```

```
SiteA# sh int et 35/1 phy detail
Ethernet35/1
                                  Current State
                                  -------------
  Interface state                 up
  Transceiver                     400GBASE-ZR
  PHY state                       linkUp
  Oper speed                      400Gbps
  Lane count                      8
  PCS RX link status              up
  PCS RX fault                    ok
  PCS TX fault                    ok
  PCS BER                         0
  Forward Error Correction        Reed-Solomon
  Reed-Solomon codeword size      544
  PMA/PMD RX link status          up
  PMA/PMD lane RX link status
    Lane 0                        up
    Lane 1                        up
    Lane 2                        up
    Lane 3                        up
    Lane 4                        up
    Lane 5                        up
    Lane 6                        up
    Lane 7                        up
```


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400G-ZR+ / **750 km** / Interface configuration

```
SiteC#sh run section 36/
interface Ethernet36/1
   speed 100g-2
   no switchport
   transceiver power ignore
   transceiver application override 7 lanes start 1
   transceiver application override 7 lanes start 3
   transceiver application override 7 lanes start 5
   transceiver frequency 192275.000
   transceiver transmitter signal-power -10.00
interface Ethernet36/3
   speed 100g-2
   no switchport
interface Ethernet36/5
   speed 100g-2
   no switchport
interface Ethernet36/7
   speed 100g-2
   no switchport
```

```
SiteC#sh interfaces et36/1 transceiver hardware
Name: Et36/1
Media type: 400GBASE-ZR
Maximum module power (W): 23.75 (Power limit check disabled)
Maximum slot power (W): 20.0
Configured frequency (GHz): 192275.0
Computed wavelength (nm): 1559.19
Operational frequency (GHz): 192,275.0
Operational wavelength (nm): 1559.19
Configured TX power (dBm): -10.0
Operational TX power (dBm): -10.0
```

Appl mode	Line rate	Host format
4	400G	1x 400GAUI-8
5	400G	1x 400GAUI-8
6	400G	4x 100GAUI-2
7	300G	3x 100GAUI-2
8	400G	1x 400GAUI-8
9	400G	4x 100GAUI-2
10	300G	3x 100GAUI-2

Arista-specific configuration is documented in this TOI

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400G-ZR+ / **750 km** / Link status

```
SiteA# sh int et 36/1 transceiver dom
                                          Value
                                    ---------------
   Case temperature                      50.00 C
   Voltage                                3.19 V
   TX power                             -10.22 dBm
   RX total power                        -7.80 dBm
   RX channel power                     -11.43 dBm
   Pre-FEC BER                       5.73e-03
   Post-FEC errored frames ratio     0.00e+00
   Chromatic dispersion (short link)     12674.00 ps/nm
   Chromatic dispersion (long link)      12660.00 ps/nm
   Differential group delay               1.00 ps
   SOPMD                                 51.00 ps^2
   Polarization dependent loss            1.20 dB
   Received OSNR estimate                21.50 dB
   Received ESNR estimate                12.40 dB
   Carrier frequency offset             131.00 MHz
   SOP rate of change                     0.00 krad/s
   Laser temperature                     49.68 C
   Laser frequency                       193000.00 GHz
```

```
SiteA# sh transceiver status | i 36/
Et36/1              connected    routed    full    100G    400GBASE-ZR
Et36/3              connected    routed    full    100G    400GBASE-ZR
Et36/5              connected    routed    full    100G    400GBASE-ZR
Et36/7              notconnect   routed    full    100G    400GBASE-ZR
```

Appl mode	Line rate	Host format
4	400G	1x 400GAUI-8
5	400G	1x 400GAUI-8
6	400G	4x 100GAUI-2
7	300G	3x 100GAUI-2
8	400G	1x 400GAUI-8
9	400G	4x 100GAUI-2
10	300G	3x 100GAUI-2

Appl mode	Line rate	Host format	Tx Power [1]	Rx sens @ high OSNR	Rx @ OSNR	Rx OSNR @0.5dB penalty	Rx OSNR @1dB penalty	CDC range
7	300G	3x 100GAUI-2	-12dBm to -8dBm	-22dBm	20.3dB@-15dBm	20.8dB@-17dBm	21.3dB@-19dBm	26 000ps/nm

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Summary

400G-ZR+

- 400G-ZR+ is a > 120km long haul solution
  - Low optical output power → not compatible with most brownfield long haul line systems
  - Not compatible with every platform due to power and thermal constraints
  - Transceivers vary between 18W and 25W - it is very inconsistent
  - Using those transceiver in unsupported platforms could irreversibly damage your device!
- 400G-ZR+ with > 0dBm Tx power is compatible with most long-haul line systems
  - 400G-ZR+ transceivers with > 0dBm Tx power not available yet
  - Even higher power consumption, so always check platform support as this could irreversibly damage your device!
  - Customer needs to test & validate 3rd party line systems w/ their optical vendors

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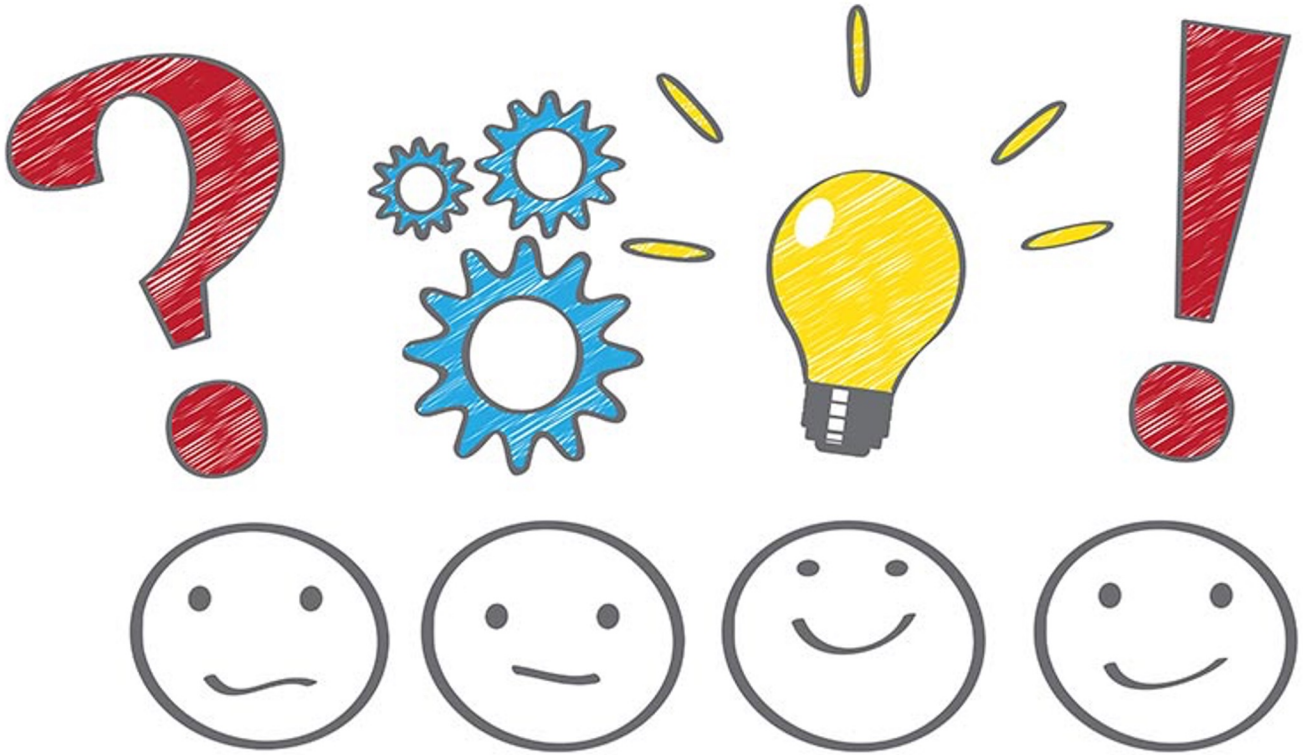
Questions?



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Thank you for your attention!

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