Solution Brief

Introducing 400G Pluggable DWDM

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Introducing 400G Pluggable DWDM

The ever-growing demand for a richer media experience and information sharing drive a never-ending quest for more broadband communications capacity. What was once state of the art data rates for optical links in metro networks and between data centers is now superseded by the even higher rate of 400G DWDM.

The new 400ZR standard brings you four times as much capacity as 100G, while still being deployable in the same, simple, and disaggregated way using pluggable transceivers, thanks to Smartoptics' innovative design. The complete and verified Smartoptics solution includes all that is needed for a successful capacity upgrade to 400G; transceivers, line systems with ROADM:s as well as transponders and muxponders, providing you with a cost-effective optical infrastructure meeting the requirements of today and tomorrow.

»Another major advantage of 400G is that it is based on a new optical connectivity standard, named 400ZR, defined by the Optical Internetworking Forum (OIF). «

Why 400G?

With 400G DWDM, optical networking technology has taken yet another major step forward. Given that your switches support 400G interfaces, you may directly leverage the full capacity between sites and towards your customers. And the higher capacity means that you now can carry four 100G channels over one single wavelength. An obvious cost saving in many situations.

Another major advantage of 400G is that it is based on a new optical connectivity standard, named 400ZR, defined by the Optical Internetworking Forum (OIF).

This is the first time since the introduction of 10G DWDM such a standard has been agreed upon, a fact that will secure interoperability between systems from different vendors and keep costs down.

Further, 400G DWDM according to the 400ZR standard is also ideally suited to leverage disaggregated optical networking as advocated by major equipment vendors such as Cisco, Juniper and Arista. In a disaggregated optical network, the electro-optical transceivers are plugged directly

into the switches/routers, using an active optical line system between sites. 400ZR therefore defines two new form factors for such pluggable transceivers, QSFP-DD and OSFP, capable of handling the higher power required for 400G.

For an operator, typically serving some 5-10 data centers and associated end customers in a metro area, 400G DWDM offers the possibility to increase the overall network capacity as well as to introduce new transport services. Your 400G networks may be built with point-to-point links or use mesh or ring topologies, just as before with 10G, 40G or 100G DWDM, and even with the same open line system that you already have in place.
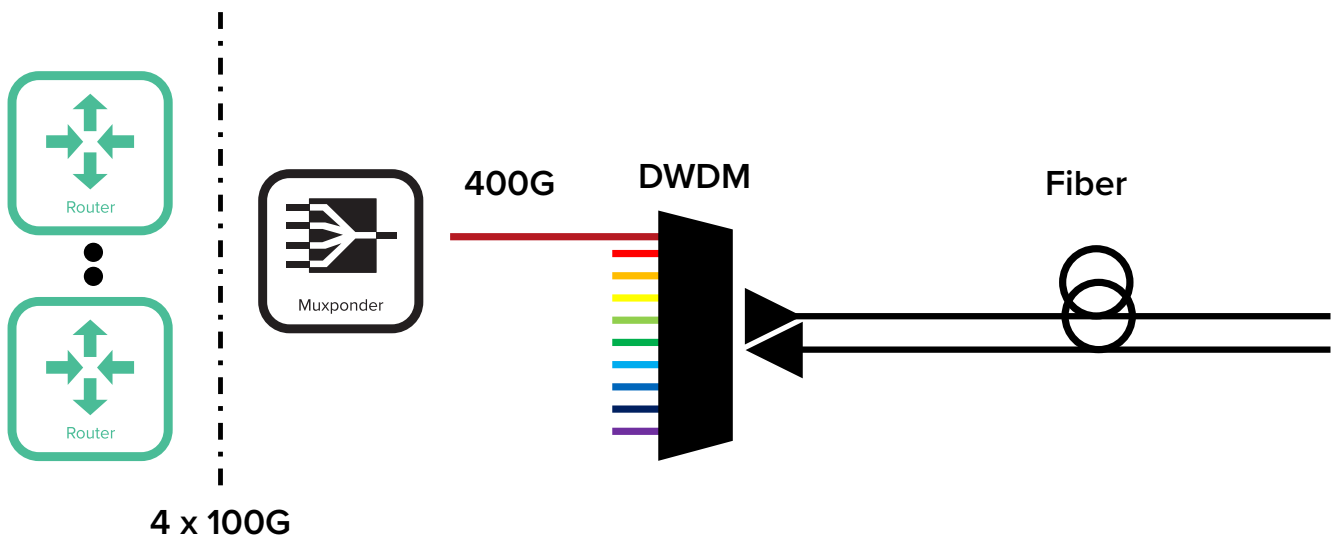

Figure 1. 400G allows you to multiplex four 100G links over one single wavelength with the new Smartoptics muxponder
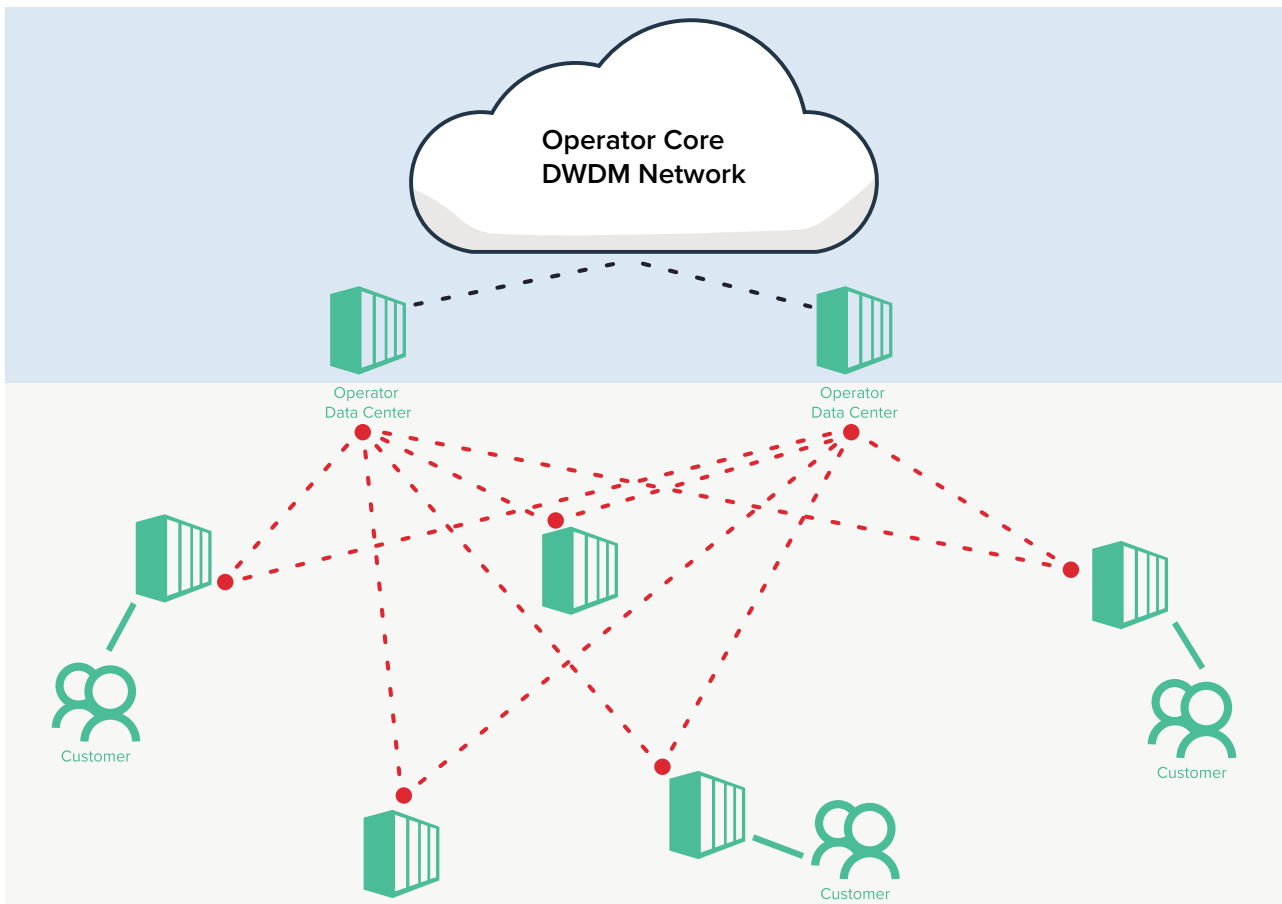
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Figure 2.   Logical view of a typical metro network

As indicated in the illustration, 400G DWDM links can act as an efficient on-ramp for metro customer traffic to your core DWDM network, eliminating any bottlenecks possibly created by lower capacities. Using 400G instead of 100G links also lowers the cost per transported bit, thus improving the overall economy of the services offered.

Furthermore, thanks to the inherent flexibility of the Smartoptics open line system ROADMs, 400G services can easily be introduced in the same optical infrastructure that has already been deployed for 100G.

For large corporations, government agencies and others requiring interconnection of data centers at sites typically 10 – 80 km apart, 400G DWDM offers increased capacity for redundant point-to-point links as well as for meshed networks. Not only does the higher data rate allow for shorter transfer times of large data sets, but it also improves the overall economy of the solution, due to the lower cost per transported bit of data. The use of one 400G high speed interface instead of multiple 100G interfaces also simplifies the load sharing configurations on the router side.
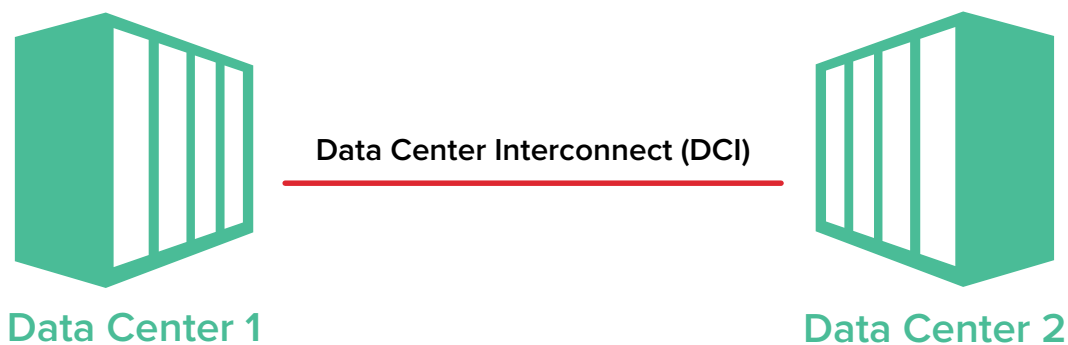

Data Center Interconnect (DCI)

Data Center 1

Data Center 2

Figure 3.   Data Centre Interconnect (DCI)

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Coherent 400G DWDM

One of the most significant innovations in DWDM system development has been the introduction of coherent optical modulation[1]. Coherent optical systems utilize advanced optics and digital signal processors (DSP:s) to transmit and receive complex light wave modulations, enabling high-speed data transmission. Coherent modulation continues to be the driving force behind high-speed optical devices, including 400G and beyond.
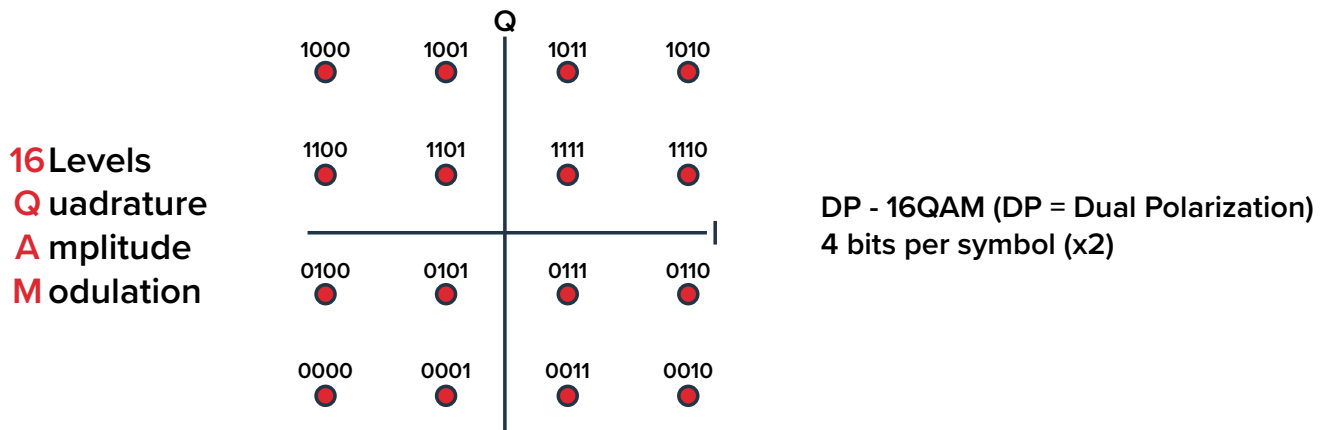
16 Levels
Q uadrature
A mplitude
M odulation

DP - 16QAM (DP = Dual Polarization)
4 bits per symbol (x2)

Figure 4.   Coherent 400G DWDM builds on Quadrature Amplitude Modulation and Dual Polarization (e.g. DP-16QAM) to achieve the desired data rate.

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[1] In physics, two wave sources are perfectly coherent if their frequency and waveform are identical and their phase difference is constant. Coherence is an ideal property of waves that enables stationary (i.e. temporally and spatially constant) interference. It contains several distinct concepts, that describes all properties of the correlation between physical quantities of a single wave, or between several waves or wave packets.

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The 400ZR Standards

Several standardization initiatives exist to ensure the full interoperability of coherent 400G DWDM systems. First out was the Ethernet-based fiber optic networking standard **400ZR** published by the Optical Internetworking Forum (OIF) in April 2020. The standard was designed for transmitting 400G speeds at distances of at least 80 km and was published by OIF under the Implementation Agreement (IA) for a 400ZR coherent optical interface. **400ZR+** and **OpenZR**+ are two separate initiatives loosely based on the original OIF 400ZR. When referring to 400ZR broadly, we mean all of the above standardization initiatives. Together, they will play a key role in enabling next-generation data center interconnect (DCI) and metro network solutions to meet the bandwidth requirements of today and tomorrow.

400ZR for DCI – the original standard

As large-scale data center operators looked to the future, they saw the need for greater cost efficiency, simplicity, and interoperability to go along with the higher bandwidth promised by 400G. As a result, they urged the OIF to create the 400ZR IA to ensure that next-generation DCI solutions will be well suited to their needs. To meet these data center needs, the focus of the 400ZR project was on 400G Ethernet with amplified point-to-point DWDM links up to 120 km and unamplified, single wavelength links with a loss budget of 11dB. This approach was designed to reduce the cost per bit and enable easy use of embedded optics with 400G switches and routers.

400ZR for metro networks - a flurry of new standards

The OIF **400ZR** project eventually also caught the eye of network operators who saw the potential of 400G for boosting the capacity, flexibility, and efficiency of their metro networks. However, these network operators had needs that went beyond those of data center networks, which led to work on a couple of new standards.

400ZR+ was designed to add a bit more to the original 400ZR standard, such as expanding the range beyond 120 km and enabling a 4 x 100G client rate as opposed to only 1 x 400G. Although the term 400ZR+ has become widely adopted, it is largely subject to each vendor's own interpretation and will eventually be replaced by OpenZR+ although both will coexist for a certain period.

OpenZR+ is a standard based on a multi-source agreement that was born out of the goal of taking the best of the 400ZR+ and the Open ROADM standards. OpenZR+ aims to combine simplified functionality, high-performance oFEC and interoperability tailored to the needs of service providers. OpenZR+ adds more flexibility to the line rate and line modulation along with interoperability missing from 400ZR+.

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400ZR interoperability drives cost efficiencies

Relatively solid multi-vendor interoperability of transceivers had been achieved within data centers prior to 400ZR. However, the longer-range connections between data centers were not as effective when combining transceivers and switches from different vendors. Therefore, 400ZR aims to bring the same level of interoperability found within data centers to DCI. Interoperability has been a major driving force and focus for both OIF 400ZR and OpenZR+.

400ZR interoperability is at its best when using QSFP-DD transceivers because they are backwards compatible with previous QSFP system transceiver modules. As a result, 400ZR transceivers can be easily connected to existing switches and other infrastructure without having to replace anything. This is well aligned with the open networking trend and the needs of enterprise data center and metro network operators to make upgrading network infrastructure less expensive and less complex.

The most popular form factor for embedded 400ZR transceivers is QSFP-DD (Quad Small Form-Factor Pluggable Double Density) making them easy to deploy and manage in DCI and metro networks. QSFP-DD improves on QSFP (QSFP+, QSFP28, QSFP56) by doubling the number of high-speed electrical interfaces while still maintaining largely the same convenient form factor. This results in a jump from 40G or 100G aggregate to 200G or 400G. This way, 400ZR will make network capacity future-proof by making it easy to grow.

	OIF 400ZR	OpenROADM	OpenZR+
Target application	Edge, DCI/Campus	Metro/Regional, DCI	Metro/Regional, DCI
Reach	80-120 km / 11 dB	>120 km	>120 km
Line capacity	400G	200G/300G/400G	100G/200G/300G/400G
Client formats	400GE	100GE-400GE + OTN	100GE/200GE/400GE
FEC	CFEC	oFEC	oFEC
Line modulation	16QAM	QPSK/8QAM/16QAM	QPSK/8QAM/16QAM

Figure 5.   The three principal initiatives to provide interoperable 400G solutions and Dual Polarization (e.g. DP-16QAM) to achieve the desired data rate.

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A Complete 400G Solution from Smartoptics

Smartoptics specializes in innovative solutions and devices for the new era of open networking, based on disaggregated optical networks with pluggable transceivers embedded directly into the switches and routers. As one of the first on the market we can therefore offer a complete coherent, 400G, pluggable solution, including 400ZR compliant 400G transceivers and compatible flexible optical line systems based on the DCP-family products DCP-M, DCP-F and DCP-R.
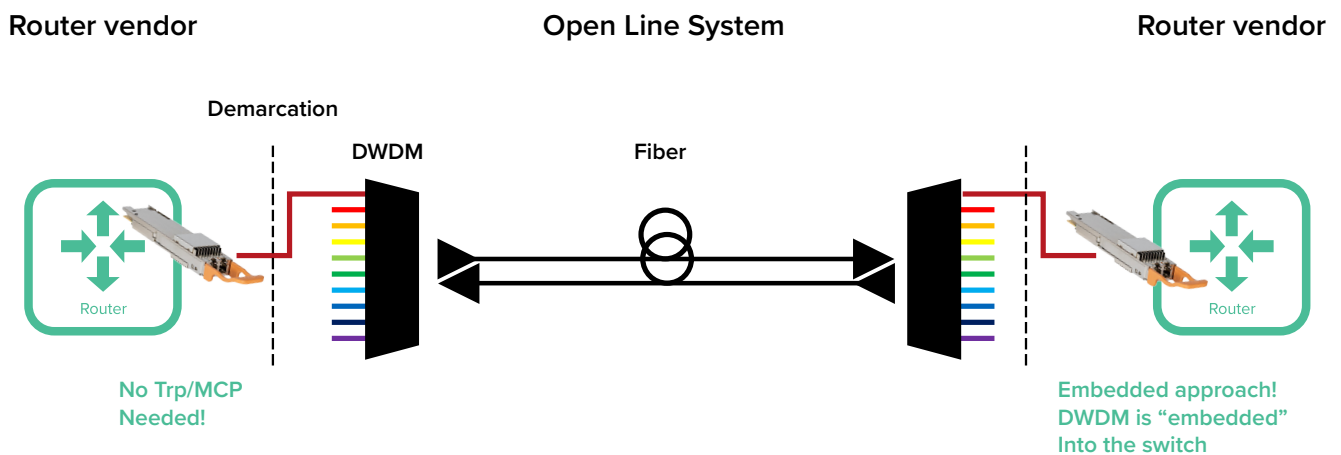

Figure 6.   A disaggregated optical network based on pluggable transceivers and an open line system

A major application of 400G DWDM will undoubtedly be the multiplexing of already existing 100G links over a single wavelength. Smartoptics is therefore also offering the DCP-404 layer 1 muxponder when four 100 GbE client signals are to be transported over a single 400G link. As a further addition to the 400G capable network elements, the Smartoptics DCP-1604 transponder supports four times 100G or 400G transponder functionality.
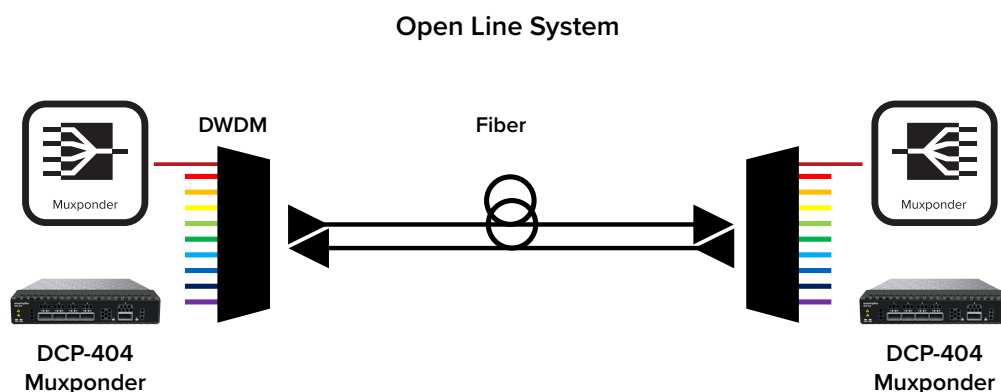

Figure 7.   The DCP-404 muxponder is used for multiplexing of up to four 100GbE channels

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The 400G Transceivers

Coherent 400G pluggable transceivers are extremely complex devices comprising sophisticated silicon optical sub-systems, DSP:s for signal processing and associated software for control and management. Smartoptics has initially focused on providing two types of MSA compliant transceivers, both using the QSFP-DD (Quad Small Form-Factor Pluggable Double Density) form factor.

- The Smartoptics OIF 400ZR transceiver for OIF 400ZR amplified and un-amplified links

- The Smartoptics Open400ZR+ transceiver with support for 11 different operational modes including both the OIF 400ZR amplified and un-amplified mode as well as various modes supporting the data rates specified by the Open400ZR+ multi-source agreement. The flexibility of this transceiver allows for not only a line rate of 400G with DP-16QAM modulation but also for 300G, 200G and 100G line rates using DP-8QAM and DP-QPSK modulation enabling significantly longer reach in e.g. core network applications.

The actual data rates possible in a disaggregated optical network depends on the capabilities of the host systems, i.e. on the switches and routers, using the optical link. The Smartoptics transceivers announce their operating modes to the host system, which in turn decides on which mode to use. Contact your Smartoptics reseller for more information about host systems capable to leverage coherent 400G DWDM.
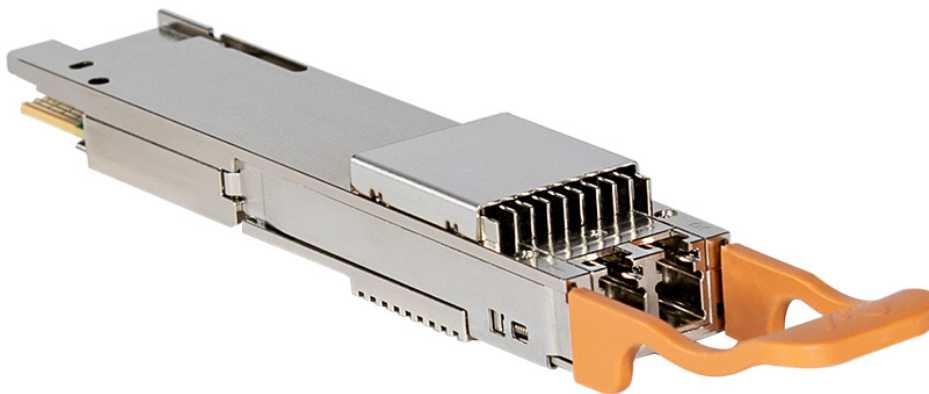

Figure 8.   The QSFP-DD form factor

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Upgrading to 400G with Smartoptics Flexible Open Line Systems

400ZR transceivers implemented in the QSFP-DD form factor makes it easy to upgrade to 400G by just switching transceivers. But it is even easier with flexible DWDM-based open networking from Smartoptics. The Smartoptics solution combines the benefits of pluggable 400ZR and PAM4 transceivers with the flexible DCP-M and DCP-R open line systems. This enables highly automated, low-cost 100G PAM4 networking while also supporting 400ZR, so that existing 100G channels will not be impacted at all while adding 400G channels alongside them. This way, you do not have to replace your optical infrastructure.
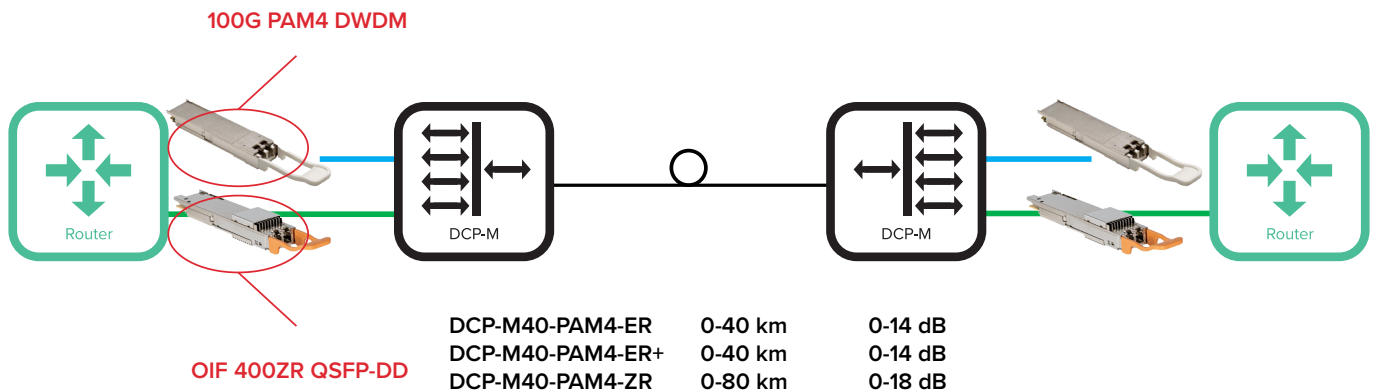

DCP-M40-PAM4-ER	0-40 km	0-14 dB
DCP-M40-PAM4-ER+	0-40 km	0-14 dB
DCP-M40-PAM4-ZR	0-80 km	0-18 dB

Figure 9. The DCP-M and DCP-R flexible open line systems allow for mixed use of both 100G PAM4 modulated DWDM and coherent 400G DWDM channels.

DCP-M for Point-to-point Links

Since the 400ZR standard has less stringent optical signal requirements than 100G PAM4 DWDM, it is always possible to run a 400ZR based coherent 400G DWDM link over the same DCP-M40 flexible open line system that you have already been using for 100G PAM4 DWDM. And even better, the two modulation formats can exist on the same flexible open DCP-M line system without interference or distance penalties.

This means that all existing DCP-M-40-PAM4 line systems from Smartoptics are also ready for coherent 400G DWDM links based on the 400ZR standard without any further action. The same simple and automated set up of links between sites that you are used to for 100G PAM4 also applies for 400G.

To further leverage the optical characteristics of 400ZR Smartoptics is also introducing the DCP-M40-C-ZR+ open line system optimized specifically for coherent 400G DWDM.
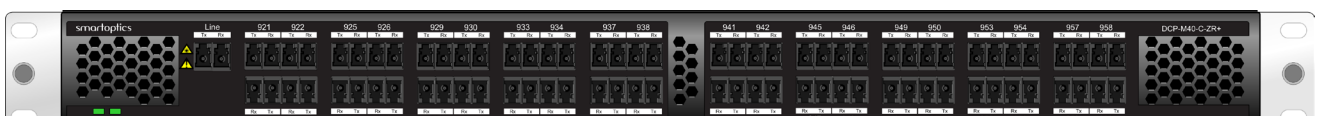

Figure 10. The DCP-M40-C-ZR+ flexible open line system optimized for 400ZR

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This 40 channel, 16 Tbit, open line system has been designed for situations where you explicitly want to leverage the longer reach possible with coherent 100G, 200G or 400G DWDM as to compared to 100G PAM4 DWDM. In addition to the coherent modulation, the DCP-M40-C-ZR+ also supports NRZ modulated formats, although with less optical reach. The new member of the DCP-M family shares the same zero-touch, automatic, optical line set-up with the existing DCP-M systems, making it as simple to use as a passive multiplexer.

Optical performance based on OIF 400ZR

400G 16QAM	0-120 km	0-26 dB

Optical performance based on OpenZR+

400G 16QAM	0-140 km	0-28 dB
200G QPSK	0-160 km	0-32 dB

Figure 11. DCP-M40-C-ZR+ optical performance

The following table gives an overview of the entire DCP-M family and the supported formats for each of the open line systems.

DCP-M Model	Loss budget (dB)	Dispersion budget (km)	Supported Formats
DCP-M40-PAM4-ER	0-14 dB	0-40 km	PAM4, Coherent & NRZ
DCP-M40-PAM4-ER+	0-14 dB	20-60 km	PAM4, Coherent & NRZ
DCP-M40-PAM4-ZR	0-18 dB	0-80 km	PAM4, Coherent & NRZ
DCP-M40-C-ZR+	0-32 dB	0-160 km	Coherent & NRZ
DCP-M8-PAM4	0-20 dB	0-80 km	PAM4

Figure 12. The DCP-M family of flexible open line systems

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DCP-R as ROADM for Ring and Mesh Networks

ROADMs (Reconfigurable Optical Add/Drop Multiplexers) are used in bus, ring and mesh shaped optical networks to enable flexible add/drop of individual wavelengths and for adding of new wavelengths without affecting the traffic on adjacent channels.

ROADM-based metro/regional and metro access networks can easily be built by the Smartoptics DCP-F family of versatile active optical units, by the dedicated DCP-R family ROADMs or by a combination of products from both families.

The Smartoptics DCP-R family comprises compact, 1U per degree ROADMs having Flexgrid support and colorless, directionless and contentionless capabilities. The ROADMs, with integrated mux/demux for local add/drop, are true multipurpose units, designed for use with 100G PAM4 and 400ZR transceivers as well as with legacy 100G QPSK, 200G 16QAM, Ethernet and Fibre Channel

traffic formats. The DCP-R ROADMs use the same compact chassis as the well-known Smartoptics DCP-M family.

All members of the DCP-R family support a high level of automation and openness. The ROADMs are typically controlled through the NetConf protocol compliant with the principles outlined by the OpenROADM MSA architecture and with TransportPCE as the SDN controller. The configuration of the ROADMs is further simplified by the integrated automatic fiber distance measurement and dispersion compensation setting.

Specifically, the 9-degree ROADM DCP-R-9D comes in two models, MS for Multi-Services, and CS for Coherent Services. The MS model being specially designed for combined use of both PAM4 and 400ZR traffic formats with Ethernet, Fibre Channel, and standard coherent modulation schemes, and the CS model being optimized for coherent traffic formats such as 400ZR.
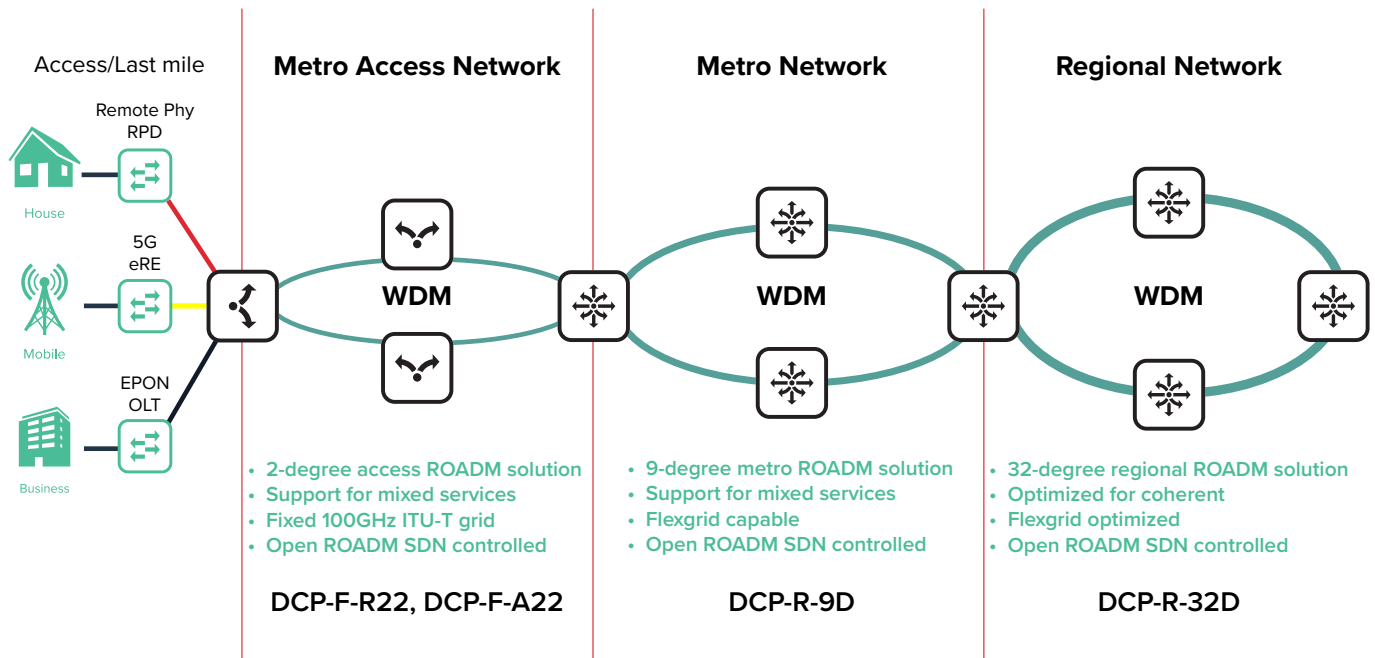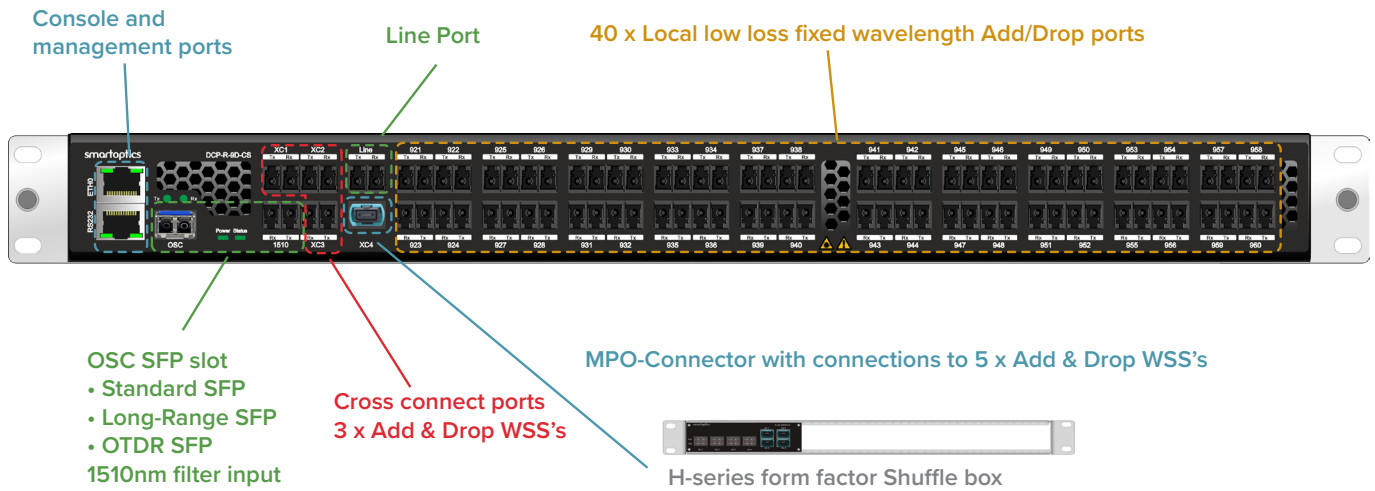

Figure 13. Smartoptics ROADM Portfolio

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Console and
management ports

Line Port

40 x Local low loss fixed wavelength Add/Drop ports

OSC SFP slot
• Standard SFP
• Long-Range SFP
• OTDR SFP
1510nm filter input

Cross connect ports
3 x Add & Drop WSS's

MPO-Connector with connections to 5 x Add & Drop WSS's

H-series form factor Shuffle box

Figure 14. The DCP-R-9D chassis

Traffic Formats and Modulation Support

A prominent characteristic of the DCP-R family is the great flexibility with which traffic formats can be mixed within the same ROADM. With the MS model, both direct detect and coherent formats can be supported simultaneously, alternatively the CS model, optimized for coherent formats,

and providing more topology alternatives, can be chosen. This unique flexibility of the DCP-R family allows for efficient handling of legacy formats while offering an excellent upgrade path when new traffic formats based on new technologies are introduced in the network.

The DCP-R-9D ROADMs support the following traffic formats:

Traffic format	Supported by DCP- R-9D-MS	Supported by DCP-R-9D-CS
PAM (Colorz) modulated wavelengths (100G)	Yes	
OIF 400ZR coherent modulated wavelenghts (400G)	Yes	Yes
NRZ modulated wavelengths (1-10G Ethernet, 1-32G Fibre Channel, CPRI 1-10, SONET, SDH, OTN etc.)	Yes	Limited reach
Other coherent modulated wavelengths (100G, 200G & 400G)	Yes	Yes

Figure 15. Traffic formats supported by the DCP-R-9D models

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The achievable optical reach and supported number of ROADM hops are traffic format dependent as well as DCP-R model dependent as can be seen on the following table for the 400ZR formats when using DCP-R-9D-CS.

Traffic format	OSNR tolerance (db)	CD Tolerance (ps/nm)	ROADM Hops
OIF 400ZR	26	2,400	3
OpenZR+ 400G	24	20,000	5
OpenZR+ 300G	21	40,000	10
OpenZR+ 200G	16	50,000	20+
OpenZR+ 100G	12,5	100,000	20++

Figure 16. Supported number of ROADM hops for DCP-R-9D-CS

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400G Muxponder

DCP-404

The DCP-404 layer 1 muxponder has been specifically developed for the multiplexing of four 100GbE client signals over one 400G link.

The muxponder supports any type of QSFP28 form factor transceiver for 100GbE on the client side and requires the OpenZR+ QSFP-DD transceiver on the line side. The OpenZR+ transceiver allows

for a 400G line rate, but it also supports 300G, 200G and 100G line rates, if extended operating distances are to be covered.

The low power and low latency muxponder is accommodated in the Smartoptics DCP-2 chassis, occupying one out of two slots in a 1RU chassis .
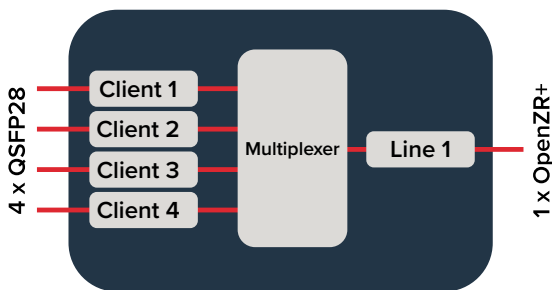

Figure 17. The DCP-404 layer 1 muxponder

The Early Adopters

Leveraging the flexibility of open optical networking, Smartoptics has been able to introduce coherent 400G DWDM based on the 400ZR standards earlier than most other players on the market. Once again, the advantage of disaggregated optical networking, where transceivers and line systems can take immediate advances in their respective technologies, has enabled Smartoptics to develop a solution having superior performance without excessive costs. Our capability of rapid innovation has been recognized by several of our customers – please contact Smartoptics for a detailed list of references using our coherent 400G DWDM solutions.

Summary

Smartoptics offers a complete and straightforward solution for operators and enterprises wanting to upgrade their existing 100G DWDM links to 400G. Coherent 400G DWDM channels according to the 400ZR standards can easily be added to your already installed DCP-M, DCP-F and DCP-R flexible open line systems just by installing the new 400ZR transceivers in your host systems. Additionally, Smartoptics also introduces new models of both the DCP-M and the DCP-R line systems optimized for coherent traffic formats and longer reach. The coherent 400G capable portfolio is made complete by a 4 x 100 GbE muxponder and a unit with four individual layer 1 transponders for 400ZR. With all products designed for the highest level of quality and simplicity in use – 400G from Smartoptics is a given choice for your network.

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Ryensvingen 7
NO-0680 Oslo,
Norway

+47 214 174 00

info@smartoptics.com
smartoptics.com

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