

State of the Art IP and
Optical Networking

Ribbon's Market-Disrupting 400G ZR+ Solution

TM400_2 Reshapes the Economics of Metro and LH Optical Networks



Abstract

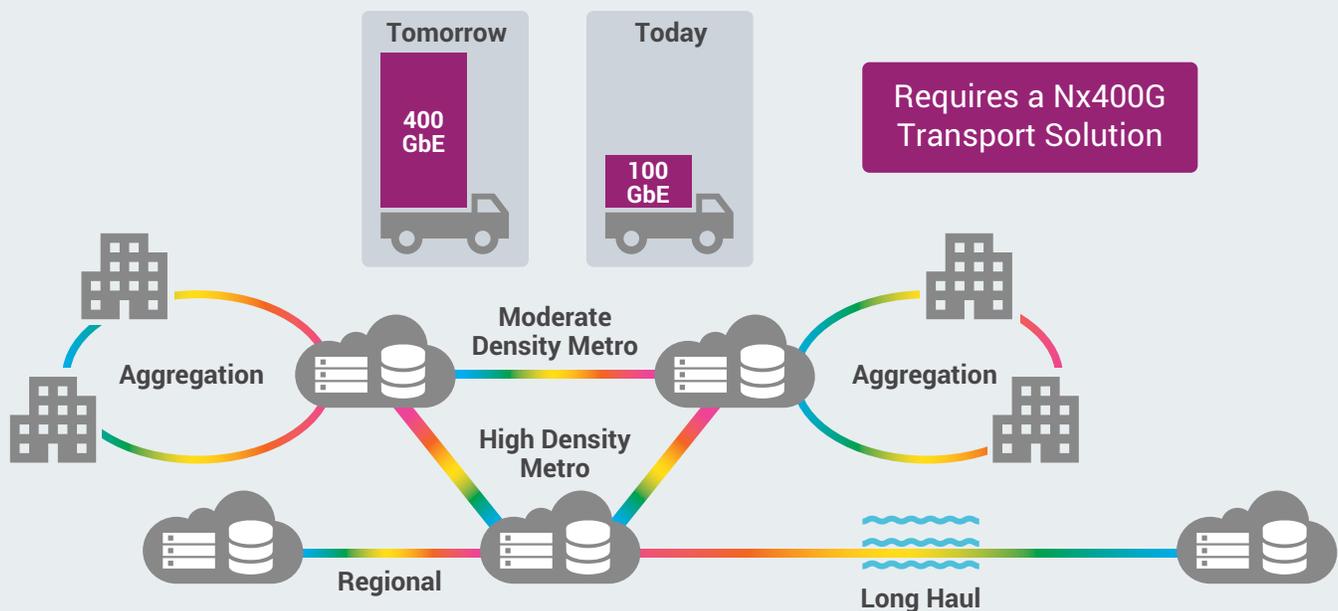
400G ZR+ is a disruptive technology that delivers 400G optical transmission in standard and interoperable pluggable form factors. With sourcing from multiple suppliers, 400G ZR+ promises to bring improved economics to service providers for transporting 100GbE, and growing 400GbE client traffic, all while being superior to 800G solutions that rely on expensive embedded and proprietary technology.

Ribbon's programmable TM400_2 dual 400G line card is first to market using 400G ZR+ in CFP2-DCO pluggables. Its unique design incorporates an internal switch that allows using its two pluggables in either independent or dual wavelength modes. This provides exceptional advantages.

- In independent wavelength mode, the TM400_2 provides superior 2x400G cost-performance to 1x800G embedded solutions, for metro applications. Moreover, its modular design enables “pay as you grow”, where 400G wavelengths are added incrementally as traffic increases.
- In dual wavelength mode, the TM400_2 combines 2x200G wavelengths with highest-performance QPSK modulation to extend 400GbE transport to long haul applications. This has superior cost-performance to current embedded solutions operating at 400G that by necessity must use less efficient modulation.

The 100GbE and 400GbE Transport Mission

The primary mission of optical networks is to transport client interfaces across wide geographic areas, connecting routers, switches and other edge devices with each other. We are now at the beginning of a period where 400GbE will break out of data centers and displace 100GbE as the dominant client interface requiring transport. As a result, there is a wide industry consensus that 400G transmission is the basic building block of optical networks.



400G Transceiver Solutions

The industry is relying primarily on three types of transceivers to deliver 400G transmission. Each type has different optimization priorities based on its target applications and size-power constraints.

Embedded Modules



- Relative cost: \$\$
- Vendor proprietary
- >200cm³/Power 60W+
- **Performance-optimized** up to 2x600G or 800G
- Signal launch: 0dBm (1mW)
- Application: CD/CDC ROADM networks, OTN
- Not interoperable

CFP2 DCO Pluggable



- Relative cost: \$
- Multi-vendor pluggable
- 55cm³/Power 25W
- **Power-cost optimized** up to 400G
- Signal launch: 0dBm (1mW)
- Application: CD/CDC ROADM networks, OTN
- Interoperable based on OpenROADM MSA (400G ZR+)

QSFP-DD Pluggable



- Relative cost: \$-
- Multi-vendor pluggable
- 14cm³/Power 15W/20W
- **Power-cost optimized** up to 400G
- Signal launch: -10dBm (0.1mW)
- Application: P2P DCI, IPoDWDM, simple ROADM networks
- Interoperable based on OIF 400GZR and OpenZR+ MSA (400G ZR+)

Vendor proprietary embedded transceiver 400G+ modules do not conform to a standard size or power ceiling, other than being practical to integrate into optical system line cards or pizza box shelves. They focus on maximizing spectral efficiency for any distance and fiber condition. Today, there are two main varieties of these embedded modules: transmitting up to 800G on a single wavelength, or transmitting up to 600G on a single wavelength, but with a special mode that enables these wavelengths to combine into a 1200G channel. These embedded transceivers began introduction in late 2019, and have been the subject of many announcements surrounding high-speed transmission trials and early deployments.

In 2021, these embedded transceivers will begin to see competition from 400G pluggable transceivers. These exploit the same 7nm silicon technology as embedded transceivers, but they are optimized to reduce power and space to fit into standard pluggable form factors, while delivering performance that is suitable for most applications. They also have notably lower costs than embedded modules. Most importantly, to maximize the potential of this technology, the industry has banded together to create standards and multi-source agreements (MSAs) that specify modes for pluggables coming from different vendors to interoperate.

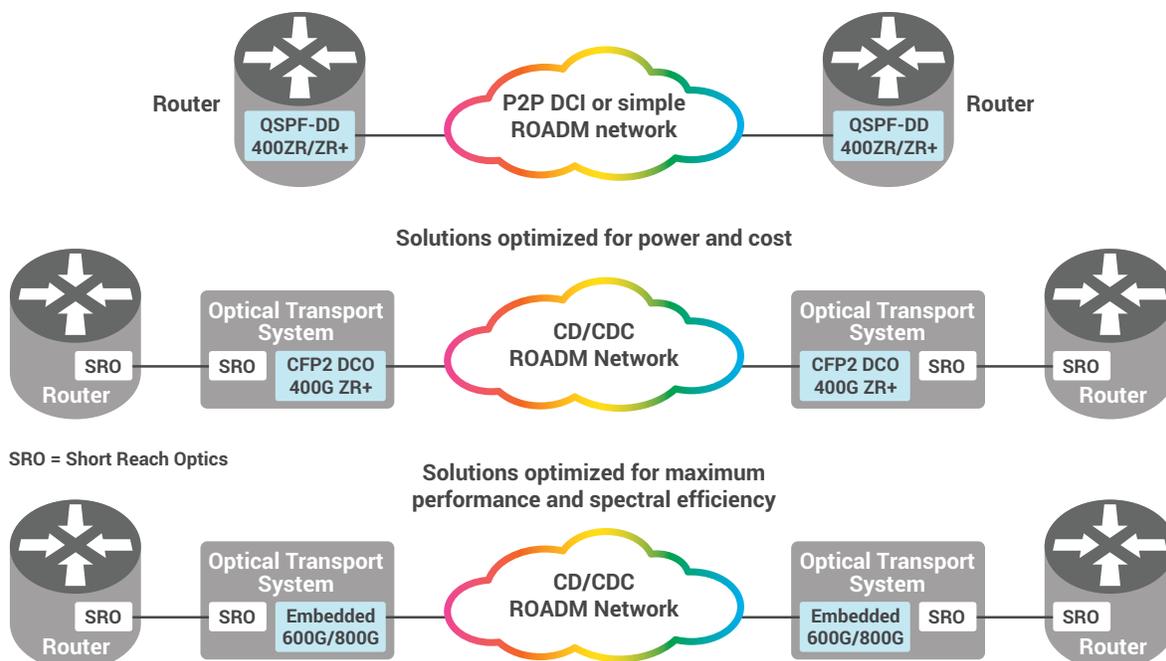
- **400ZR:** Router vendors initiated this OIF standard to obtain multi-source interoperable optics in the QSFP-DD and lesser-used OSFP small form factor pluggables, primarily for point-to-point DCI. It operates only at 400G and uses simple concatenated forward error correction (CFEC) for interoperability.
- **OpenZR+ MSA:** Also initiated by router vendors, this MSA expands the application space for coherent 400G solutions packages in small form factor pluggables. It focuses on longer reach P2P DCI and networked metro applications. However, due to its low signal launch power, it can be used only over simple ROADM networks. This MSA operates at 100G/200G/300G/400G line rates, and supports interoperability using high performance OFEC (open FEC).

- OpenRoadm MSA:** Initiated by leading optical carriers and transport vendors, this MSA targets a 400G coherent solution in larger and higher-powered CFP2-DCO pluggables, for use in highly flexible CD/CDC (colorless, directionless, contentionless) ROADM networks. This MSA also operates at 100G/200G/300G/400G line rates, and supports interoperability using high performance OFEC.

The table summarizes major aspects of the 400G pluggable solutions. All implementations beyond the basic 400ZR standard are considered **400G ZR+**. These include proprietary versions aimed at providing higher performance at the expense of not supporting interoperability. Some 400G ZR+ pluggables support both interoperable and proprietary modes.

Pluggable Specification Name	Type	Application	Client Interfaces	Line Interfaces	Initial Form Factors	Typical 400G Reach
400ZR	OIF Standard	P2P short reach DCI	400GbE only	400G	QSFP-DD (OSFP)	80 km
400G ZR+	OpenZR+	Longer reach P2P DCI and simple ROADM metro networks	100-200-400 GbE	100-200-300-400G	QSFP-DD (OSFP)	600 km
	OpenROADM	Metro and LH CD/CDC ROADM networks	100-200-400 GbE; OTN; FlexO	100-200-300-400G	CFP2-DCO	600 km
	Proprietary	Max performance CD/CDC ROADM metro and LH networks	Multiple	100-200-300-400G	CFP2-DCO QSFP-DD	> 600 km

The diagram shows the main configurations for using pluggable and embedded transceiver modules. Until 2021, *only* the bottom configuration using embedded modules existed for 400G or higher transport; including solutions with single wavelengths up to 800G over CD/CDC ROADM networks.



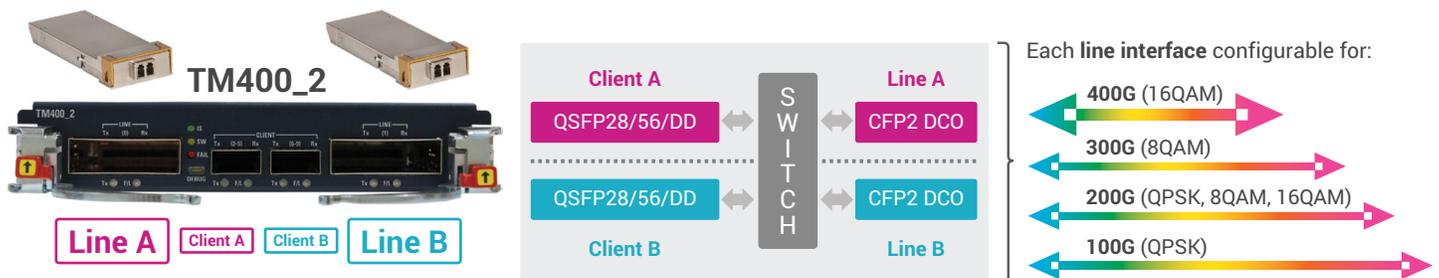
In 2021, Ribbon will be the first vendor to introduce 400G ZR+, with the Apollo TM400_2 transponder/muxponder blade using CFP2-DCO pluggables to implement the middle configuration. In the next part of this document, we show how the TM400_2 disrupts the current embedded modules approach, to compete against those solutions for both metro transport and even LH applications!

Ribbon is also deploying 400G ZR+ pluggables in its 9904X Metro OTN switch, boosting the capacity of its metro aggregation links to 400G. In addition, Ribbon will deploy 400G ZR+ pluggables in its Neptune IP routers, implementing the top configuration in the diagram. These applications are not addressed further in this document.

TM400_2 Dual 400G Coherent Transponder/Muxponder

The Apollo TM400_2 dual transponder-muxponder combines software-programmable modulation with an internal switch to provide the industry's most compact, low power, and versatile transport of 100GbE and 400GbE clients for metro, regional, and long haul applications. It is ultra-compact and ultra-low power, featuring < 0.15W/Gbps with all plug-ins at 2 x 400G.

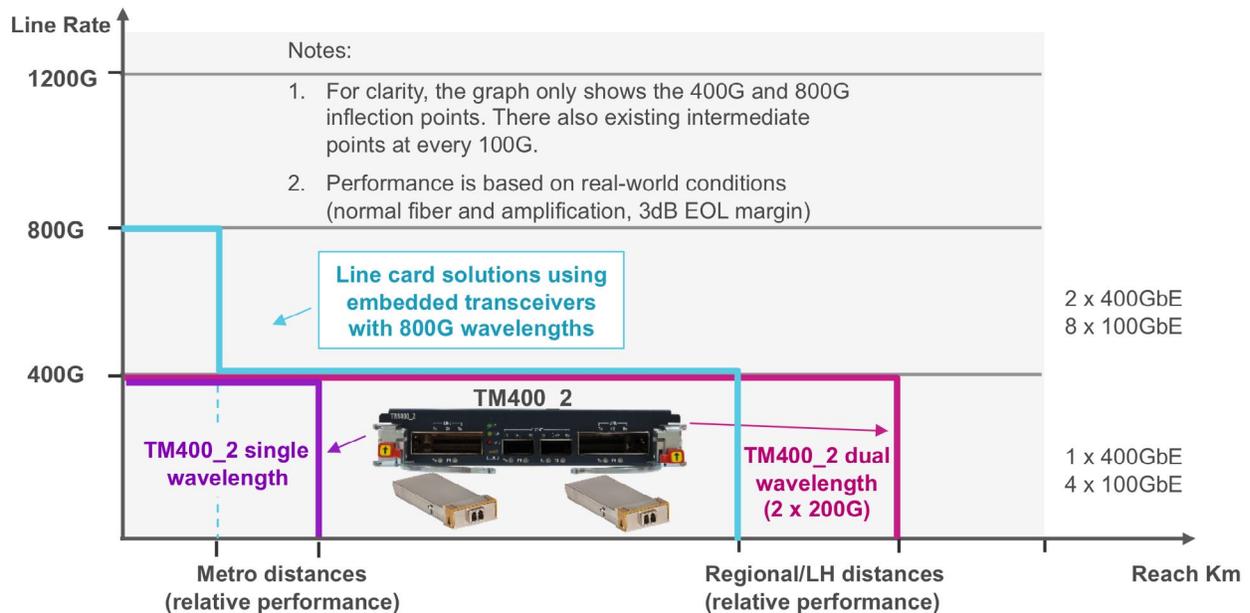
The TM400_2 rides the price-performance curve for 400G ZR+ CFP2-DCO pluggables and is configurable with several versions of these pluggables. This includes proprietary modulations and SD-FEC for maximum long haul reach, as well as using standard OpenROADM OFEC that can interwork with other 400G ZR+ line cards to support interoperable disaggregated networks.



Client Type	Client A	Client B	Line A	Line B	Application
100GbE	4 x 100GbE*	4 x 100GbE*	400G	400G	DCI-Metro
	2 x 100GbE	2 x 100GbE	400G	—	DCI-Metro
	2 x 100GbE	100GbE	300G	—	Metro
	2 x 100GbE	2 x 100GbE	200G	200G	Metro-LH
	2 x 100GbE	100GbE	200G	100G	Metro-LH/ULH
*fan-out	100GbE	100GbE	100G	100G	ULH-Submarine
400GbE	400 GbE	400 GbE	400G	400G	DCI-Metro
	400 GbE	—	200G	200G	LH

The graph illustrates how the performance of the TM400_2 compares to solutions using 800G embedded modules. An examination of the details makes it clear how the TM400_2 provides more cost effective solutions for both metro and long haul networking applications.

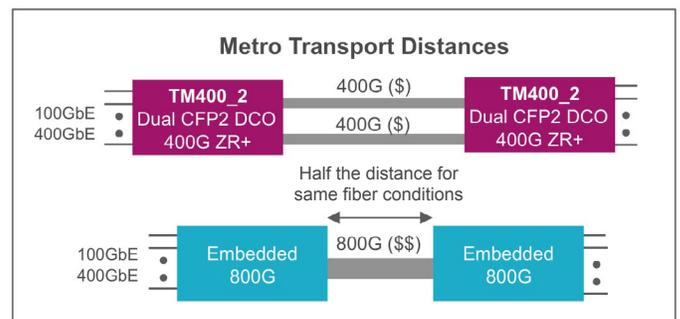
Ribbon's Market-Disrupting 400G ZR+ Solution



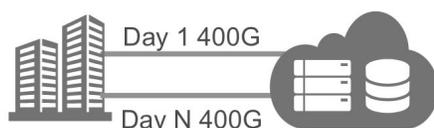
Metro Applications with Pay as you Grow

The TM400_2 can transmit a single 400G wavelength, carrying 4x100GbE clients or a single 1x400GbE client, over a CD/ CDC ROADM network for a typical reach of 600Km. Alternatively, solutions using current embedded transceivers can transmit a single 800G wavelength with twice the client capacity. However, in an “apples to apples” comparison (equivalent fiber and amplification) this will be half the distance! This is because two ZR+ 400G wavelengths have an inherent distance performance advantage due to a higher total baud rate, of 2x64GBaud versus 95GBaud. This provides a huge advantage with respect to OSNR handling and being able to use a less dense modulation scheme that propagates further.

Moreover, as we noted earlier, the cost of a single 800G embedded transceiver is double that of a 400G ZR+ CFP2-DCO pluggable. Therefore, the TM400_2 can transport 800G worth of traffic much further, and for lower effective cost, than line cards using embedded 800G transceivers.

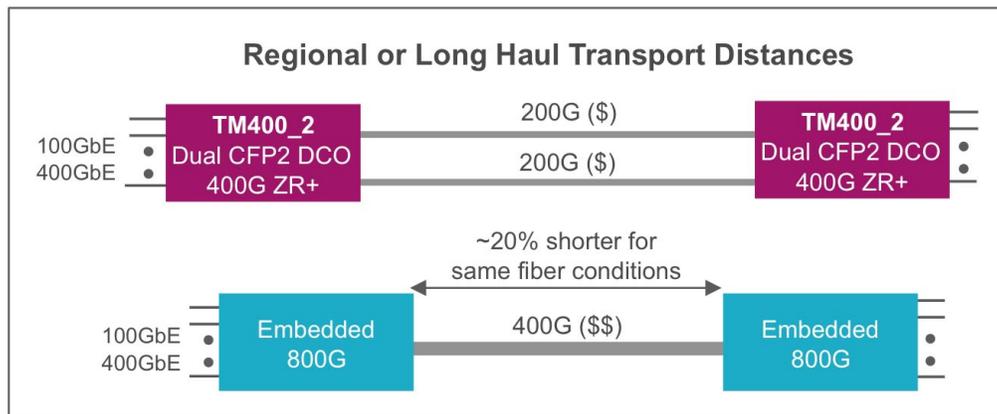


In addition, the modular design of the TM400_2 enables “pay as you grow”, whereby 400G wavelengths can be added incrementally as traffic increases. This is not achievable with embedded solutions that require a complete and expensive 800G wavelength upfront.



Long Haul Applications

The TM400_2 has a unique mode in which it can combine 2 x 200G wavelengths (one from each 400G ZR+ pluggable) to create an effective 400G channel. These 200G wavelengths use highest performance QPSK modulation with a total typical reach of about 2500Km. In an equivalent deployment, the maximum 400G distance of current embedded transceivers is about 20% less, due to their lower baud rate mandating higher density modulation. The result is the same as above, whereby a TM400_2 with two CFP2-DCO's (each running 400G ZR+ in 200G mode) provides better performance at lower cost than a single 400G wavelength from an embedded transceiver.



Looking Forward – Importance of 400G QPSK LH and a Standard Channel Plan

To provide a more complete picture, the table below provides further technical insights into the various solutions, and adds a row for a future embedded solution that Ribbon plans to adopt. Based on a new generation of 5nm silicon technology and operating at a projected 130Gbaud, this will support two important capabilities that go beyond existing embedded transceiver solutions:

- A single 1200G wavelength for high capacity short haul applications.
- A 400G wavelength using QPSK modulation enabling longer reach long haul applications.

QPSK has always been the “gold standard” for LH. This has progressed from 100G in the past, to 200G today. While current 800G embedded solutions cannot achieve 400G QPSK, Ribbon’s next generation embedded solution operating at 130Gbaud will achieve this goal.

Ribbon's Market-Disrupting 400G ZR+ Solution

Transmission Solutions	Availability	Line Rate	Transport Capacity	Distance (km)*	Relative Cost	Carrier Baud Rate (Gbaud)	Channel Width (GHz)	Modulation**
Line cards with current generation embedded transceiver	2020-2021	800G	800GbE	300	\$\$	95	112.5	16QAM
		400G	400GbE	2000	\$\$	95	112.5	PS-16QAM
TM400_2 with 400G ZR+ CFP2 DCO pluggable (single wavelength)	2021	400G	400GbE	600	\$ (per wavelength)	64	75	16QAM
TM400_2 with 400G ZR+ CFP2 DCO pluggable (dual wavelengths)	2021	2 x 200G	400GbE	2500	\$ (per wavelength)	64	150	QPSK
Ribbon line card with next generation embedded transceiver	Late 2022	1200G	1200GbE	120	\$\$	130	150	64QAM
		800G	800GbE	800	\$\$	130	150	16QAM
		400G	400GbE	3000	\$\$	130	150	QPSK

* Distances should be regarded as typical spans, and be compared "relative to each other" under equivalent fiber, amplification, and EOL margin conditions

** For the embedded modules these modulations are sometimes enhanced using proprietary schemes

The table also draws attention to the need to consider channel width, as well as price-performance, when formulating a 400G+ transmission strategy.

In theory, current flexible grid technology allows continuously optimizing channel widths across the entire spectrum on a fiber. In practice, however, flexible grid is used mostly in a set and forget fashion. The reason is largely operational, in that it is not easy to keep track of changes across multiple hops between ROADM-powered network nodes. Spectrum re-assigned to a channel on one hop, may not be available on the next one, creating a need for complex re-shuffling across the entire network that becomes exceedingly difficult to manage. Ultimately, spectrum "defragmentation" becomes so complex that it can lead to abandoned and thus wasted spectrum.

This may happen with current 800G embedded transceiver solutions that require a "strange" channel width of 112.5GHz. 400G ZR+ in CFP2-DCO pluggables offer a more ordered approach. These serve all metro and long haul applications today based on a natural channel plan of 75GHz or 150GHz channel widths. Moreover, this approach evolves smoothly to a next generation high performance embedded solution based on 150GHz channel widths, leaving no fragmented or abandoned spectrum.

5nm/130Gbaud technology. Brings:

- 1200G wavelength for short haul
- 400G wavelength with QPSK modulation for true LH



Summary – Delivering the Emerging Optical Highway

The focus of optical networks is now turning to effective transport of 400GbE clients on top of existing 100GbE clients.

By leveraging power and cost optimized CFP2-DCO pluggables that support 400G ZR+ transmission, Ribbon enables operators to create an optical highway with multiple 400G lanes to carry this traffic for metro and LH applications more efficiently than current 800G embedded solutions. Moreover, Ribbon's planned 1200G embedded solution is compatible with this approach, fitting within a future-proof channel plan based on multiples of 75GHz ensuring there is no wasted spectrum.

About Ribbon

Ribbon Communications (Nasdaq: RBBN) delivers communications software, IP and optical networking solutions to service providers, enterprises and critical infrastructure sectors globally. We engage deeply with our customers, helping them modernize their networks for improved competitive positioning and business outcomes in today's smart, always-on and data-hungry world. Our innovative, end-to-end solutions portfolio delivers unparalleled scale, performance, and agility, including core to edge software-centric solutions, cloud-native offers, leading-edge security and analytics tools, along with IP and optical networking solutions for 5G.