



State of the Art IP and
Optical Networking



The Emerging Optical Highway

N x 400G Line Rates on M x 75GHz Lanes

400GbE Clients Drives Need for Multiples of 400G Speeds

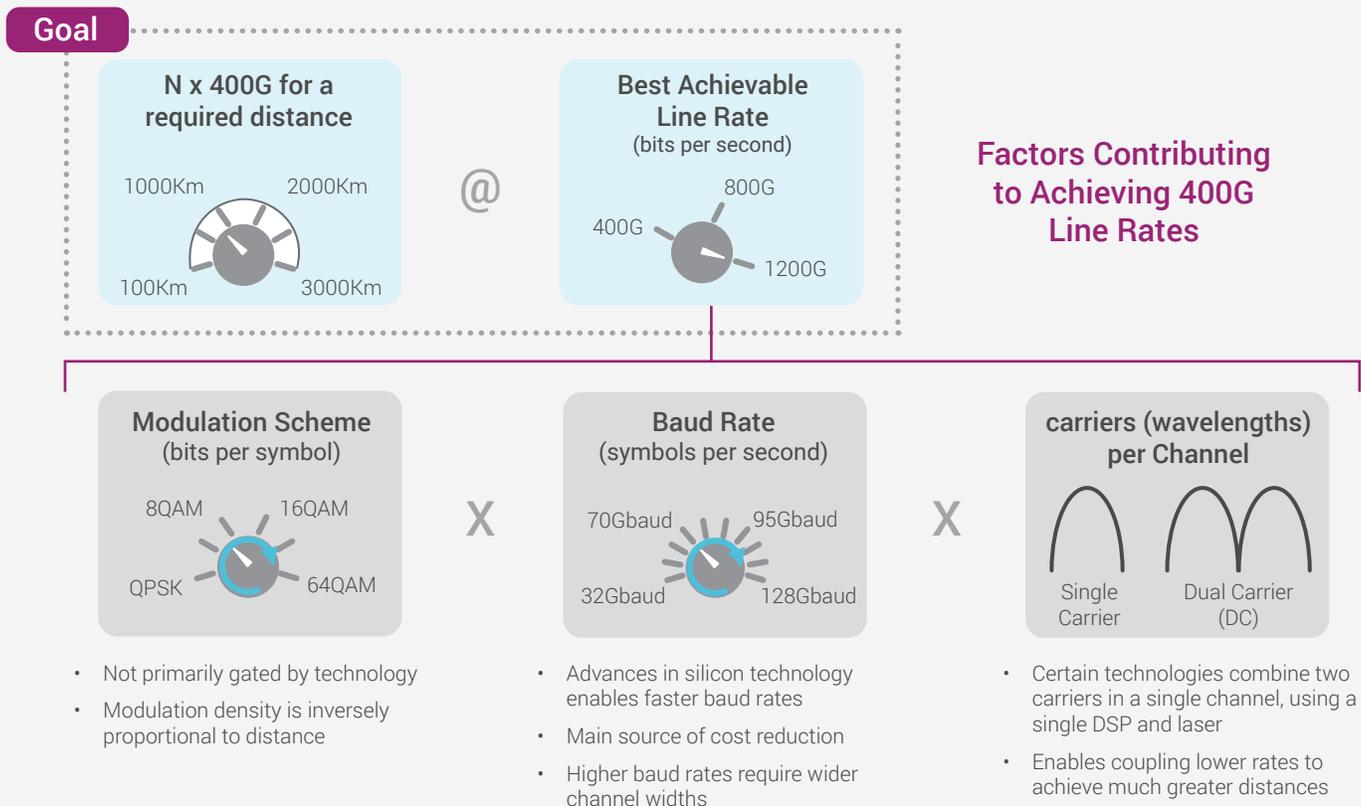
The purpose of optical networks is to transport layer 1 client interfaces (also called service interfaces) across wide geographic areas, connecting routers, switches and other edge devices with each other. We are now at the beginning of a period where 400GbE is displacing 100GbE as the dominant client interface requiring transport. Therefore, it is important that optical networks support an orderly mapping of 400GbE clients onto transmission line rates. This means mapping a single 400GbE client onto a 400G line rate, two 400GbE clients onto an 800G line rate, and so on, insofar as a line rate is achievable for a given distance.

In this paper, we show how to achieve this goal for both high-performance and cost-optimized transport solutions using a channel plan based on multiples of 75GHz that ensures there is no wasted spectrum.

Achieving Multiples of 400G Speeds

The elements that combine to determine transmission rates in multiples of 400G are:

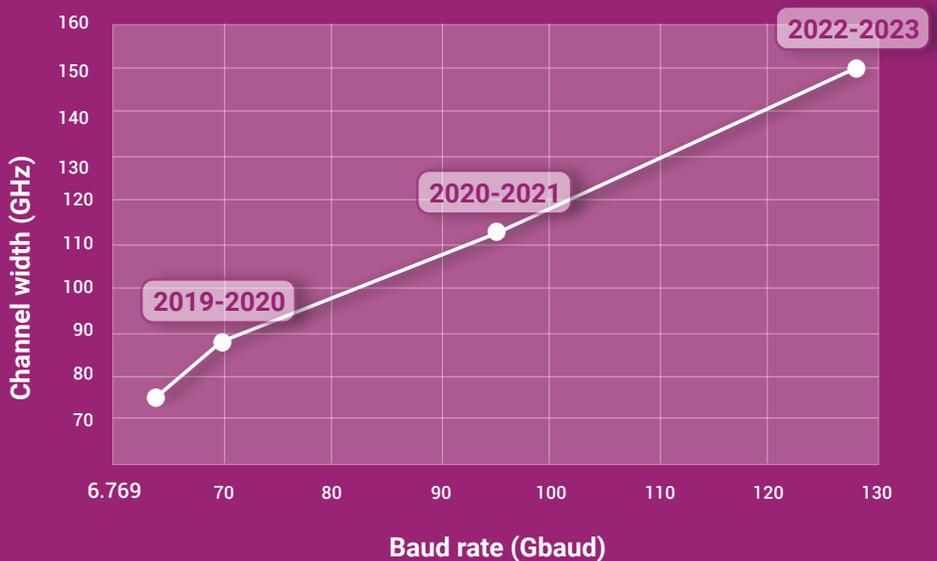
- modulation scheme [bits per symbol]
- **times** two polarizations of light (not shown in diagram)
- **times** the baud rate [symbols per second]
- **times** the number of carriers (wavelengths) per channel (supported by certain technologies)



The **modulation scheme** encodes strings of bits onto different combinations of phase and amplitude of an analog optical sine wave carrier, where each combination becomes a “symbol”. The simplest scheme, QPSK (quadrature phase shift keying) uses four phases at a constant amplitude, encoding 2 bits. 8QAM (quadrature amplitude modulation) uses two amplitude levels with these four phases, creating 8 symbol types that encode 3 bits. 16QAM uses four amplitude levels to encode 4 bits, 32QAM encodes 5 bits, and 64QAM encodes 6 bits. In practice, these symbol rates are doubled using two polarizations of light.

It may seem that using increasingly dense modulation is an easy way to increase the line rate. However, this approach is constrained because modulation density is inversely proportional to distance. This is because with denser modulation schemes, symbols that closely resemble each other *smear together* more easily as they propagate along the fiber, making it more difficult to distinguish between them at the receiver.

The **baud rate** is the rate at which modulated symbols are transmitted within an optical channel and are recovered by a coherent receiver. Here we can leverage ongoing advances in smaller scale silicon to achieve denser integration of DSP and RF/mixed signal technologies, to increase the baud rate and thus increase the line rate. However, this comes with a tradeoff due to the theoretical Shannon limit on spectral efficiency, which mandates that the baud rate is directly proportional to required channel width. Faster baud rates require wider channels, as the illustration shows for some popular baud rates. The diagram also shows there is a general progress to faster baud rates over time, as would be expected. One point this paper identifies is that current solutions based on 95Gbaud are an intermediate generation, which mandate use of an awkward 112.5GHz channel width that can lead to stranded spectrum.



Finally, certain technologies allow **dual carriers** within a single optical channel. The huge benefit of this approach is that combining two carriers with less dense modulation schemes delivers the same effective line rate as a single carrier using a denser modulation scheme, but far exceeds the single carrier in transport distance!

Transceiver Solution Types

We have shown how modulation schemes, baud rates, channel widths, and carriers, combine to achieve transmission line rates. The full story must also consider practical transceiver solutions that define form factors and place limits on power consumption. Here the industry is focusing on three types of transceiver solution for 400GbE clients. Each type has different optimization priorities based on its target applications and size-power constraints. Note that while these transceivers can also support other rates, in this paper we focus only on their ability to deliver multiples of 400G.

Embedded Modules



- Vendor proprietary
- Power 60W+
- **Performance-optimized** 400G-800G-1200G
- Application: ROADM-based optical transport networks
- Not interoperable

CFP2 DCO



- Multi-vendor pluggable
- Power 25W
- **Power-cost optimized** for 400G
- Application: ROADM-based optical transport networks
- Interoperable based on OpenROADM MSA

QSFP-DD



- Multi-vendor pluggables
- Power 15W
- **Power-cost optimized** for 400G
- Application: P2P DCI, IPoDWDM
- Interoperable based on OIF 400ZR and OpenZR+ MSA

OSFP

Vendor proprietary embedded transceiver 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. These modules focus on maximizing spectral efficiency for any distance and fiber condition. While they might be more expensive for initial low traffic capacity, they achieve low cost per bit for applications with very high traffic densities or a need cover long distances, where maximizing channel capacity is very important.

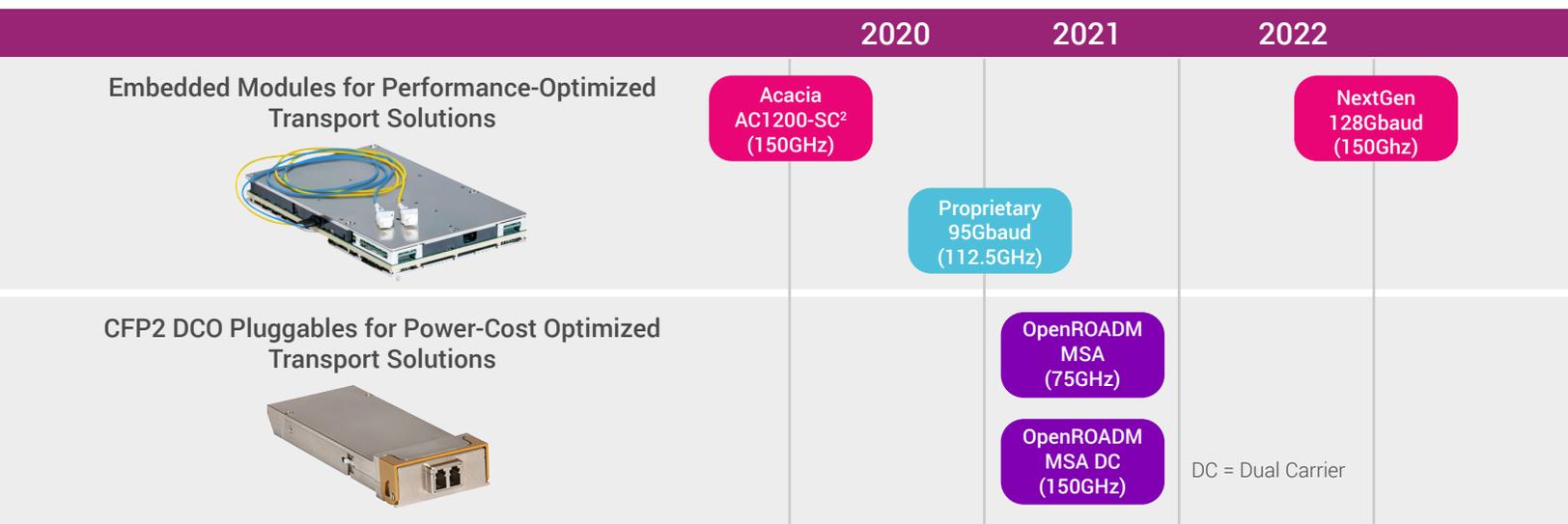
Pluggable transceivers conform to industry standard form factors and electrical interfaces. They focus on optimizing power and cost while delivering performance that is strong enough for most applications. Pluggables have an array of benefits:

- As multi-source products, they are subject to more competitive pricing, driving costs lower.
- They can be used to build “pay as you grow” transport blades and sub-systems with lower day-one costs, and adding on line capacity as traffic grows.
- They are upgradeable to higher performance versions as these become available in the same form factor.
- By adopting common OpenFEC settings, pluggables can interoperate with each other, allowing disaggregated multi-vendor networks.

There are two major pluggable classes supporting 400G. In this paper, we are interested in the CFP2 DCO (digital coherent optics) pluggable with a 25W power profile that targets ROADM-based mesh optical transport networks. We note but do not explore further the capabilities of more compact and lower power QSFP-DD and OSFP pluggables, whose primary applications are point-to-point transmission for data center interconnection and IP-over-DWDM.

Transceiver Solution Rollout

The diagram summarizes the major 400G+ solutions for the proprietary embedded and CFP2 DCO form factors, from 2020 through 2022. The embedded modules category starts with a solution from Acacia who is a lead merchant supplier of these modules to optical networking companies. Also analyzed are a class of proprietary solutions based on 95Gbaud technology. These are available from a few companies that make and primarily use these modules in their own optical networking products, and sometimes make them available to the general market. Finally, this category projects the capabilities of a 128Gbaud solution that the industry has started discussing. In the CFP2 DCO pluggables category, there are multiple suppliers with similarly performing solutions, by definition.



Acacia AC1200-SC² module. This 1200G module has two carriers that can operate independently or together in a dual-carrier mode. Each carrier is tunable from 100G to 600G in 50G increments. In dual carrier mode, the AC1200-SC² couples the two carriers into a single channel, effectively delivering line rates of 400G, 800G and 1200G for 400GbE client transport. Acacia uses 3D Shaping technology, which includes adaptive baud rates up to 70Gbaud and fractional QAM modulation, to maximize the line rate for a given link.

Proprietary 95Gbaud. Provided by a few optical networking companies, these modules use a 95Gbaud DSP to deliver line rates from 200G to 800G in 100G increments using a single carrier. Accordingly, these modules enable 400GbE transport solutions at 400G and 800G. These solutions also use proprietary innovations to maximize line rates for a given link.

NextGen 128Gbaud module. Next generation high baud rate modules are expected to be available for trials in 2022 and commercial availability in 2023. They leverage ongoing advances in silicon integration to implement a 128Gbaud DSP that can deliver line rates up to 1200G using a single carrier. The net effect is that they will support the same capabilities as the Acacia AC1200-SC² module but using only a single carrier rather than dual combined carriers, lowering the cost per bit.

CFP2 DCO OpenROADM MSA. This pluggable provides line rates of 100G/200G/300/400G using a single carrier, based on a fixed baud rate of 64Gbaud. It can be used for single client 400GbE transport.

CFP2 DCO OpenROADM MSA DC. This dual carrier implementation of the OpenROADM MSA combines two 200G carriers (using less dense modulations) into a single 400G channel for long haul applications.

The table and diagram below summarize the relative ability of these transceiver solutions to transport 400GbE client interfaces in ROADM-based mesh optical networks. **They show how many multiples of 400GbE client each solution can support and for what distances.** To re-emphasize a point made above, while these solutions can also transport other rates, like 100G/200G/300G/600G, for this analysis, we focus only on how well they can transport emerging predominant 400GbE clients.

NOTE: The distance performance estimates are Ribbon's own calculations based on publicly available information. They assume standard fiber and amplification, and take into account 3dB EOL margin. Suppliers of individual solutions may provide different performance figures.

Transceiver Type	Solution	Commercial Availability	# of 400GbE	Line rate	Distance (km)	Carrier Baud Rate (Gbaud)	Channel Width (GHz)	Modulation*
Embedded Modules (Performance-optimized transport)	Acacia AC1200-SC ²	2020	3	1200G	120	70	150	64QAM
			2	800G	800	70	150	16QAM
			1	400G	3000	70	150	QPSK
	Proprietary 95Gbaud	2020-2021	2	800G	200+	95	112.5	16QAM
			1	400G	2000+	95	112.5	PS-16QAM
	NextGen 128Gbaud	2022-2023	3	1200G	120	128	150	64QAM
2			800G	800	128	150	16QAM	
1			400G	3000	128	150	QPSK	
CFP2 DCO (Cost-power optimized transport)	OpenROADM MSA	2021	1	400G	600	64	75	16QAM
	OpenROADM MSA - DC	2021	1	400G	2500	64	150	QPSK

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

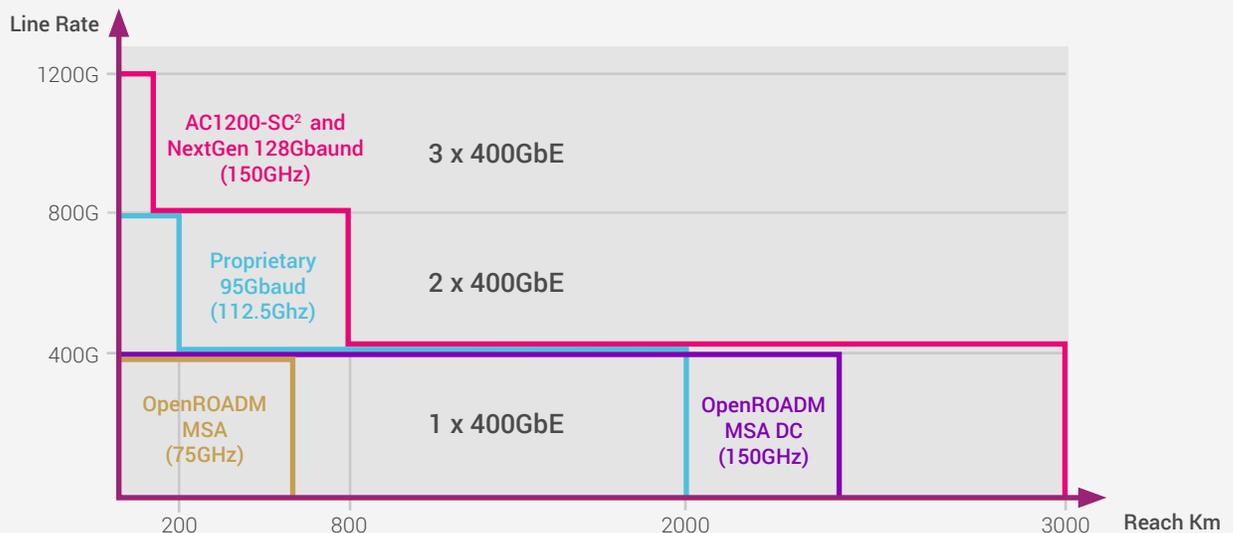


Table and Figure show that optimal performance for all applications is achievable with a uniform 75GHz/150GHz grid.

Case for an M x 75GHz Channel Plan

When we step back and look at the big picture, we can see that we can fulfill both performance-optimized and cost-power optimized 400GbE transport solutions using a 75GHz/150GHz channel plan. While the availability of flexible grid does not make this approach a technical necessity, the use of “strange” channel widths can easily lead to gaps in spectrum use and thus wasted spectrum.

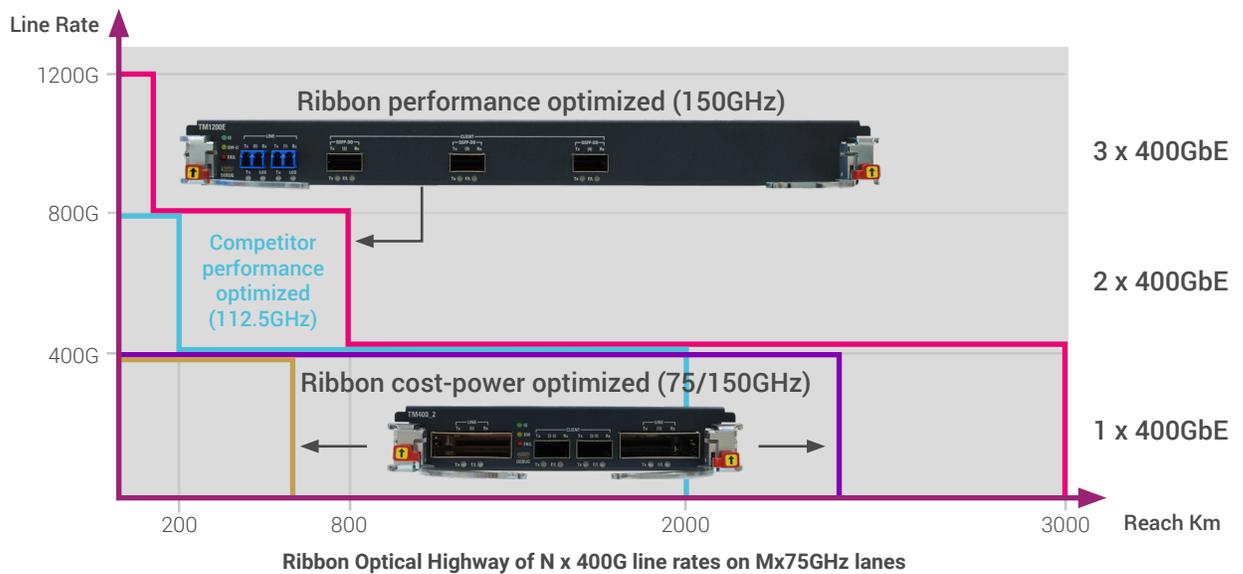
Time ↑	NextGen 128Gbaud	150GHz		150GHz	
	CFP2 DCO OpenROADM-DC	150GHz		150GHz	
	CFP2 DCO OpenROADM	75GHz	75GHz	75GHz	75GHz
	Proprietary 95Gbaud	112.5GHz	112.5GHz	112.5GHz	112.5GHz
	AC1200-SC ²	150GHz		150GHz	

By adopting a channel plan based on 75GHz, transport providers can optimize spectrum use over the long term. They can apply a mix of solutions on an end-to-end basis, spanning multiple fibers, without needing to be concerned about fragmented and abandoned sections of spectrum.

Delivering the Emerging Optical Highway

The focus of optical networks is now turning to effective transport of 400GbE clients. Some applications require a performance-optimized solution, such as when there is dense traffic with many clients requiring transport in parallel. Other applications, such as where traffic grows in increments, requires a power-cost optimized solution.

Leveraging the capabilities of both embedded and CFP2 DCO pluggable 400G transceivers, Ribbon enables operators to create an optical highway with multiple 400G lanes to carry a mix of performance-optimized and cost-power optimized traffic. By using a channel plan based on multiples of 75GHz, Ribbon’s 400G lanes ensure there is no wasted spectrum.



Contact us to find out how to optimize transport of 400GbE clients in your network

About Ribbon

Ribbon Communications (Nasdaq: RBBN), which recently merged with ECI Telecom Group, delivers global communications software and network solutions to service providers, enterprises and critical infrastructure sectors. 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 IP solutions, UCaaS/CPaaS cloud offers, leading-edge software security and analytics tools, as well as packet and optical networking leveraging ECI's Elastic Network technology.