Technology

Optical Transceiver: How It Differs in 5G and Cloud

Key Takeaway

We expect to see fundamental changes in the architecture of 1) 5G optical transport network and 2) data center design, driven by new applications for unlimited bandwidth, such as 4K video, self-driving, AR/VR. This transition will accelerate high-speed 100G & above transceiver upgrades, also significantly increase the volume level of transceivers. We view O-Net (877 HK) as a beneficiary. We also like Luxshare (002475 CH) diversifying into data center cabling.

The Rise of 100G+ and Terabit Transport Network. Thanks to the advance of optical communication technologies, optical transmission data rates have increased by 160-fold over 30 years, from 2.5Gbps to 400Gbps. This trend will continue in coming years driven by explosive data traffic in 5G and Cloud Computing. In this report, we mainly study the evolving network architecture and how it differs for the optical transceiver industry.

5G enabled applications post new requirement on RAN architecture. The major change will be the introduction of C-RAN (Centralized/Cloud RAN), with two-level fronthaul. A baseband unit (BBU) is split into a centralized unit (CU, which will evolve to cloud data centers on the edge) for non-real time tasks like AR/VR and facial recognition, and a ring of distributed units (DU, connecting to antennas and remote transceivers) for real-time tasks like self-driving. As a result, we estimate the number of transceivers in front-haul in 5G will be over 20 times more than that of 4G, in addition to 25G/50G and even 100G deployment from 6G/10G.

"West-to-East" (server-to-server) traffic surging in Data Centers. A flattening spine-leaf topology has started to replace the traditional three-layer network, in order to improve the efficiency of server-to-server traffic. We believe the cloud data center architecture change will drive new demands for high-speed 100G/400G optical transceivers, in addition to data center capex growth. We estimate 100G transceiver demand will increase by 5 times, and optical connection will replace copper in server-to-server, benefiting 25G/100G AOC vendors. In 2013~2023, data center bandwidth density per port will expand by 40 times, or double every two years.

China leaders face opportunities and challenges. Optical communication ecosystem mainly consists of 1) optical IC, 2) optical component, 3) optical transceiver/module and 4) network equipment. The IC and optical component, transceiver integration technology platform provides core capability for high data rate transmission. US and Japanese vendors are integrated players, controlling most high-end 100G+ transceiver markets. Chinese players are poised in highly competitive passive & active components and low-end 10G/25G/40G segments. Potential price competition, inventory overbuilds and accelerating 200G/400G/600G technology migration may impact their growth. We prefer leaders with 1) broad customer base in China and overseas, 2) high vertical integration in chips and components, and 3) clear product visibility.

O-Net benefits from vertical integration. O-Net is one of the few vertically integrated suppliers in China, with passive (No.3 globally) and active components, laser chip (DFB/EML), as well as SFP+/QSFP28 transceivers to come in 2018. We expect its broadening product portfolio and customer base (more internet content providers) will help it to gain market share from global peers.

Luxshare emerges in data center cabling. To address increasing optical fiber coverage in data centers, Luxshare has invested in high-speed AOC R&D in Taiwan and the US. We expect Luxshare to bring its strong execution and manufacturing capability to the industry, and ride on the strong demand from China market.

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^Prior trading day's closing price unless otherwise noted.

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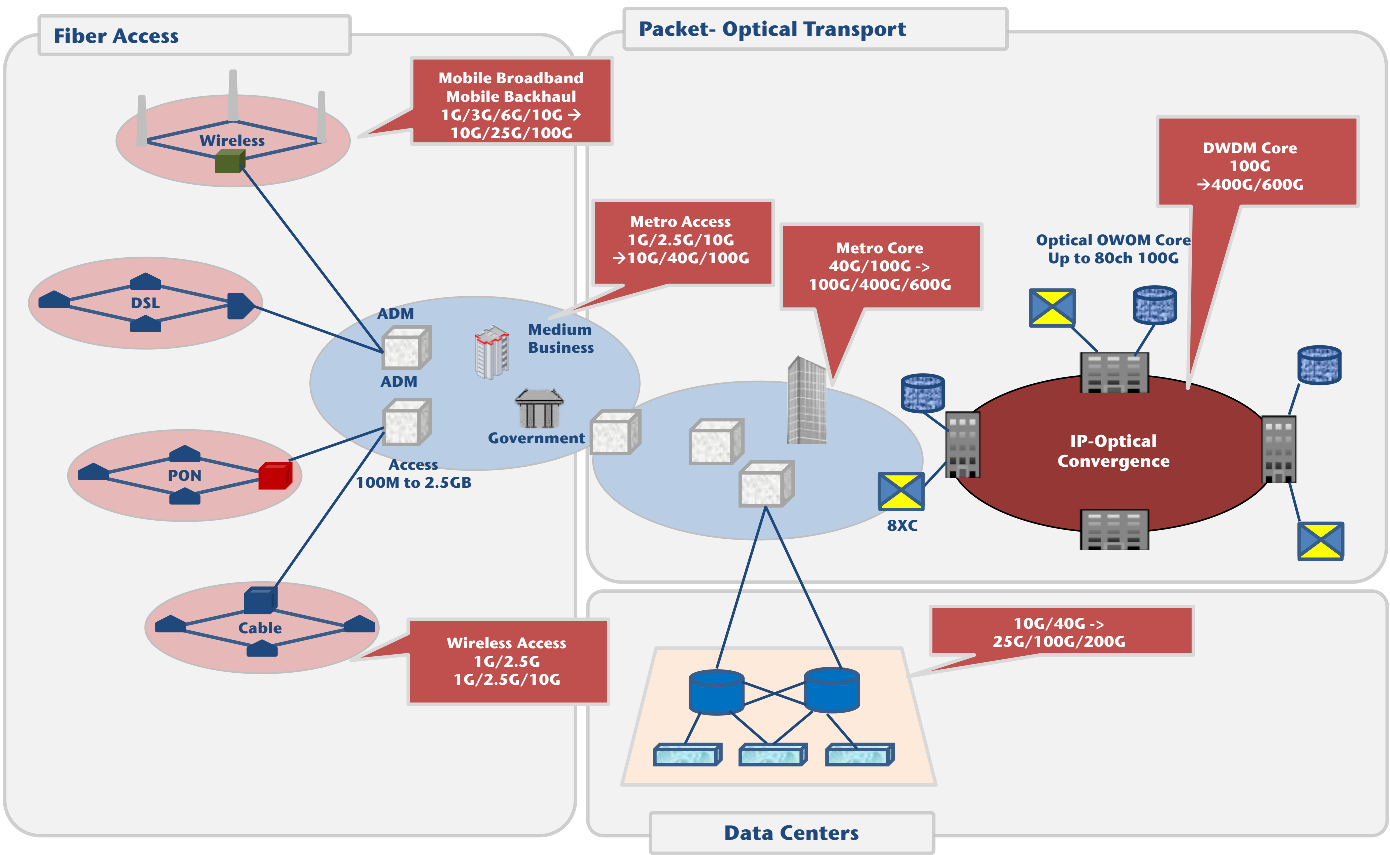
Executive Summary

High-speed transceiver deployment is also accelerating, driven by unlimited bandwidth applications.

We expect to see several fundamental changes in the architecture of 1) 5G transport networks and 2) data center design, driven by diverse demands of new applications for unlimited bandwidth, such as 4K/8K video traffic and AR/VR are sensitive to network latency. This will boost significant new demand for the optical communication industry, including optical fiber and optical equipment (component, transceiver, equipment). Optical transceivers are the major cost component of the equipment, and also heavily influence the overall system performance. We believe the transition will not only accelerate high-end 100G and above transceiver deployment, but also drastically increase the transceiver's volume level. China's optical communication industry is on the rise thanks to downstream Chinese telecom operators' early move in 5G and ICPs' (Internet content providers like Alibaba, Baidu and Tencent) aggressive spending on cloud.

Chart 1: Optical transport network upgrade in telecom & datacom



Source: Oclaro, Jefferies

5G fronthaul architecture will be very different from that of 4G.

Comparing to 4G, 5G will have 1) 10~100 times throughput, 2) 10 times lower latency and 3) 10~100 times more connected devices. Before massive deployment scheduled for 2020, telecom operators can stretch their existing 4G network and start adopting C-RAN (centralized or cloud radio access network). ***The major architecture change will be two-level fronthaul, which divides baseband unit (BBU) into distributed unit (DU) and central unit (CU) to host real-time and non-real time functions, respectively. Based on our estimate, thanks to two-level fronthaul architecture, the amount of radio remote units (RRU, consists of antenna, RF and transceivers) will be over 20 times more than that of 4G.*** In addition, we believe mid-haul and backhaul architecture

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Metro-ring and backbone upgrade to 100G/400G/600G will continue in coming years.

will shift to IP networks + Optical transport networks, to achieve even more centralized computing and storage. This enables higher bandwidth and lower capex & opex, as traditional network equipment getting replaced by general cloud servers and routers. The shift will also drive another wave of transceiver upgrades in mid-haul (n*25G/50G) and backhaul (200G/400G coherent AOC/DOC self-developed by network equipment vendors).

Over 70% of data workloads are done within data center, mostly “west-east” traffic between servers. Optical port density will significantly increase in the architecture change.

Data center is the main driver for Internet traffic growth. ***Data center bandwidth density will double every two years, and expand by 40 times between 2013 and 2023.*** According to Cisco, global data center IP traffic will grow threefold from 2015 to 2020, with most workloads within the data centers. This will drive the data center architecture shifting from traditional three-layer to a flattening two-layer spine-leaf network, with increasing optical fiber coverage. The flat structure can improve efficiency of server-to-server (east-west) traffic and increase the demand for high-speed optical transceivers and switches. ***Thanks to spine-leaf topology, we estimate 100G transceiver demand will expand by at least fivefold, and optical connection will replace copper in switch-to-server, benefiting 25G/100G AOC vendors.***

Although new demand is huge, transceiver price is declining 20~30% each year. More M&A will happen, for better pricing power.

Thanks to 5G and data center, we believe China optical component, transceiver module and fiber vendors both will enjoy structural growth in the following years. In the current stage, most local players are poised in the highly competitive passive and active component and 10G/25G/40G transceivers. Potential price competition, inventory overbuilds and faster-than-expected technology migration to 100G+ may significantly impact their businesses. ***We prefer leaders with 1) broad customer base in China and overseas, 2) high vertical integration in the value chain, from chip to component and module, and 3) high R&D intensity as well as good product line visibility.*** We highlight O-Net (from passive to active components and transceivers) and Luxshare (emerging player in high-speed AOC cable).

Investment Risks

- Network equipment vendors building excessive inventory for competition.
- Faster-than-expected technology migration (e.g., 40G market disappearing after five years), driven by network equipment vendors.
- Significant price erosion due to lack of pricing power.

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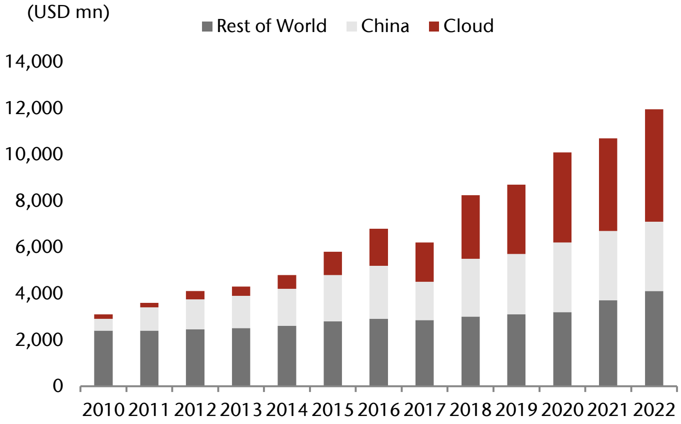
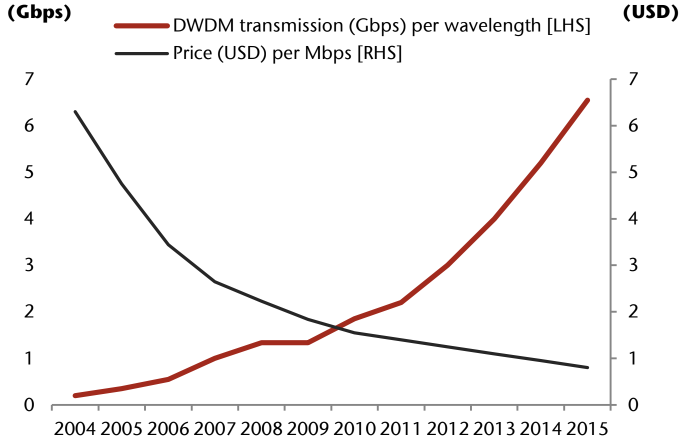
Key Charts

Chart 2: Global optical component & transceiver market trend



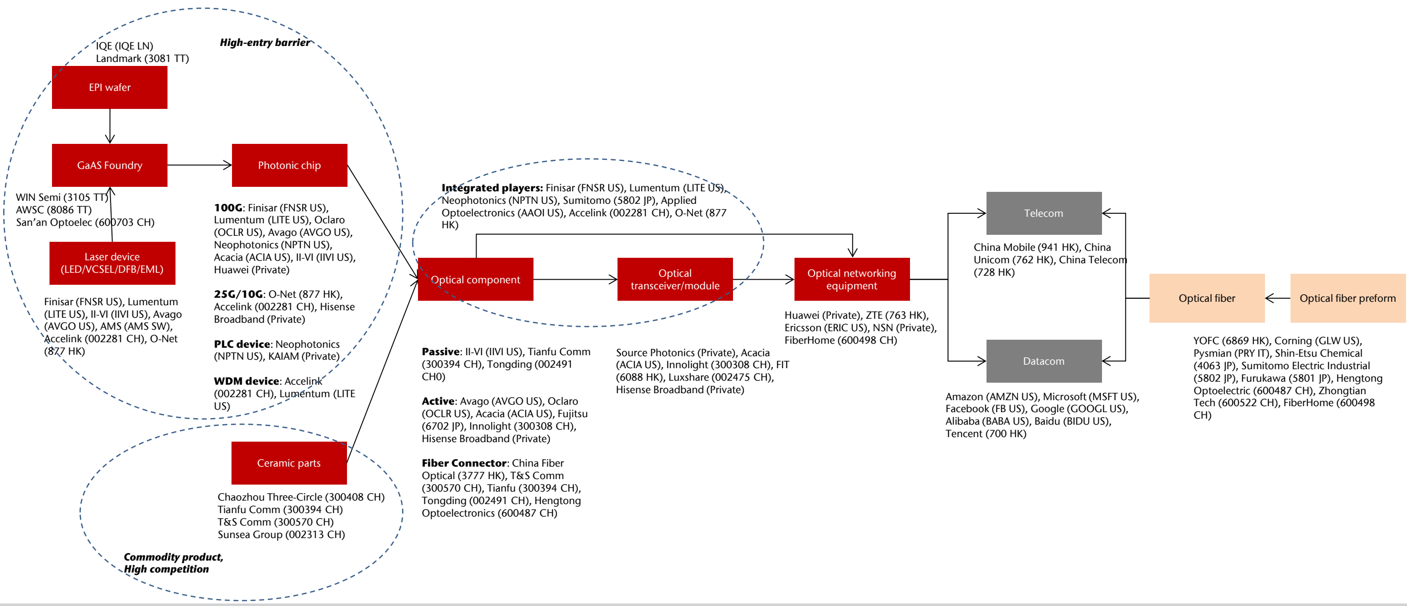
Source: LightCounting, Jefferies

Chart 3: DWDM transceiver density & price trend



Source: Jefferies

Chart 4: Optical transport network value chain



Source: Jefferies

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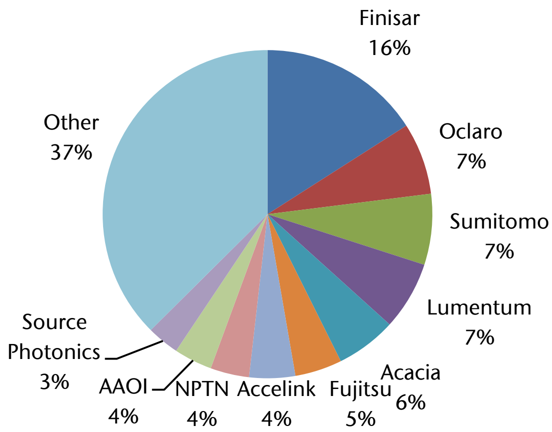
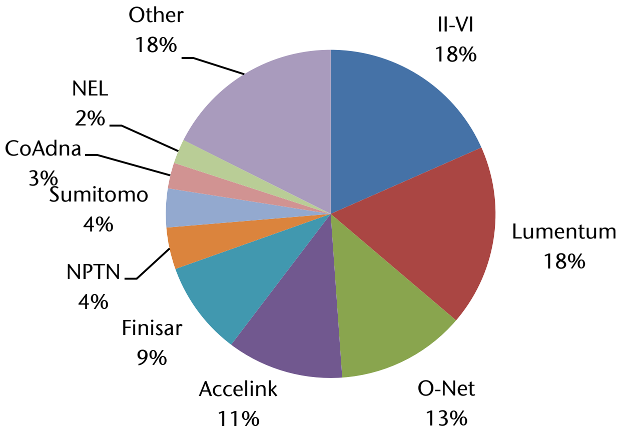
Chart 5: Global active component market landscape (Rolling share in 2Q16~1Q17)



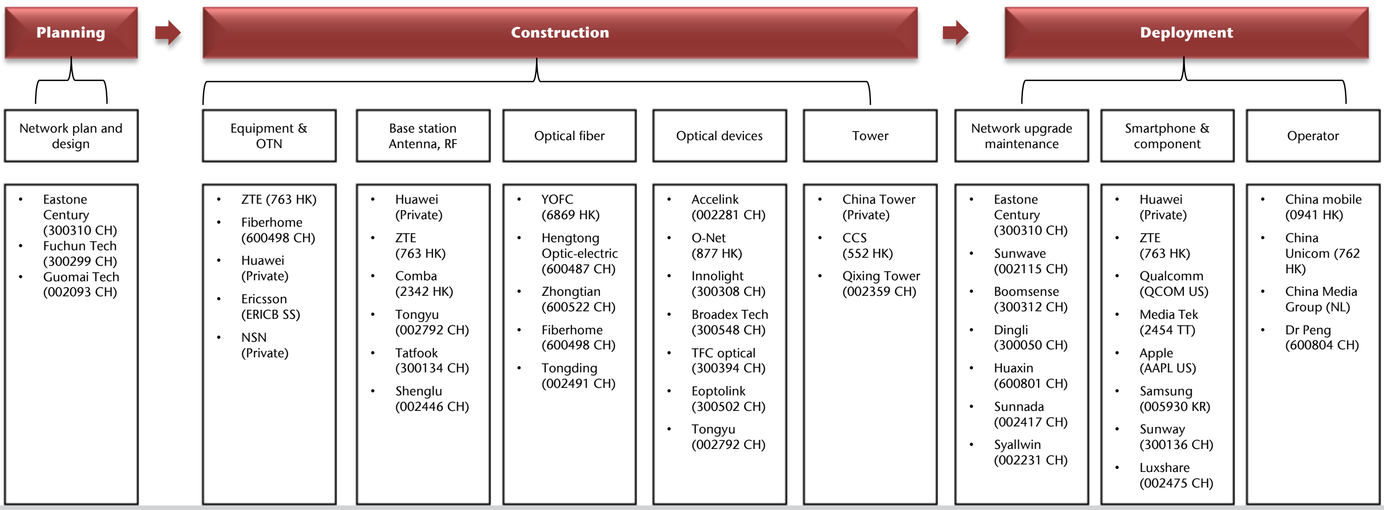
Source: OVUM, Jefferies

Chart 6: Global passive component market landscape (Rolling share in 2Q16~1Q17)



Source: OVUM, Jefferies

Chart 7: 5G value chain



Source: Jefferies

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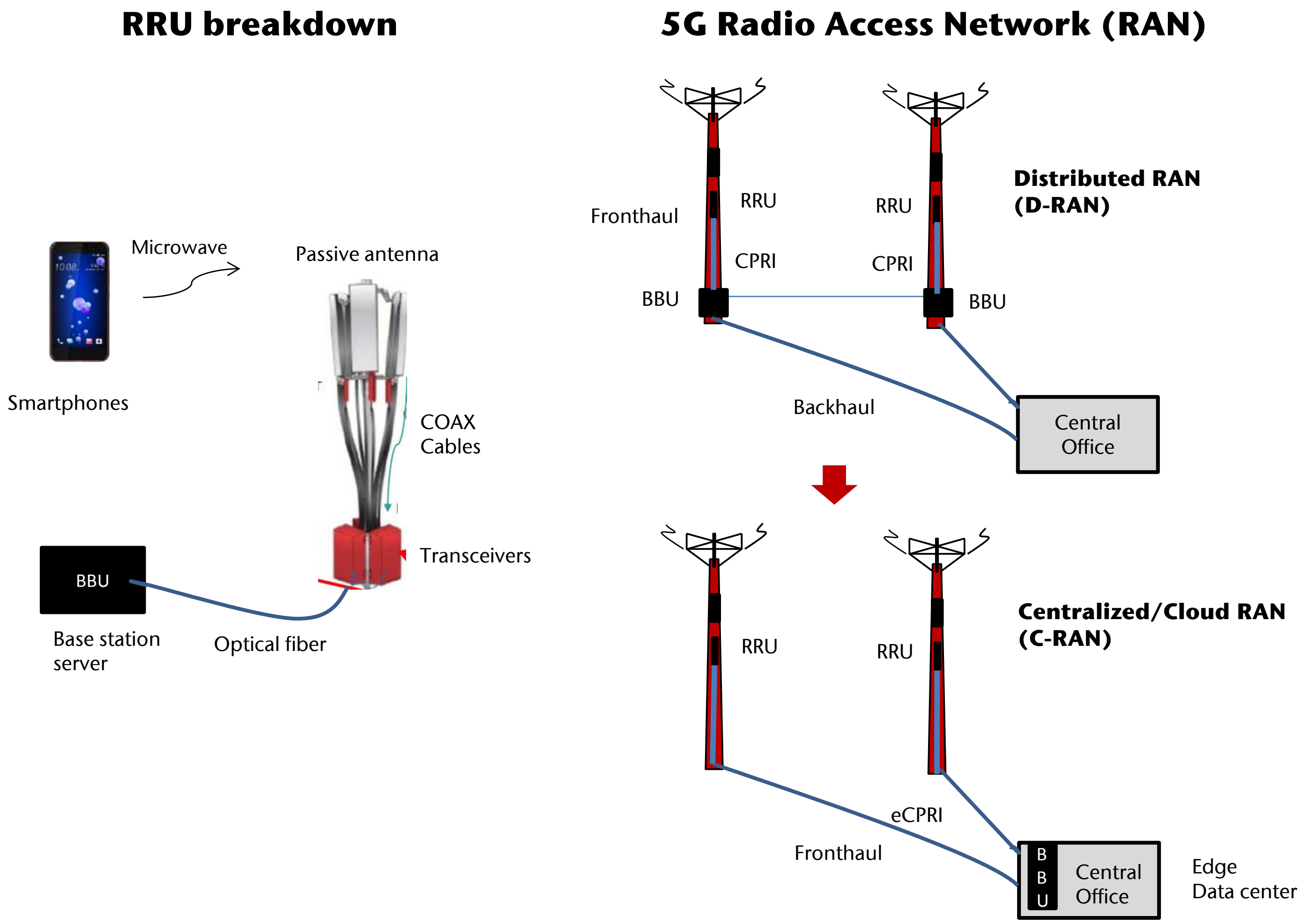
Chart 8: 5G Radio Access Network (RAN) - From D-RAN to C-RAN



Source: Jefferies

Chart 9: Alibaba Cloud's optical transceiver technology roadmap

Network speed	40G	100G	400G	1.6T?
SW-SW	40G eSR4 QSFP+	100G SR4, CWDM4 PSM4 QSFP28	400G DR4, FR4 SR4.2 QSFP56-DD	1.6T? OBO? QSFP224-DD?
SW-Server	10G AOC SFP+	25G AOC SFP28	100G AOC SFP56-DD	400G OBO? SFP224-DD?
Deployment	2013	2017	2019	2023?

Bankwidth density 40x in 10 years
Doubles - every 2 years

Source: Alibaba, Jefferies

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Chart 10: Global optical communication peer comparison table

Ticker	English name	Rating	TP	Last price	Market cap (USD mn)	Avg volume (mn shr)	2017-19 CAGR (Consensus)			P/E ratio		P/B ratio		ROE (%)	Dividend yield (%)	Share price performance			
							Sales	EBIT	EPS	2017	2018	2017	2018	2017	2017	5 Day	3 Month	YTD	1 Year
Optical component & transceiver																			
877 HK	O-Net	Buy	7.0	4.7	476	4.5	26.2%	44.8%	41.6%	16.1	10.8	2.0	1.7	13.4	2.1	-14%	-6%	23%	13%
002475 CH	Luxshare	Buy	30.0	24.6	11,813	23.2	36.5%	39.3%	34.9%	43.9	28.0	6.1	5.1	14.7	0.4	2%	17%	78%	73%
FNSR US	Finisar	Buy	28.5	17.8	2,031	3.1	5.6%	-1.3%	-0.7%	8.7	12.0	1.2	1.1	10.3	na	-9%	-20%	-41%	-44%
LITE US	Lumentum	Buy	75.0	47.2	2,923	1.7	13.7%	30.9%	26.3%	24.3	12.7	3.4	2.6	22.3	na	-14%	-19%	21%	17%
OCLR US	Oclaro	Buy	12.5	7.1	1,198	5.8	6.3%	4.6%	-0.1%	9.0	10.6	2.0	1.7	12.5	na	-1%	-16%	-22%	-16%
AAOI US	Applied Optoelectronics	NC	na	42.5	823	1.9	21.9%	63.6%	41.4%	9.3	11.3	2.7	2.1	na	na	-3%	-28%	80%	80%
NPTN US	NeoPhotonics	NC	na	6.4	282	1.5	-4.2%	-25.0%	-25.6%	na	na	1.4	1.6	na	na	-4%	11%	-39%	-47%
ACIA US	Acacia	NC	na	40.1	1,579	0.4	2.9%	-8.4%	-10.4%	23.4	23.9	2.8	2.5	14.6	na	3%	-12%	-35%	-43%
IIVI US	II-VI	NC	na	42.7	2,663	0.9	na	na	na	21.3	15.1	2.7	2.3	14.4	na	-10%	17%	44%	44%
5802 JP	Sumitomo Electrical	NC	na	1,889.0	13,305	3.2	4.3%	14.2%	12.9%	12.3	10.9	0.9	0.9	8.0	2.4	-6%	9%	8%	12%
002281 CH	Accelink	NC	na	27.9	2,657	29.3	23.7%	29.3%	28.3%	48.9	36.8	5.6	5.0	11.6	0.6	-7%	23%	9%	4%
300308 CH	Innolight	NC	na	44.3	3,175	2.2	263.0%	589.0%	103.4%	62.1	34.0	6.9	5.9	18.4	0.2	4%	7%	86%	75%
300394 CH	TFC	NC	na	22.7	638	2.1	33.7%	22.3%	19.5%	26.9	20.9	3.2	3.0	11.7	1.3	-5%	-10%	-28%	-35%
Median							*17.8%*	*25.8%*	*22.9%*	*22.3*	*13.9*	*2.7*	*2.3*	*13.4*	*1.0*	*-5%*	*-6%*	*9%*	*12%*
Optical IC																			
AVGO US	Broadcom	Buy	315.0	261.7	106,748	3.0	16.2%	25.7%	19.3%	16.4	15.4	5.3	4.9	32.0	1.7	-4%	4%	47%	58%
IQE LN	IQE	NC	na	158.3	1,607	13.6	19.9%	54.6%	27.4%	47.9	35.9	3.7	3.7	na	0.0	-7%	3%	316%	351%
3081 TT	Landmark	NC	na	395.0	1,192	1.7	23.6%	24.1%	23.7%	50.0	27.9	9.3	7.8	18.2	1.7	-5%	-4%	38%	46%
3105 TT	WIN Semi	NC	na	280.5	3,762	10.7	20.8%	25.0%	24.9%	28.7	20.7	5.4	4.8	18.6	1.8	-19%	47%	182%	186%
Median							*20.4%*	*25.3%*	*24.3%*	*38.3*	*24.3*	*5.4*	*4.8*	*18.6*	*1.7*	*-6%*	*4%*	*115%*	*122%*
Optical network equipment																			
763 HK	ZTE	Buy	40.0	27.2	20,307	24.2	9.3%	61.9%	18.0%	19.9	16.8	2.6	2.3	14.4	1.3	-10%	21%	92%	106%
ERIC US	Ericsson	NC	na	6.3	21,017	3.9	-2.3%	9.2%	8.6%	na	36.1	1.4	1.4	-6.2	1.7	-3%	8%	6%	13%
Median							*3.5%*	*35.5%*	*13.3%*	*19.9*	*26.4*	*2.0*	*1.9*	*4.1*	*1.5*	*-6%*	*15%*	*49%*	*60%*
Optical fiber																			
6869 HK	YOFC	NC	na	37.6	3,282	5.0	16.6%	24.1%	29.0%	16.6	13.8	3.7	2.9	25.2	1.6	-11%	51%	134%	126%
5801 JP	Furukawa	NC	na	5,800.0	3,636	1.3	6.3%	18.1%	27.6%	14.5	12.8	1.7	1.5	12.5	1.2	-4%	-3%	65%	62%
600522 CH	ZTT	NC	na	14.9	6,923	117.2	19.5%	28.7%	22.3%	21.4	17.1	3.2	2.7	14.7	0.8	7%	35%	49%	40%
Median							*18.0%*	*26.4%*	*28.3%*	*19.0*	*15.4*	*3.4*	*2.8*	*19.9*	*1.0*	*-2%*	*40%*	*93%*	*85%*

Source: Company Data, Bloomberg consensus for NC (not covered) companies, Jefferies estimates

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The Rise of 100G and Terabit Transport Networks

Optical communication is an enabling technology for data bandwidth and latency.

In the cloud era, we see diverse demands of new applications for unlimited bandwidth, such as 4K/8K video traffic and AR/VR are sensitive to network latency. The optical fiber transmission date rate in a single wavelength channel has increased from 2.5Gb/s in 1985 to 400Gb/s in 2015, representing a 160-fold increase over 30 years. At the transport level, the introduction of broadband optical amplifiers like EDFA and Raman amplifiers, makes wavelength-division multiplexing (WDM) a reality. The single-fiber transmission capacity of optical fiber has increased from 2.5Gb/s in 1985 to 20Tb/s in 2015, representing an increase of 8,000 times.

Chart 11: Advance of optical transmission technologies

Year:	1980	1990	2000	2010	2020
Data rate per channel	**2.5 Gb/s**	**10 Gb/s**	**40 Gb/s**	**100 Gb/s**	**200G/400G/1T and beyond**
Modulation format (typical)	OOK (NRZ) 0 √2	OOK (RZ) 0 2	DPSK -1 0 1 DPSK	PDM-QPSK X-pol. Y-Pol.	PDM-16QAM X-pol. Y-Pol.
System features (newly added)	Single-span, single-channel	Multi-span with EDFAs, WDM	DWDM, Raman, amplofication, and ROADMs	1:N WSS, CDC-ROADMs	Flexible-grid WDM, M:N WSS
System capacity (typical)	**2.5 Gb/s** (single channel)	**400 Gb/s** (40 WDM channels)	**1.6 Tb/s** (40 WDM channels)	**8 Tb/s** (80 WDM channels)	**20 Tb/s** (50 flexible-grid WDM channels)
System reach (typical)	100 km (single span)	1000 km	1000 km @40G 3000 km @10G	2000 km @100G	4000/2500 km @100(200)G
Enabling technologies	Optical modulation and detection	High-speed modulation, HD-FEC	Differential phase-shift-keying	Coherent detection with ODSP	SD-FEC, PDM-QAM, FTN, Superchannel

Source: Huawei, Jefferies

Optical Communication Ecosystem

In the ecosystem, optical IC has the highest entry barrier. Optical component and transceiver is a highly fragmented sector. Network equipment vendors have the most pricing power.

The optical communication ecosystem mainly consists of 1) optical IC (drivers, amplifiers, lasers and modulators), 2) optical component (passive & active), 3) optical transceiver and 4) network equipment. We note that optical IC has the highest technology barrier. The IC and integration technology platform provide core capability for high data rate transmission and switching. Most US and Japanese transceiver vendors are integrated players; while Chinese companies like O-Net and Accelink are mainly poised in the optical component segment. Downstream optical network equipment is dominated by Huawei, ZTE, Ciena, Nokia and Fujitsu.

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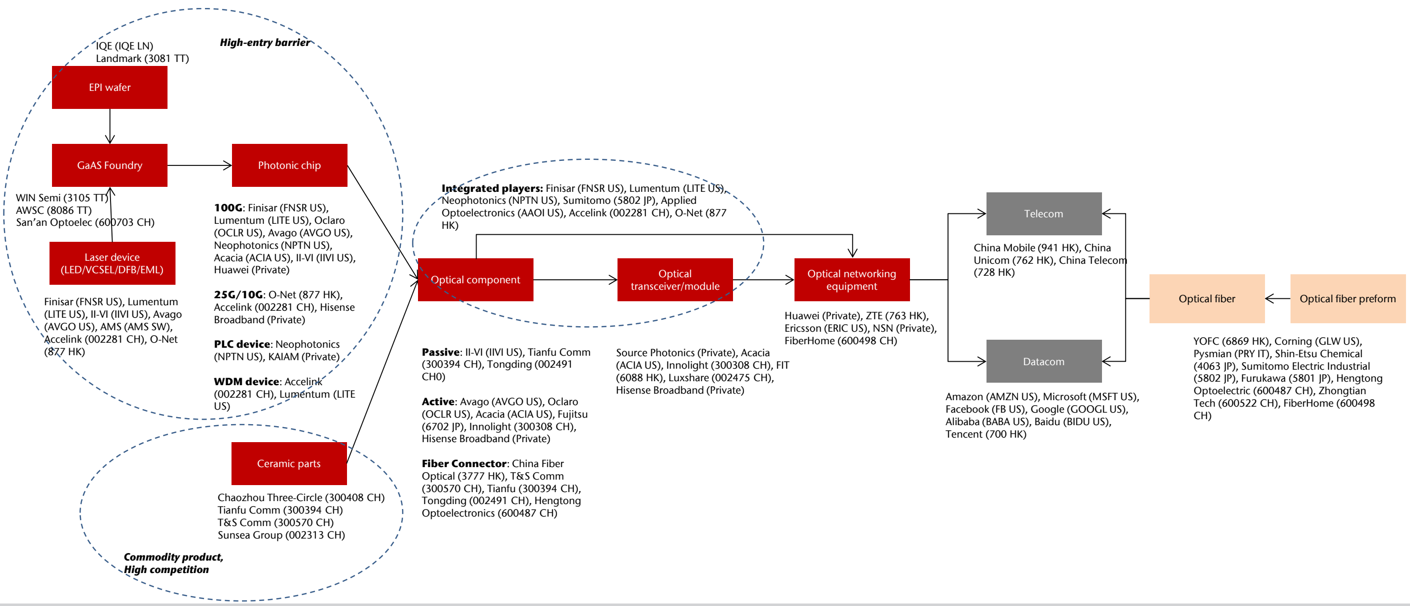
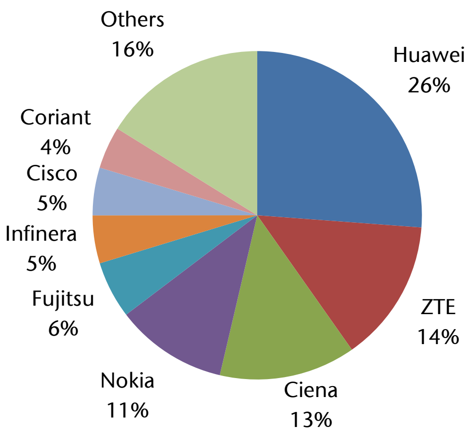
Chart 12: Optical transport network value chain



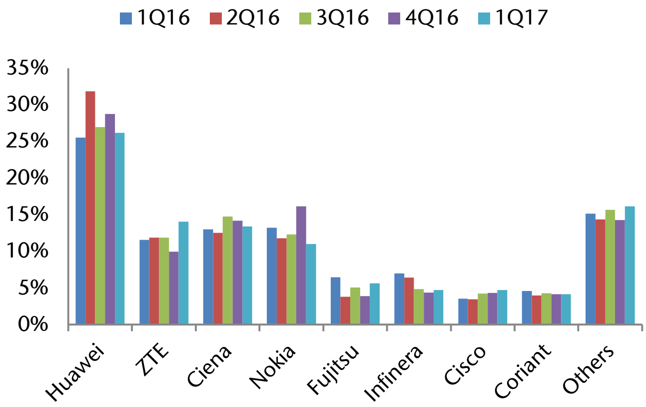
Source: Jefferies

Chart 13: Global optical network equipment market share (1Q17)



Source: IHS, Jefferies

Chart 14: Global optical network equipment market share trend



Source: IHS, Jefferies

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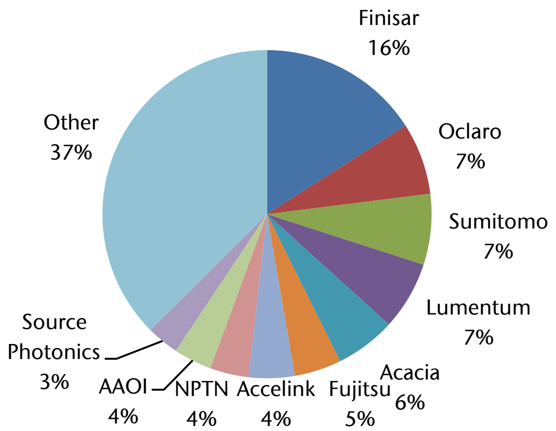
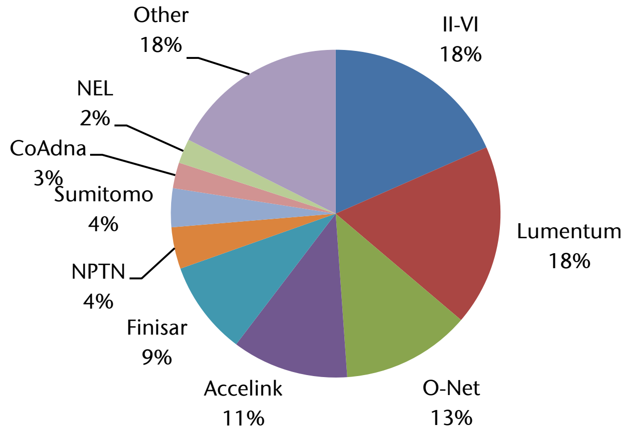
Chart 15: Global active component market landscape (Rolling share in 2Q16~1Q17)



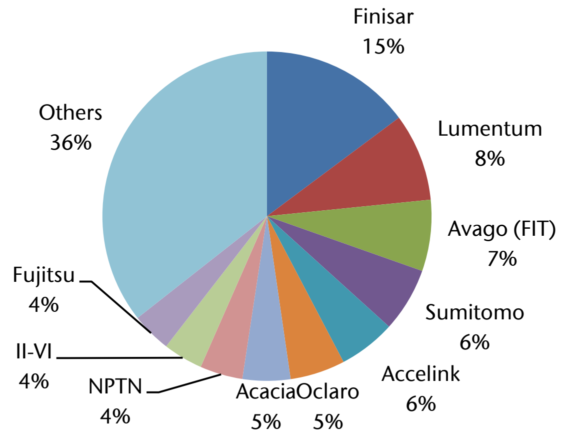
Source: OVUM, Jefferies

Chart 16: Global passive component market landscape (Rolling share in 2Q16~1Q17)



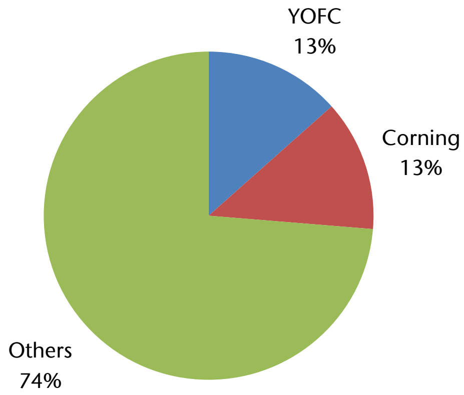
Source: OVUM, Jefferies

Chart 17: Global optical transceiver market landscape (2016)



Source: Finisar, Jefferies

Chart 18: Global optical fiber preform the market landscape (2016, in term of production)



Source: Jefferies

What is Optical Transceiver?

Optical transceivers decide the performance of the entire transport network system.

Optical transceivers are designed in small form factors with integrated sub-assemblies. Optical components account for around 73% of total transceiver cost, mainly **1)** TOSA (transmitter optical sub-assembly, which converts an electrical signal to optical signal) and **2)** ROSA (receiver optical sub-assembly, which couple the light and convert back to electrical signal). In addition, there is also a BOSA (Bidirectional Optical Sub-assembly) which acts as TOSA + ROSA.

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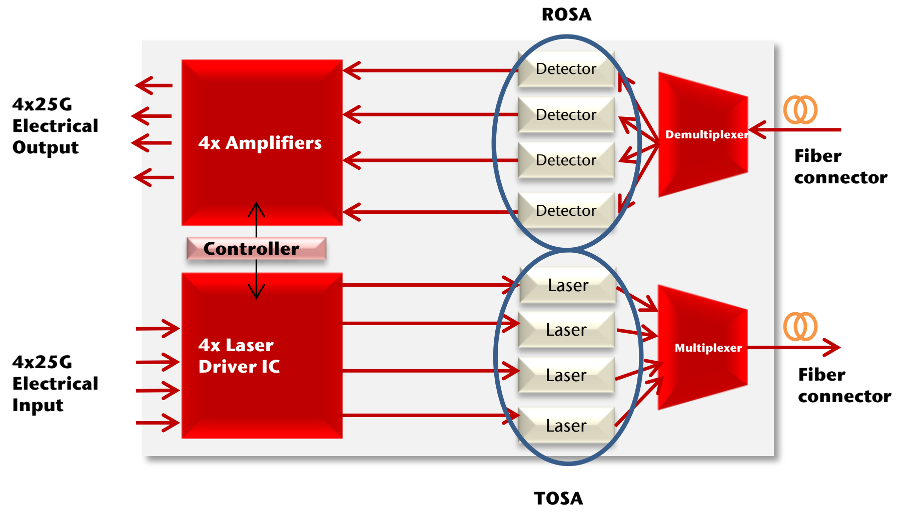
Chart 19: A 100G QSFP28 DWDM transceiver structure



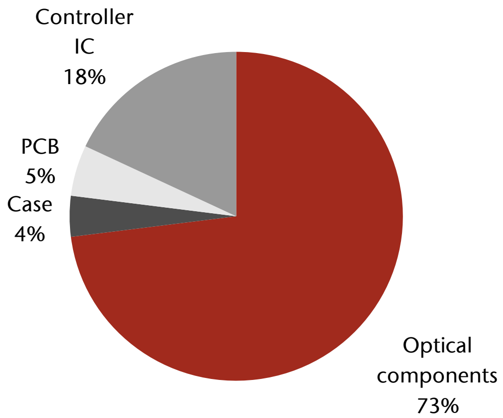
Source: Jefferies

Transmitter converts electrical data to light.

Receiver converts light back to electrical data.

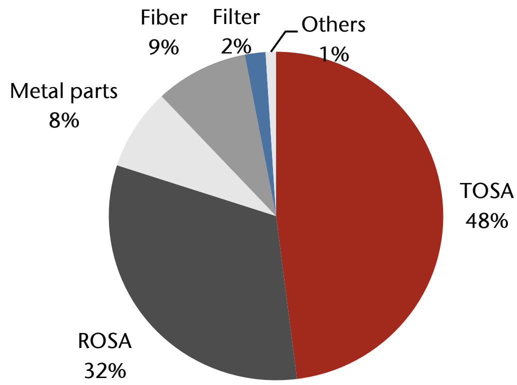
- TOSA consists of a laser diode (light source), optical interface, monitor photodiode, metal housing and electrical interface. Depending on functionality, it may also have filters and isolators.
- ROSA consists of a photodiode, optical interface, metal housing, electrical interface, as well as amplifiers.
- BOSA consists of a TOSA, ROSA and a WDM (wavelength division multiplexer) so it can use bidirectional technology to support two wavelengths in a fiber. It is intended to save cost on fibers.

Chart 20: Optical transceiver cost breakdown



Source: Jefferies estimates

Chart 21: Sub-assemblies cost breakdown



Source: Jefferies estimates

Optical IC industry is very consolidated. Major players are integrated optics vendors like FNSR, LITE and AVGO and niche players.

Commonly used types of laser sources are 1) vertical cavity surface-emitting lasers (**VCSEL**) for short range (3~100 meters), 2) fabry-perot (**FP**) laser for medium range (100m~2km), 3) distributed feedback (**DFB**) laser for long range (2~10km), 4) electro-absorption modulated laser (**EML**) for long-haul (10~30km).

Receivers, mainly **PD** (photodiode) and **APD** (avalanche photodiode) use semiconductor detectors to convert optical signals to electrical signals. Long wavelength systems usually

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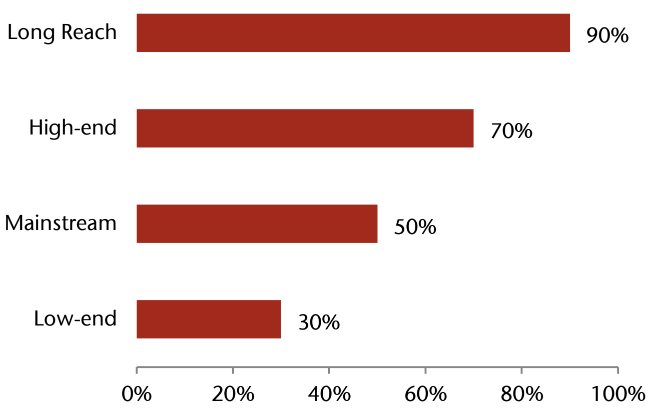
use InGaAs (indium gallium arsenide) detectors and short wavelength links mainly use silicon photodiodes.

Optical IC is the major cost component in transceivers, especially high-end 100G+.

We believe optical chip (design and manufacturing) has the highest entry-barrier in the entire value chain, also the key cost element in a transceiver. According to O-Net, optical chip is around 50% of mainstream 100G transceivers and 70~90% of high-end 100G+ transceivers. The manufacturing involves epitaxy wafer growing, which is the decomposition of an epitaxy layer over a substrate. The epi-layer may consist of compounds like GaN (gallium nitride), GaAs (gallium arsenide) or combination of elements gallium, indium, aluminum, nitrogen, phosphorus or arsenic. The epi-layer growing process includes various types of CVD (chemical vapor deposition) such as atmospheric particular CVD, metal organic CVD and molecular beam epitaxy (MBE).

Chart 22: Optical chip cost weight in transceivers



Source: Jefferies

Chart 23: Transmitter and Receiver chip types

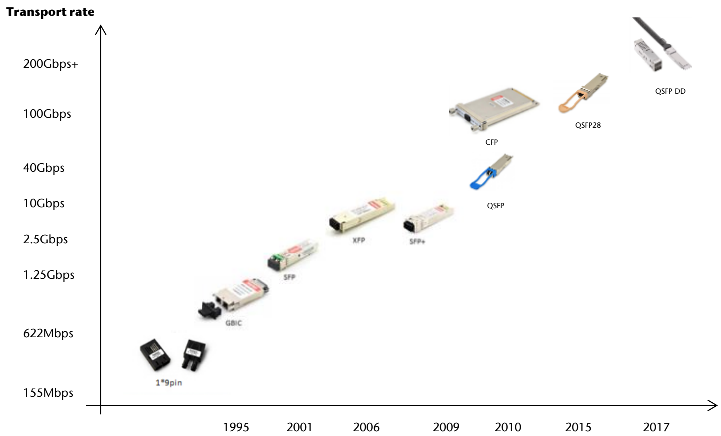
	Transmitter			Receiver	
	VCSEL	DFB	EML	PIN PD	APD
Wavelength	850nm	850~1310nm	1310~1550nm	830~860/1100~1600	1550
ASP (USD)	1.5~3	8	60	na	na
Range	3~100m	2~10km	10~30km	Low~mid, <40km	<80km
Application	Short range, mainly data center; 3D sensing	Long range, access/metro ring	Long-haul	Low cost, long life	High sensitivity
Vendors					
Finisar	x	x	x	x	x
Lumentum	x	x	x	x	x
Oclaro	Sold to II-VI	x	x	x	x
AAOI	na	x	na	x	x
NeoPhotonics	na	na	x	x	x
Innolight	No plan	No plan	No plan	No plan	No plan
Accelink	2018	x	x	Yes	
Hisense Broadband	2018	2018	2018	na	na
O-Net	na	x	x	No	No

Source: Jefferies

Transfer rate and distance, size, and power efficiency are key factors for transceivers.

Transceivers are packaged based on industry standards, called MSA (Multi Source Agreement) defined by major vendors including Broadcom, Cisco, Corning, Finisar, Oclaro, FIT, as well as Huawei, Intel, Juniper, Alibaba, etc.

Chart 24: Evolution of optical transceivers



Source: Jefferies

- **Packaging form**: 1*9, GBIC (gigabit interface converter), SFF (small form factor), SFP (small form pluggable), XFP, SFP+, X2, XENPARK, 300Pin, as well as QSFP+ for 40G and 100G, CFP (Centum Form Factor Pluggable) for 100G transceivers.

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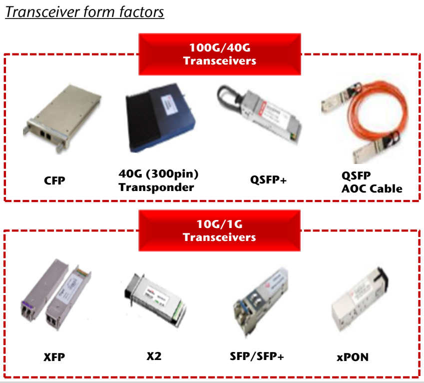
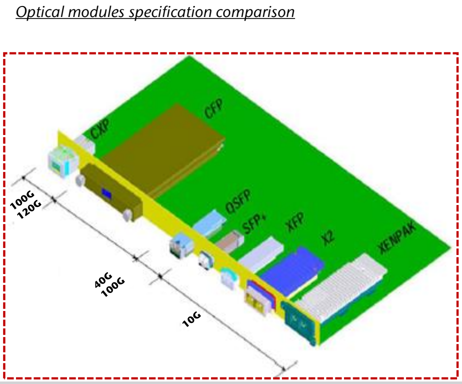
- **Transfer rate:** 100Base (100Mbps [megabits per second]), 1000Base (1Gbps [gigabits per second]), 10GBase (10Gbps), 40G/100G/400GBase, etc.

Chart 25: Optical transceivers by packaging



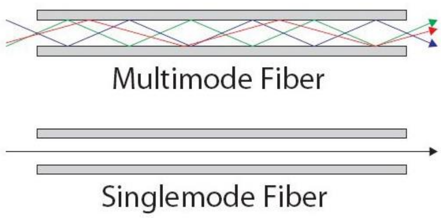


Source: Jefferies

- **Wavelength:** Regular, CWDM (coarse wavelength division multiplexing), DWDM (dense wavelength division, multiplexing).
- **Fiber mode:**
  - SMF (single mode fiber), only allows a single mode of light to couple. The weak dispersion allows single model fiber to support long-haul transmission distances. The most common type of single mode fiber is termed as OS1.
  - MMF (multi-mode fiber, transceiver marked in orange colour), with larger core aperture, allows multiple modes of light to couple into the core. Multi-mode applications are always for short reach, and the price of multimode transceivers is typically a fraction of single mode transceivers.

In addition, transceivers have a color code system based on compatibility by fiber mode. Single mode transceivers will be in yellow; Multi-mode transceivers will be in orange, black or gray.

Chart 26: Single mode fiber vs. Multi-mode fiber



Source: Jefferies

- **Transmission distance:** mainly classified by SR (short range, multi-mode transceivers) and LR (long range, single mode transceivers). By using optical amplifiers and dispersion compensators, over 1000's of kilometers transmission distance is possible.

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Chart 27: Multi-mode transceiver transmission distance

Transfer rate	Form	Multimode fiber classification			
		OM1	OM2	OM3	OM4
100M	FX	2km	2km	2km	2km
1G	SX	500m	2km	2km	2km
10G	SR, USR, LRM	33m	82m	300m	400m
40G	SR, SR4, CSR4	na	na	100m	150m
100G	SR4, SR10	na	na	100m	150m

Source: Fluxlight, Jefferies

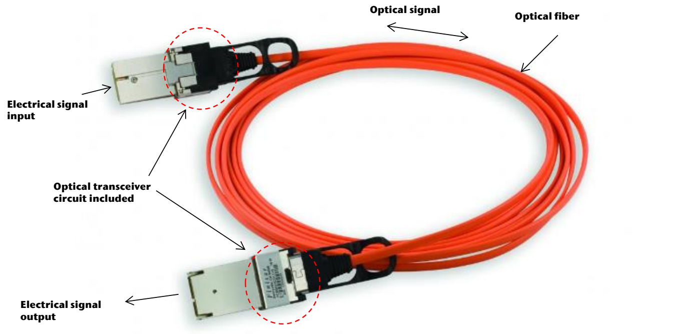
Chart 28: Single mode transceiver transmission distance

100M		1G		10G	
Form	Distance	Form	Distance	Form	Distance
LX	10km	LX	10km	LR	10km
EX	40km	EX	40km	ER	40km
ZX	80km	ZX	80km	ZR	80km
ZX120	120km	ZX120	120km		
40G		100G			
Form	Distance	Form	Distance		
LR4	10km	LR4	10km		
ER4	40km	ER4	40km		

Source: Fluxlight, Jefferies

- **Connector type:** Connectors couple and align transceivers, so the light can pass through the fiber core. Transceivers are also classified into different groups based on connector types, which are SC (subscriber connector), LC (lucent connector), MPO (multi-fiber push-on) and ST (straight tip connector). In addition, DAC (direct attach copper) and AOC (active optical cable) are short-range multi-lane cables with optical and electrical devices embedded in the connectors. They have emerged significantly in data centers thanks to growing bandwidth demand.

Chart 29: AOC (active optical cable) structure



Source: Jefferies

Chart 30: Traditional optical connector types

Connector		Description	Transceivers using
SC		Snap-in connector	GBIC, X2, XENPAK, some 40G QSFP and 100G CFP
LC		Smaller version of SC	SFP, SFP+, XFP
MPO		Commonly 12 or 24 fibers per device	Some 40G QSFP and 100G CFP
ST		bayonet mount connector	Not in transceivers but in optical patch panels

Source: Jefferies

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Chart 31: Different type of transceivers

SFP/CFP/QSFP	SMP/MMF	SR/LR	PSM/CWDM/DWDM
❑ SFP (Small Form-factor Pluggable) is a specification for a new generation of optical modular transceivers, an upgraded version of GBIC. The devices are designed for use with small form factor (SFF) connectors, and offer high speed (100Mpbs/1,000Mpbs) and physical compactness (half the size). SFP+10G Speed.	❑ SMF (Single Mode Fiber) can only carry single mode optical as its thin fiber core. SMF is good at remote communications (>10km) thanks to the small dispersion between modules.	❑ SR (Short Range) supports short-wave (850nm) multimode fiber with 64B/66B coding scheme. Effective communication distance is between 2m-300m.	❑ PSM (Parallel Single Mode Fiber) can bilaterally carry several same and separate parallel single mode fibers.
❑ CFP(Centum Form-factor Pluggable) is a multi-source agreement to produce a common form-factor for the transmission of high-speed digital signals. CFP includes CFP, CFP2, CFP4, all can applied to 100G optical module. ❑ QSFP (Quad Small Form-factor Pluggable) is a compact, hot-pluggable transceiver used for data communications applications. QSFP and QSFP+ mainly applied to 40G. And QSFP28 support 100G.	❑ MMF (Multi Mode Fiber) can carry several modes optical thanks to the thick fiber core. SMF is applicable to short distance communications as its large dispersion between modules and the dispersion is increasing with the increase of transmission distance.	❑ LR (Long Range) supports long-wave (1,310nm) multimode fiber with 64B/66B coding scheme. Effective communication distance is between 2m-10km.	❑ CWDM (Coarse Wavelength Division Multiplexing) and DWDM (Dense Wavelength Division Multiplexing) can couple optical with different wavelength into a single core fiber for transmission.

Source: Haitong_1

Key Technology Elements

Key technology elements for high-density and high-speed transceivers include:

- Silicon Photonics IC
- Higher bandwidth modulator
- Integrated high bandwidth receiver
- Lower linewidth laser
- Compact InP structures
- Higher levels of integration
- Integrated VOAs (variable optical attenuators)
- L band option

Market Dynamics

China accounts for ~27% of global optical component and transceiver market.

Global sales of optical transceivers will reach USD6.2bn in 2017 according to LightCounting, only flattish y-y, due to excess inventory of 100G products built by Huawei during 2016. The Ethernet transceiver market will still grow at 17% y-y thanks to strong sales of 100G PSM4 and CWDM4 products to cloud data center players.

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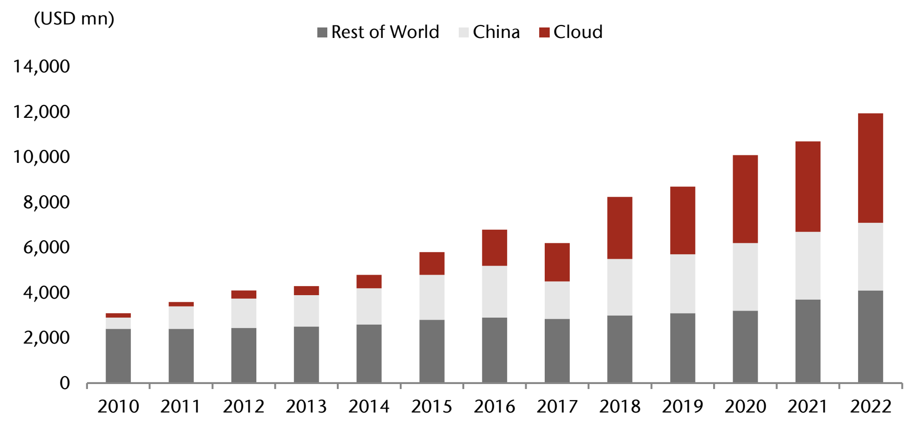
Chart 32: Global optical component and transceiver market growth

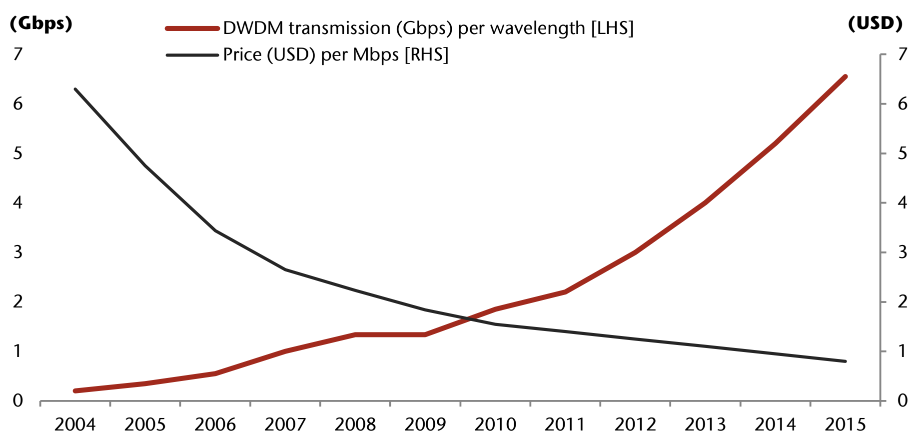


Source: LightCounting, Jefferies

Transceiver price generally decline by around 20~30% per year.

On the other hand, we see transceiver price has a natural 20~30% decline per year although transmission data rates are growing at an even faster pace. Transceiver vendors has limited pricing power to network equipment companies due to market fragmentation, and their R&D visibility is based on a customers' (network equipment, telecom operators, ICPs) technology roadmap.

Chart 33: DWDM transceiver data rate growth vs. price decline



Source: Jefferies estimates

Most growth in telecom transceivers comes from 100G+ upgrade. 40G market is disappearing.

On the telecom side, total market revenue was up 38% y-y to USD1.2bn in 2016, thanks to 100G long-haul upgrade in China. The market is expected to continue expanding at 3.3% CAGR in 2017-21E, according to IHS. While 100G still growing at 8.1% CAGR in this period, 40G segment will disappear and 10G will contract at 23.7% CAGR.

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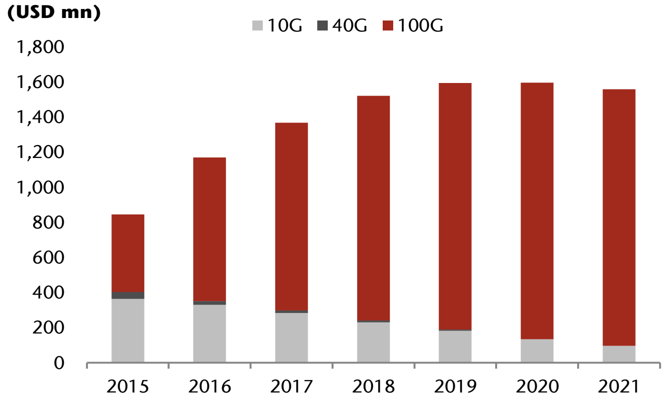
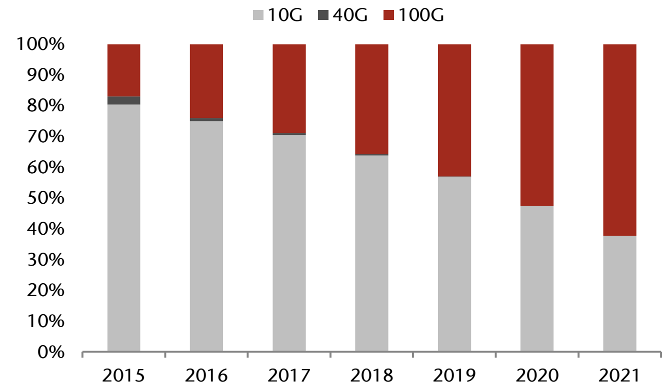
Chart 34: Telecom transceiver industry revenue trend



Source: IHS, Jefferies

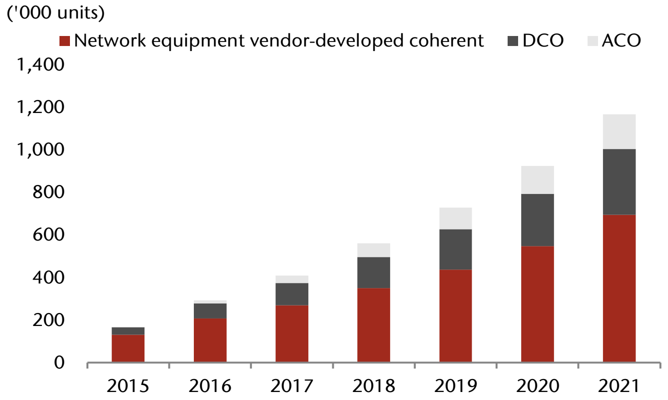
Chart 35: Telecom transceiver unit mix



Source: IHS, Jefferies

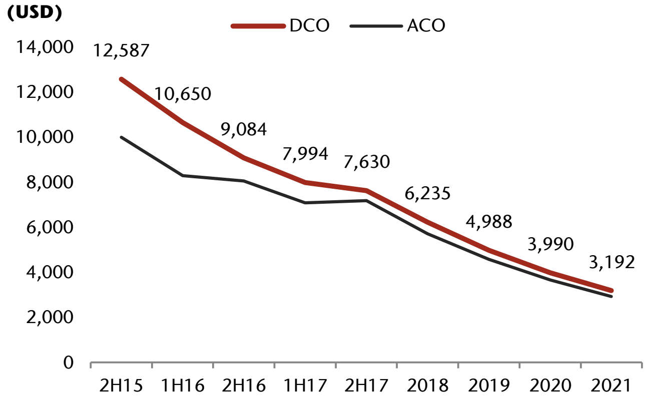
- For 100G, strong demand for long-haul uptake from China was a major driver in 2016, including CFP-DCO (digital coherent optics) thanks to adoption of 100G coherent technology in long-haul and metro-ring. Over 70% of this market is taken up by network equipment vendors, using their own DSP technology. Huawei has developed CFP-DCO transceivers in-house, and ZTE is working with Acacia and NEL. CFP-ACO (analog coherent optics) ramp is relatively slow, due to qualification and component issues.

Chart 36: 100G telecom transceiver shipment & mix



Source: Jefferies

Chart 37: 100G telecom transceiver price trend



Source: Jefferies

- 10G products see significant price contraction from 2H16, outpaced volume growth. In 2017, we still see demand for front-haul upgrade.

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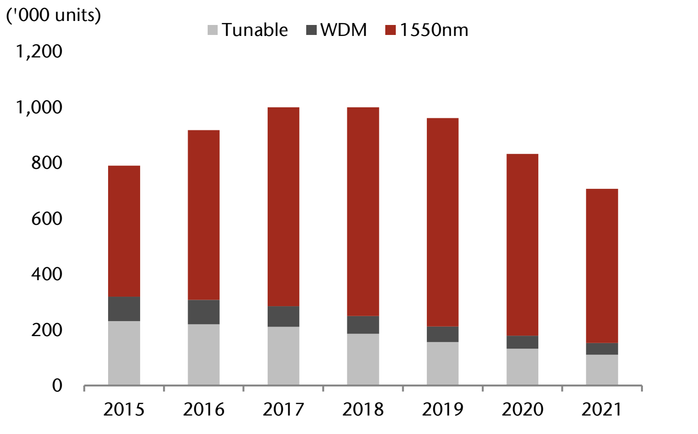
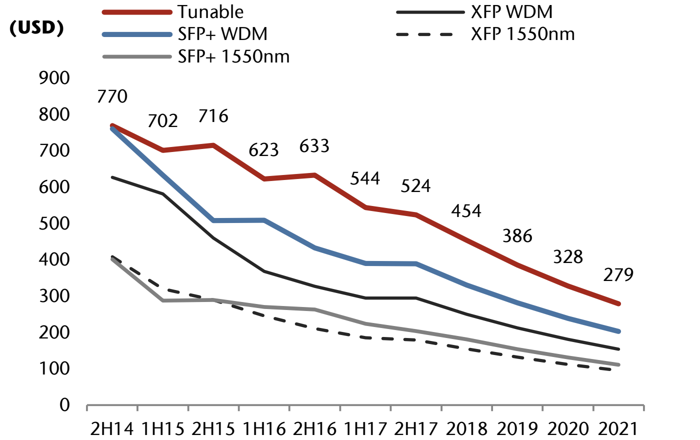
Chart 38: 10G telecom transceiver shipment & mix



Source: Jefferies

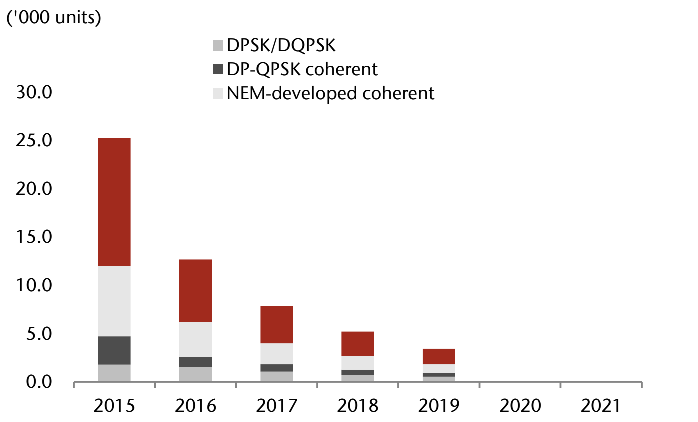
Chart 39: 10G telecom transceiver ASP trend



Source: Jefferies

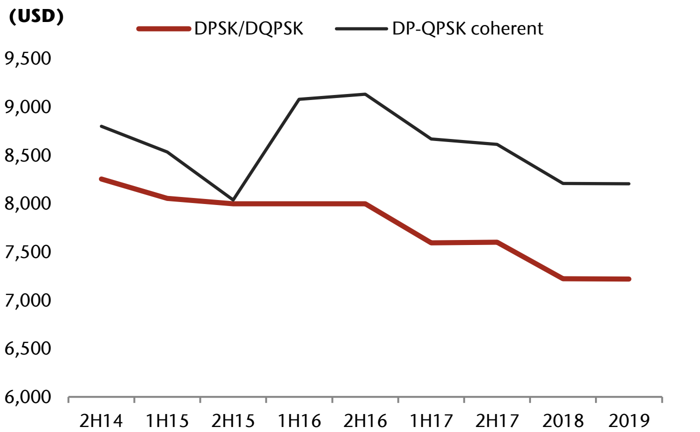
- 40G declined sharply in 2016, with revenue down 44% y-y in 2016. The 40G network equipment market is disappearing. We believe 40G will be only deployed if 100G cannot be used due to technical or compatibility issues or low cost.

Chart 40: 40G telecom transceiver shipment & mix



Source: Jefferies

Chart 41: 40G telecom transceiver price trend



Source: Jefferies

- 200G coherent transceivers start to ramp thanks to North American ICPs (Internet Content Providers). 400G coherent trial starts in 2017 thanks to the availability of next generation coherent DSPs, and 600G coherent is also on the horizon. According to IHS, 100G+ units CAGR in 2016-21will reach 32%.

Data center transceivers are going from 40G/10G to 100G/25G.

On the datacom side, total 10G/40G/100G transceiver sales grew 42% y-y in 2016, reaching USD2.3bn. According to IHS estimate, datacom transceivers will maintain 16.5% CAGR in 2017-21E, thanks to strong 100G deployment in cloud data centers. Similar to telecom, the 40G market will gradually disappear.

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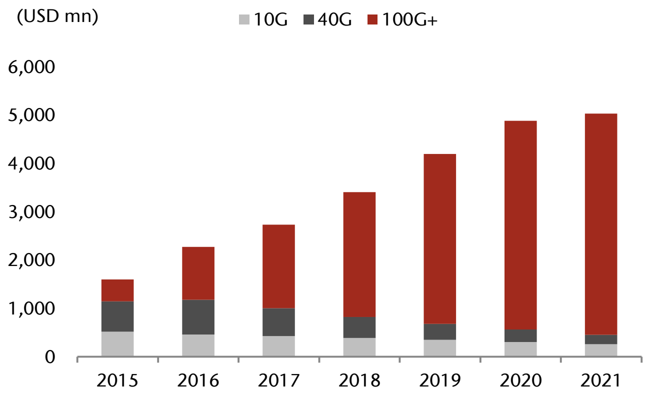
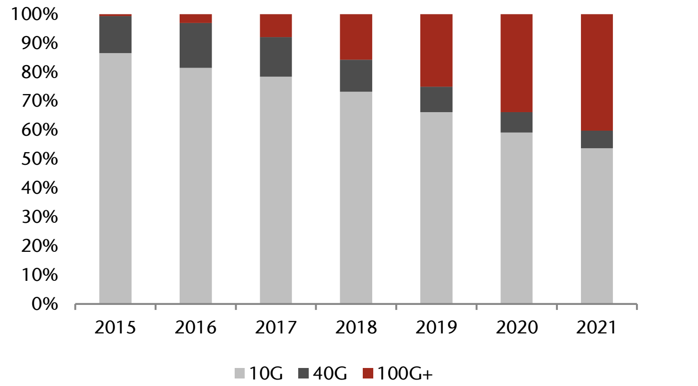
Chart 42: Datacom transceiver revenue forecast



Source: IHS, Jefferies

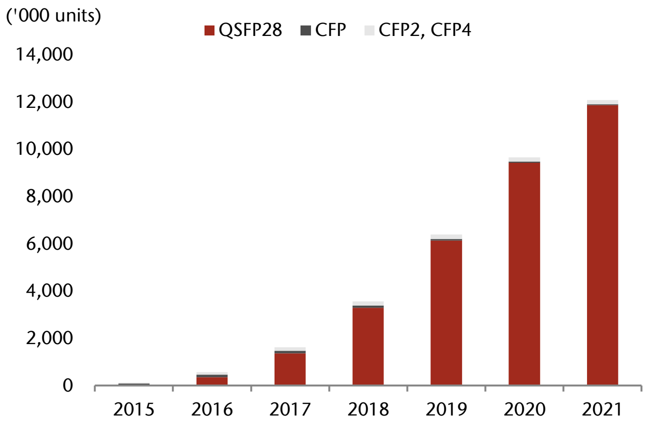
Chart 43: Datacom transceiver mix by shipment



Source: IHS, Jefferies

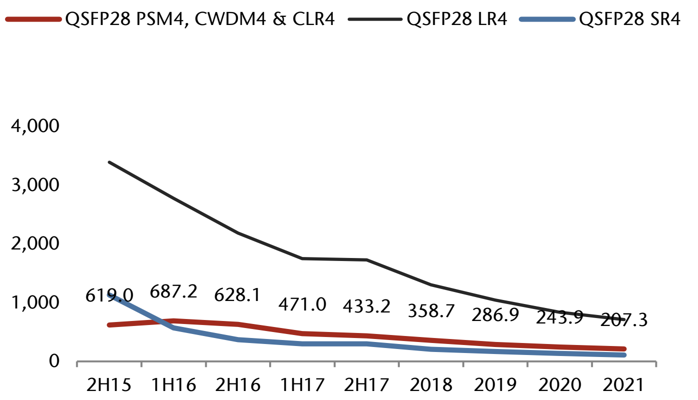
- 100G data center transceivers continued to surge from 2H16 driven by the ramp-up of 100G QSFP28 transceiver shipments. As the supply bottleneck is getting resolved, we expect 100G shipments continue to remain strong.

Chart 44: 100G transceiver unit & mix



Source: Jefferies

Chart 45: 100G transceiver price trend



Source: Jefferies

- Meanwhile, the 40G transceivers market will peak out due to the 100G migration. 10G will only see flattish growth, but the price erosion will be quite significant, in our view.

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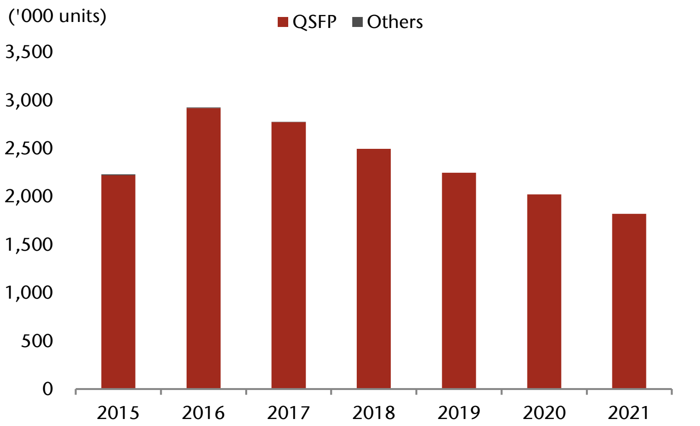
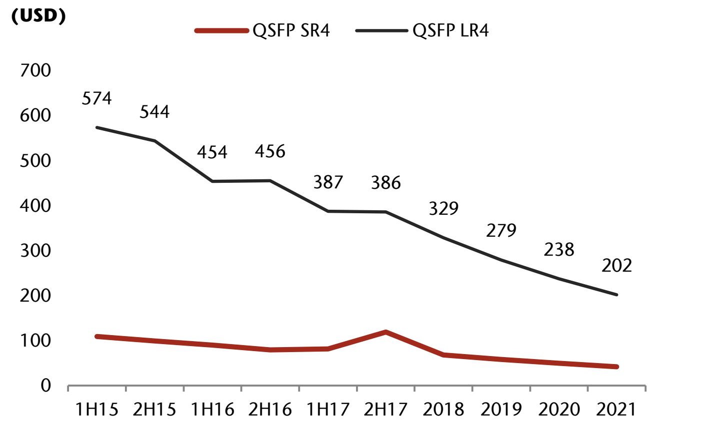
Chart 46: 40G transceiver unit & mix



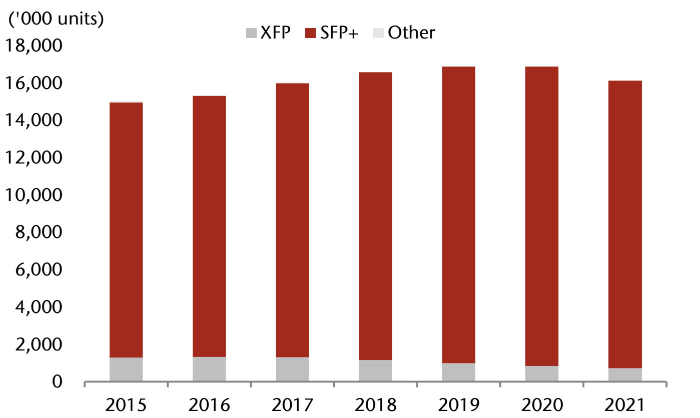
Source: Jefferies

Chart 47: 40G transceiver price trend



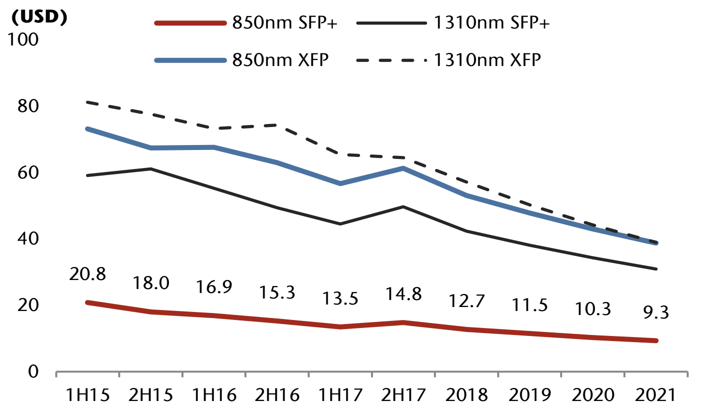
Source: Jefferies

Chart 48: 10G transceiver shipment & mix



Source: Jefferies

Chart 49: 10G transceiver price trend



Source: Jefferies

- The 400G market will likely take off in 2019, mainly driven by Internet Content Providers (ISP). Alibaba Cloud expects to deploy 400G QSFP-56 transceivers from 2019.
- Some ISPs, like Amazon, may take 200G as a temporary solution before the long wait for 400G, which can be achieved by using a 4x50G PAM4 solution. But other incumbents are advocating the industry to fully focus on 400G development. We expect 200G to peak out in late-2018 or early 2019.

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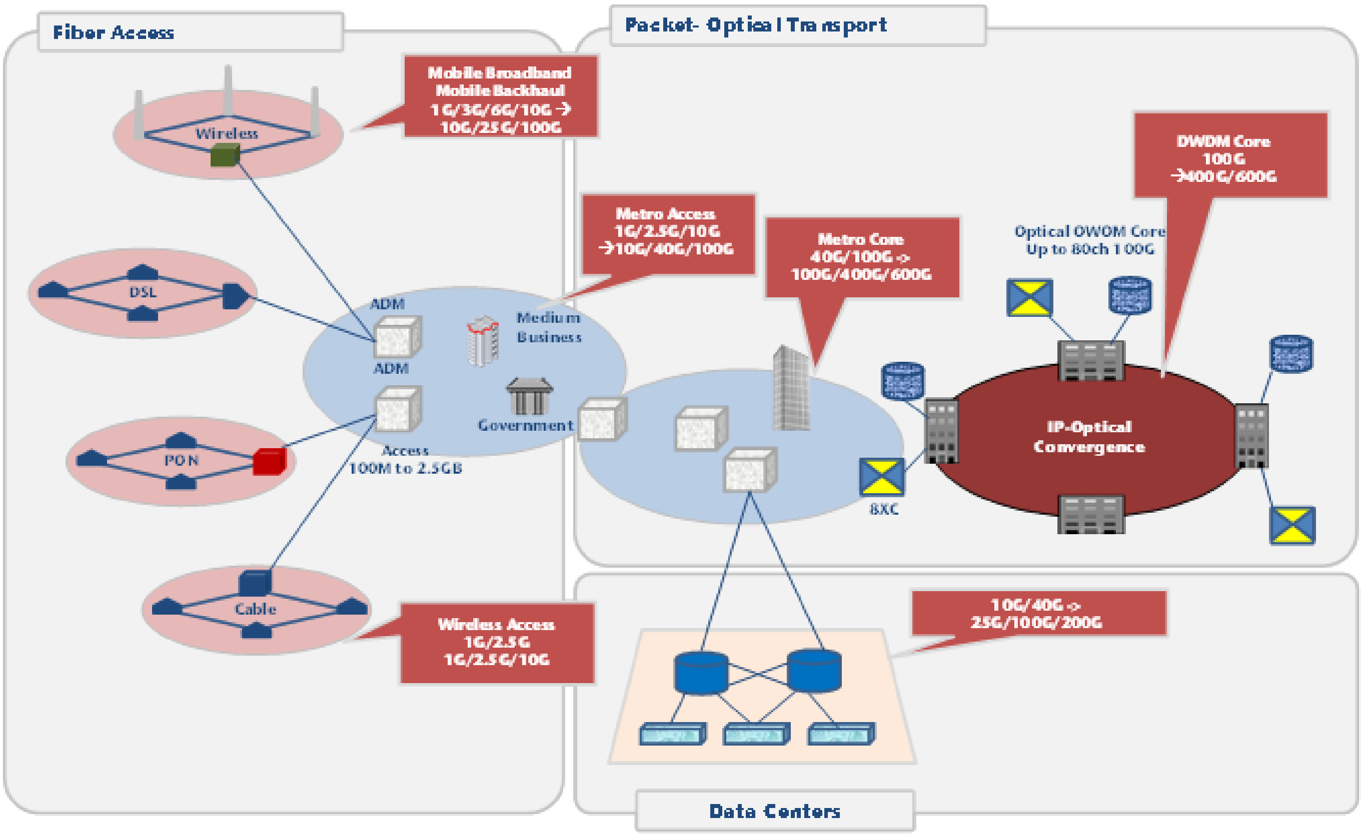
Chart 50: Optical transport network upgrade in telecom & datacom



Source: Oclaro, Jefferies

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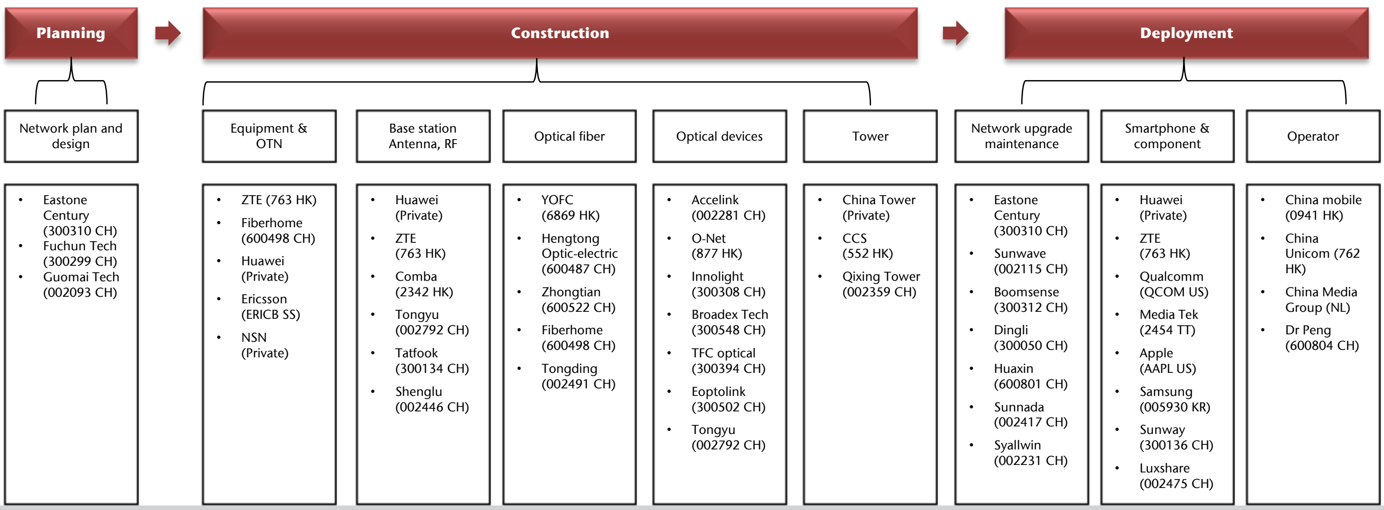
Telecom: 5G – How it Differs from 4G for Optical Companies?

Telecom operators are facing several challenges now, such as:

- Shortage of spectrum to grow the data throughput;
- Rising mobile data traffic demand with video service subscribers;
- New revenue stream from IoT.

Chart 51: 5G value chain

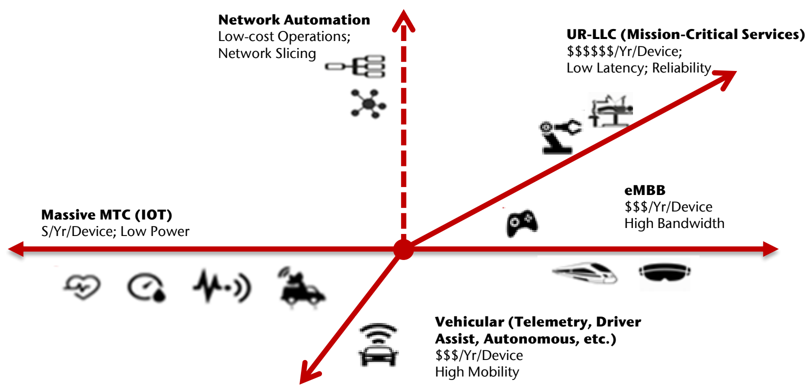


Source: Jefferies

New applications will post challenges to 5G transport network. 5G RAN (radio access network) will likely adopt C-RAN (centralized/cloud RAN) architecture.

5G will be able to address these problems through: 1) 10-100 times throughput, 2) 10 times lower latency, and 3) 10-100 times more connected devices. Meanwhile, there will be several dimensions in the future mobile networks, which presents new challenges on RAN. Before the massive 5G deployment scheduled for 2020, telecom operators can stretch their existing 4G network and start adopting C-RAN (Centralized RAN [Radio Access Network]).

Chart 52: Service dimensions in the future mobile network



Source: Huawei, Jefferies

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Structural Change in 5G Fronthaul Network

Major change will be in front-haul, which will be a two-level architecture, in order to solve increasing traffic load, flexible flow direction and complicated traffic scheduling.

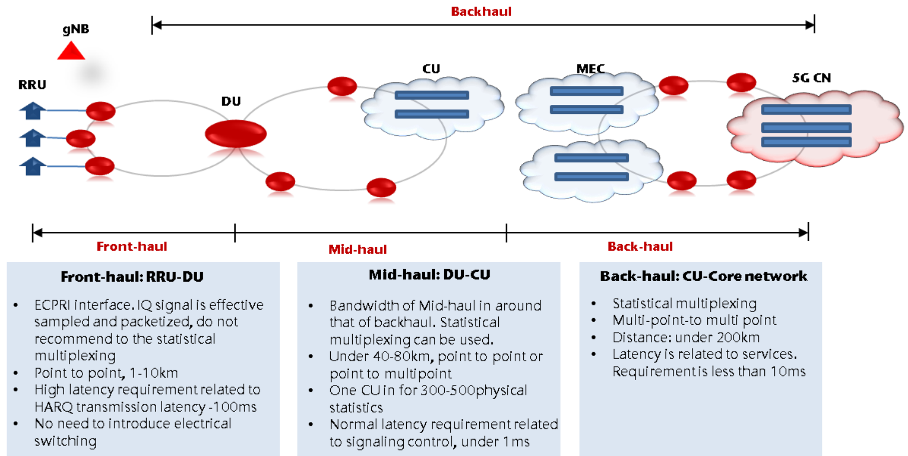
We see the major architecture change of 5G RAN (radio access network) will be two-level fronthaul. BBU (baseband unit) will be divided into the functional entities of CU (central unit) and DU (distributed unit).

- Real-time functions are deployed at the antenna site to manage air interface resources, **between RRU and DU**, such as autonomous/driverless driving.
- Non-real-time functions are hosted centrally to coordinate transmissions across the coverage area, **between DU and CU**. For delay-sensitive functions that don't require real-time processing, like VR/AR, facial recognition, a large centralized data center is more appropriate.

C-RAN is cost saving to telcos, thanks to centralized deployment. It mainly reduce equipment and real estate costs.

On the other hand, adopting C-RAN will mainly benefit telecom operators, in terms of smaller capex and opex. C-RAN allows large scale centralized deployment, allowing hundreds of thousands of RRU connecting to a centralized BBU pool. Based on China Mobile's trial, C-RAN adoption can reduce opex by 50% (no BBU cabinet), capex by 15% (simplify equipment), but improve energy saving by 70% (lower power loss with fiber than with cable).

Chart 53: 5G transport network architecture



Source: China Mobile Research Institute, Jefferies

5G fronthaul solution is still not decided yet. We think WDM/OTN is best solution by far.

We note that there are several technical solutions for 5G fronthaul design as below, based on Huawei and ZTE's whitepaper on 5G optical transport network. We think the WDM/OTN method is recommended, for saving fibers, eliminating the power loss issue, and better service visibility.

- **Dedicated fiber** – the access sites will need a large number of optical fibers.
- **Passive WDM** – CWDM transceivers are directly inserted into wireless RRUs to work with OADMs (optical add-drop multiplexer). This solution is suitable for moderately concentrated solutions. The major issue is that optical transceivers in the passive solution may not meet wireless products' requirements on transmission distance and power consumption.
- **WDM/OTN** – It employs the traditional telecom architecture, as the client side uses grey optical modules to connect the RRUs and the line side uses colour optical modules to connect the RRUs. The ring structure and requirement for only one backbone optical fiber allow the active WDM/OTN solution to minimize the use of fibers.
- **Ethernet** – This method uses packet technologies and multiplex to achieve traffic convergence and improve line bandwidth. It also supports point-to-

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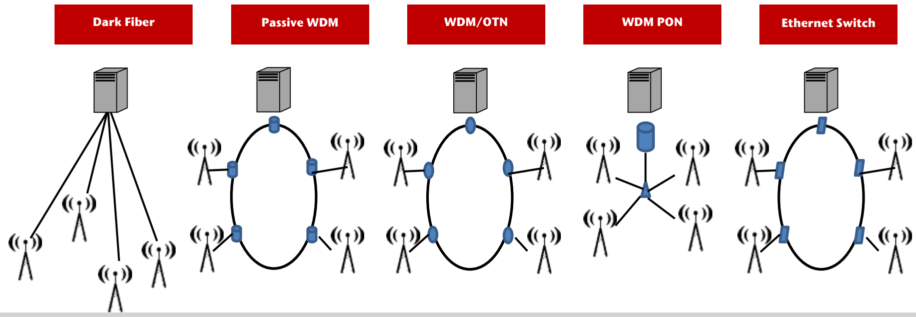
multipoint transmission and saves fiber resources. The industry is still discussing the standards.

Chart 54: 5G C-RAN fronthaul technical solutions



Source: ZTE, Jefferies

Traditional Distributed RAN

Traditional RAN consists of many standalone base stations (BTS). Each BTS only covers a small area, but also needs its own cooling, backup battery, backhaul transport systems. C-RAN is based on Data Center network technology, having two main components: 1) distributed radio unit, deployed with the antenna; 2) centralized baseband unit, deployed centrally at a network-edge data center. Comparing to the classic centralized architecture, the next generation cloud-based C-RAN can support multi-layer, ultra-dense operations in many different service scenarios, which will incorporate macro, micro and small cells in diverse spectrums.

The most popular type of wireless base station deployment consists of a Base Transceiver Station (BTS) located in close proximity to the antenna tower. The BTS connects to the Mobile Switching Centre (direct hand-offs between towers for mobile users) and the RF transmitters/receivers located on the tower structure.

The Distributed Base Station architecture illustrated places the RF transceivers on the tower. The arrangement requires an optical fibre to connect the digital baseband signals inside the BST hut with the tower mounted RRU (remote radio unit). This allows a much shorter coax connection between the RRU, the transmitters and receivers on the top of the tower. This arrangement also consumes much less RF power due to the reduced losses that result from using the shorter coaxial cable and the optical fibre.

This concept can be further expanded by using a central remote “hotel” for multiple tower sites. This approach significantly reduces the required footprint, which allows for an easier expansion of the 3G and 4G base stations in densely populated areas.

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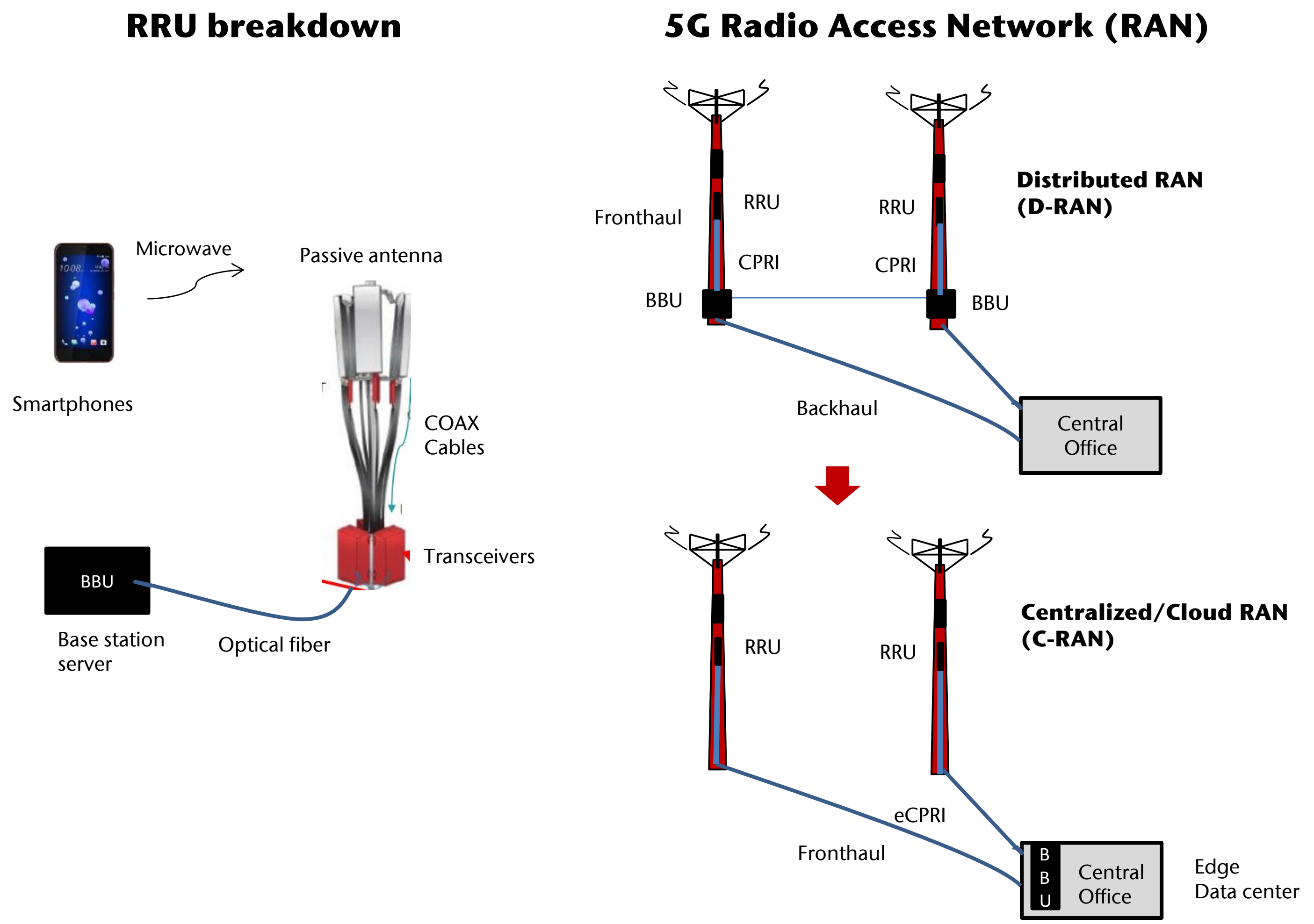
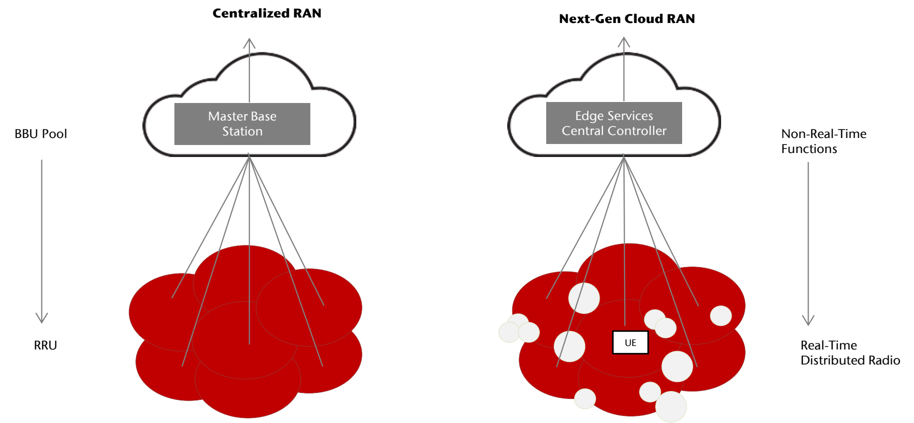
Chart 55: 5G Radio Access Network (RAN) - From D-RAN to C-RAN



Source: Jefferies

Chart 56: Advanced Cloud RAN architecture



Source: Heavy Reading, Jefferies

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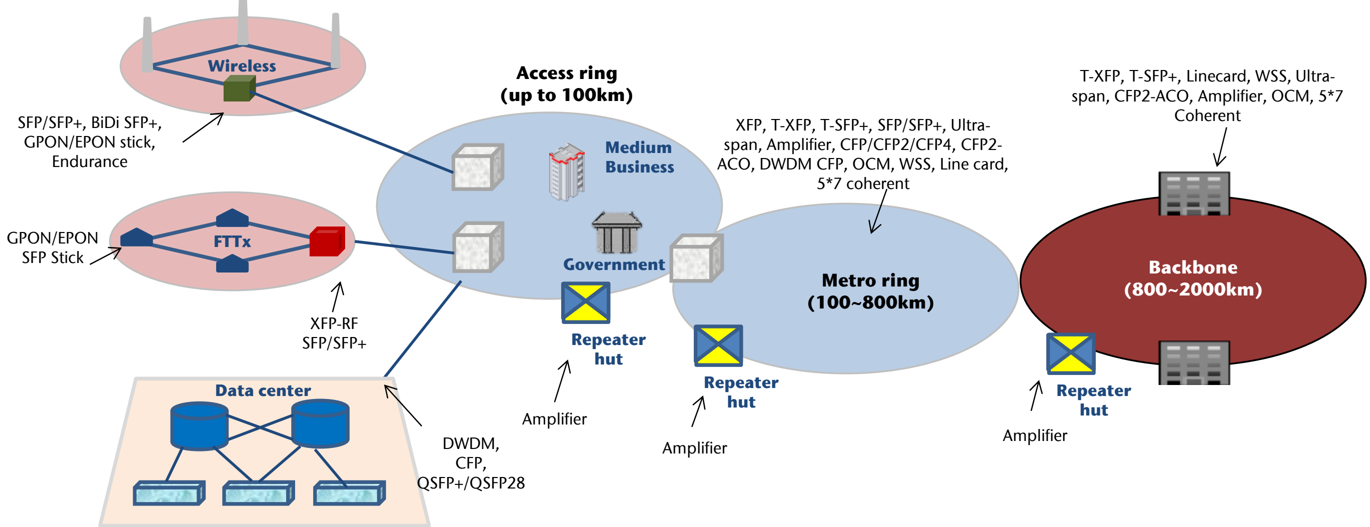
Telecom Transceivers – How it Differs in 5G?

We see the following ongoing optical transceiver upgrades in the telecom network:

High-speed transceiver upgrade is one theme.

- Access ring (up to 100km distance): GPON -> 10GPON. Mainstream products are SFP+ and GPON stick in FTTH.
- Metro ring (100~800km distance): 10G/40G -> 100G. Mainstream products are SFP+, QSFP+ and CFP coherent transceivers.
- Long haul (800~2000km distance): 100G -> 400G. Mainstream products are CFP2 coherent transceivers.

Chart 57: Telecom optical transceivers



Source: Jefferies

Fronthaul transceiver estimate

The volume of transceivers in fronthaul will also grow explosively, driven by:

Two-level front-haul structure will significantly increase the amount of RRUs (remote radio unit).

- ***The number of 5G stations may be 1.2 times that of 4G***, according to a senior expert from the wireless technology research office of China Unicom labs.
- 5G C-RAN architecture adds 6 fronthaul transport nodes (FTN I) per DU and 6 fronthaul transport nodes (FTN II) per CU. Basic configuration is 3 RRUs per BBU (which is DU + CU in 5G) and 2 transceivers per RRU. ***We estimate the amount of RRUs in 5G will be over 20 times more than that of 4G.***

In the 4G era, the communication protocol running over fronthaul (between RRU and BBU) is the Common Public Radio Interface (CPRI). CPRI was established in 2003 by equipment vendors including Ericsson, NSN, Alcatel Lucent, Huawei and NEC. CPRI currently supports operating speeds up to 6G/8G/10G/25G, so SFP/SFP+ transceivers are designed for the use. Telecom operators and equipment vendors have standardized on 10G capable multi-rate transceivers for the 4G LTE fronthaul needs.

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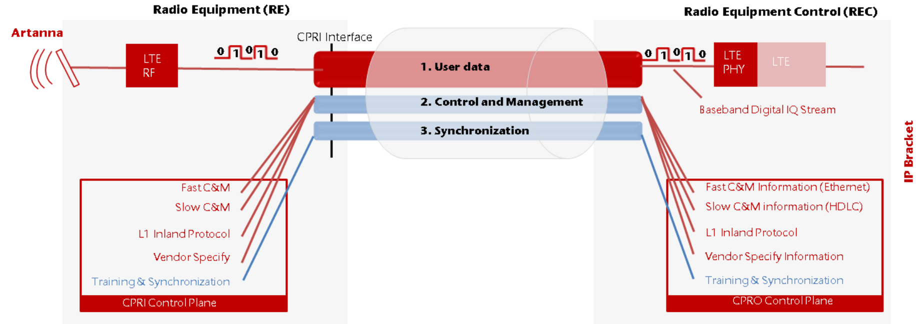
Chart 58: How CPRI works between RRU and BBU



Source: EXFO

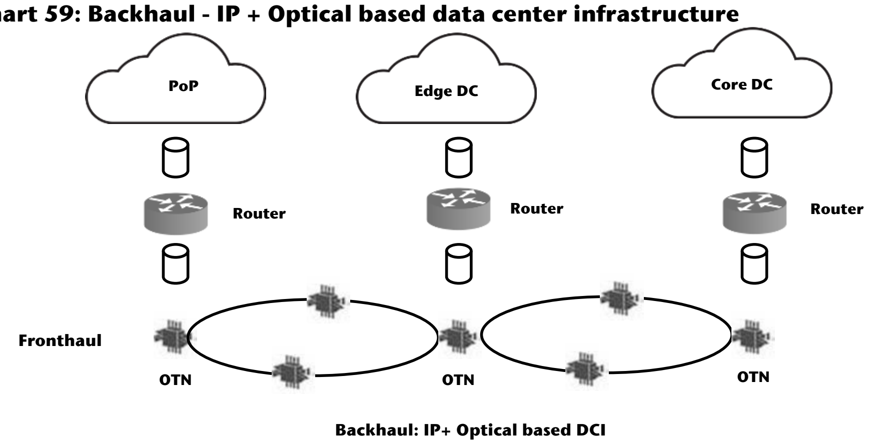
5G fronthaul sees higher DU-to-RRU data rates brought by higher carrier bandwidth (from 100MHz to 1GHz) and massive MIMO (from 8x8 to 64x64 antennas [64 antennas each for upstream and downstream signal]). According to the China Mobile Research Institute, the eCPRI (published in August 2017) bandwidth for single RRU is 25Gbps for each 100MHz. Hence, we expect to see 25G devices to be deployed in high volumes. 50G/100G and even 400G devices will be needed for fronthaul as 5G matures.

Mid-haul and backhaul transceiver upgrade

In the centralized deployment trend, mid-haul and back-haul nodes will become “edge” data centers.

We expect the increasing data throughput will drive another wave of optical module upgrade in mid-haul (n*25G/50G) and backhaul (n*100G/200G/400G). In the longer term, to provide an even higher bandwidth and lower latency, we believe IP networks + Optical networks will be the most basic infrastructure in backhaul. The traditional central offices are transforming into localized edge data centers. Based on SDN (software defined network) and NFV (network function virtualization), the traditional network equipment will be replaced by general cloud servers and routers. Through even more centralized computing and storage, Capex and Opex can be even more significantly reduced.

Chart 59: Backhaul - IP + Optical based data center infrastructure



Source: ZTE, Jefferies

Telecom operators have two options to expand network capacity: 1) install new fiber, which is also the traditional but costly approach, or 2) increase the effective bandwidth of existing fiber. According to Cisco, installing new fiber is estimated at about USD70k per mile, most of which is construction costs rather than fiber itself. The second approach can be accomplished by increasing the number of wavelength on a fiber. Using a wavelength division multiplexing (WDM) technology several wavelengths, or light colours, can simultaneously multiplex signals of 2.5 to 40Gbps each over a strand of fiber. Without laying new fiber, the effective capacity of existing fiber can expand by a factor of 16 or 32.

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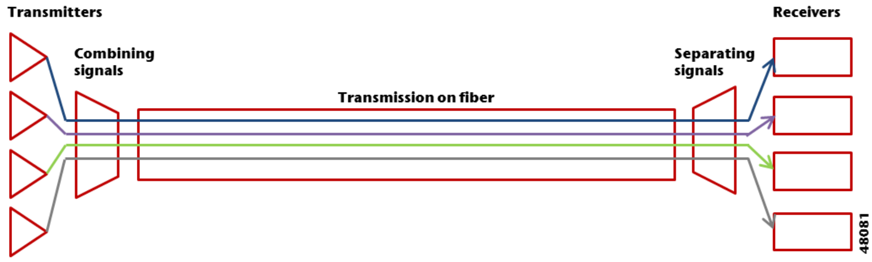
WDM assigns incoming optical signals to specific frequencies of light wavelength with a certain frequency band. The multiplexing closely resembles the radio signal on different wavelengths without interfering with each other, and the signals are demultiplexed at the receiving end.

Chart 60: Functions of DWDM



Source: https://www.cozlink.com/modules-a272-275-273/article-69318.html

There are two types of WDM standards: 1) CWDM (coarse wavelength division multiplexing) and DWDM (dense wavelength division multiplexing). CWDM is a low-cost solution (typically one third of DWDM) and supports up to 18 wavelength channels transmitted through a fiber at the same time. DWDM supports up to 80 wavelength channels. CWDM offers a convenient and cost-effective solution for short distance of up to 70km. Unlike CWDM, DWDM connections can be amplified and used for longer distance data transmission. In addition, DWDM is better suited for higher speed protocols like 10G and coherent 40G/100G, and DWDM wavelength sits in the lowest loss region of the fiber maximizing transmitting distances. Both CWDM and DWDM are available as active and passive systems.

DWDM system performs the following main functions:

- **Generating the signal**—The source, a solid-state laser, must provide stable light within a specific, narrow bandwidth that carries the digital data, modulated as an analog signal.
- **Combining the signals**—Modern DWDM systems employ multiplexers to combine the signals.
- There is some inherent loss associated with multiplexing and demultiplexing. This loss is dependent upon the number of channels but can be mitigated with optical amplifiers, which boost all the wavelengths at once without electrical conversion.
- **Transmitting the signals**—the effects of crosstalk and optical signal degradation or loss must be reckoned with in fiber optic transmission. These effects can be minimized by controlling variables such as channel spacings, wavelength tolerance, and laser power levels. Over a transmission link, the signal may need to be optically amplified.
- **Separating the received signals**—At the receiving end, the multiplexed signals must be separated out. Although this task would appear to be simply the opposite of combining the signals, it is actually more technically difficult.
- **Receiving the signals**—the demultiplexed signal is received by a photodetector.

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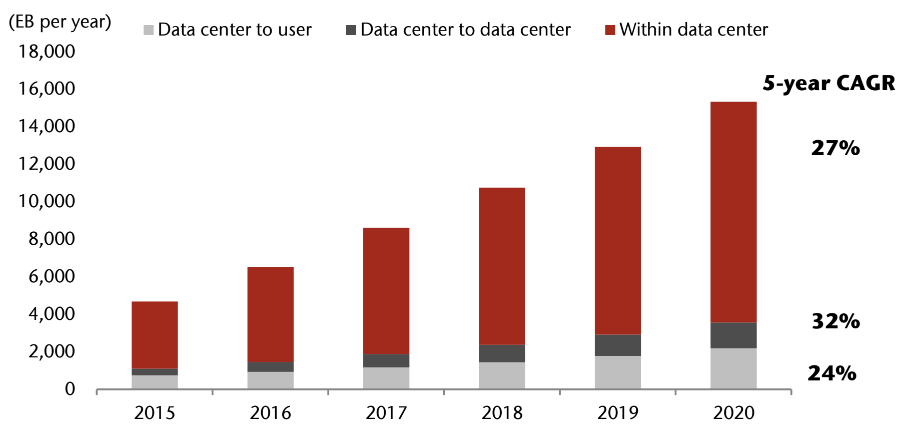
Datacom: How Many Transceivers Do We Need?

Most data traffic is between servers now, driven by virtualization, cloud computing and AI.

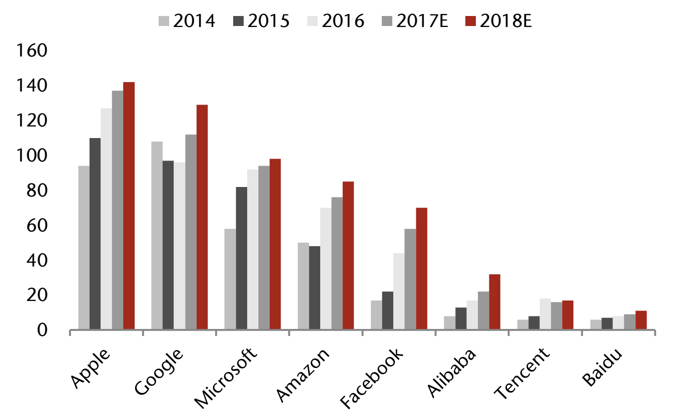
Data center is the main driver for Internet traffic growth. Data center bandwidth density will double every two years, and expand by 40 times between 2013 and 2023. According to Cisco, global data center IP traffic will grow threefold from 2015 to 2020, with most workloads within the data centers. This will drive the data center architecture shifting from traditional three-layer to flattening two-layer spine-leaf network, with increasing optical fiber coverage. The flat structure can improve efficiency of server-to-server (east-west) traffic and increase the demand for high-speed optical transceivers and switches.

Chart 61: Data center traffic breakdown



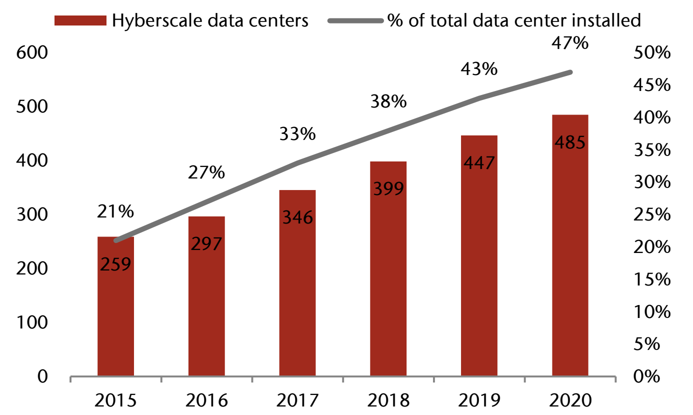
Source: Cisco, Jefferies

Chart 62: Cloud data center capex plan by vendors



Source: Company Data, Jefferies estimates

Chart 63: Global hyperscale data center growth and penetration



Source: Cisco, Jefferies

What is Spine-Leaf Network Topology?

A flattening two-level spine-leaf topology can process "west-east" traffic more efficiently.

The traditional three-layer network was designed for use by general networks. It is usually segmented into pods. The architecture consists of core switches, aggregation switches and access switches (Top of Rack switch, TOR).

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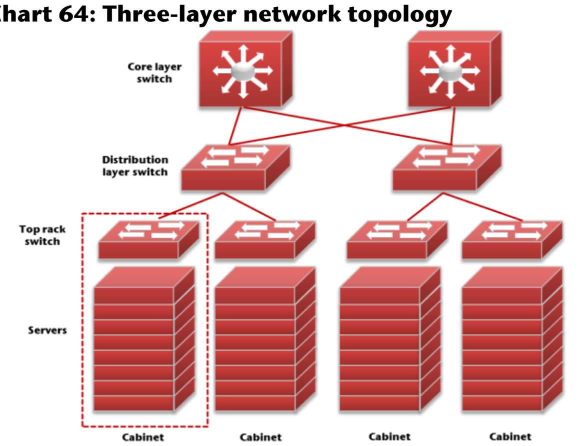
With virtual machines, applications are increasingly deployed in a distributed fashion, which leads to east-west traffic. The three-layer network can only provide two active parallel uplinks, so the bandwidth becomes a major bottleneck. In addition, the server-to-server latency varies depending on the traffic path used.

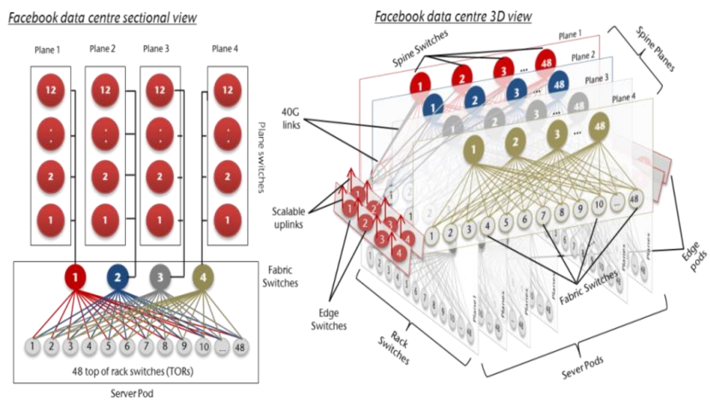
In the two-layer spine-leaf network, the lower tier switches (leaf layer) are connected to each of the top-tier switches (spine layer), in a full-mesh topology. The leaf layer consists of access switches that connect to servers. The spine layer is the backbone of the network for interconnecting all of the leaf switches. Each leaf switch connects to every spine switch in the fabric. The path is randomly chosen so that the traffic load is evenly distributed among the spine switches. This approach keeps latency at a predictable level because a payload only has to hop to a spine switch and a leaf switch to reach its destination.

Chart 64: Three-layer network topology



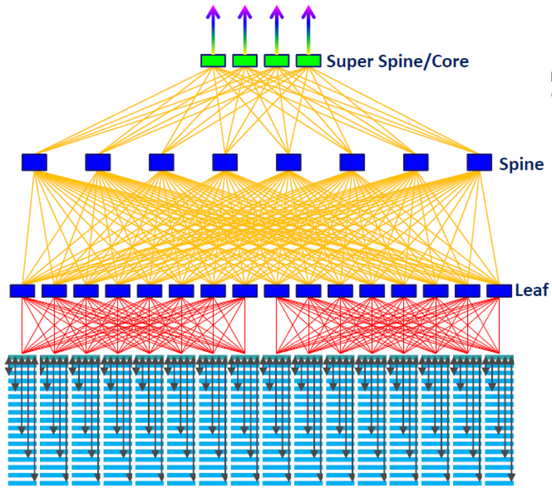
Source: Jefferies

Chart 65: Spine-leaf network topology



Source: Jefferies

Chart 66: Optical transceiver migration in spine-leaf topology



	Now	Next
Inter-Data Center (> 40km)	100G DWDM	400G DWDM
Spine-core (< 2km)	100G	400G
Leaf-spine (< 500m)	100G QSFP28 SR4	400G QSFP56-DD
Leaf-server (< 30m)	10G AOC/DAC	25G AOC

Source: Jefferies

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QSFP28 CWMD4 and PSM4 are the most popular solution for 100G optical connections in data centers.

100G QSFP28 – Mainstream Solution in Coming Years

Demand for 100G transceivers has grown quickly in recent years, mainly driven by cloud computing, mobile broadband and IPTV. 40G is the norm in data center now. 100G QSFP28 is becoming the universal choice in data center interconnections, for low cost, small size and power consumption. Alibaba Cloud has started mass adopting 100G QSFP28 transceivers from 2017, and expects to deploy QSFP56 from 2019.

Chart 67: Data center 100G transceiver use cases

	100G technology	Laser	# of fibers	Transceiver cost	Fiber cost per meter	Optimal distance
Intra-Data Center	Short Reach (SR) AOC	4xVCSEL	8	$	$$	<150m
	Long Reach, QSFP28 PSM-4	4x1310nm DFB or 1x1310nm high power + modulator (Silicon Photonic)	8	$$	$$$$$	150m<d<500m
	Long Reach, QSFP28 CWDM4	4x CWDM DFB	2	$$$	$$$	500m<d<2km
Interconnect	Extended Reach, 4WDM-10	4x CWDM	2	$$$$	$$$	2km<d<10km
	100G-Base-LR4	4xWDM (cooled)	2	$$$$$$	$$$	2km<d<10km
	Coherent (DP-QPSK)	1x1550 (tunable, narrow linewidth)	2	$$$$$$$$$$	$$$	>80km

Source: AAOI, Jefferies

Chart 68: Alibaba Cloud's optical transceiver technology roadmap

Network speed	40G →	100G →	400G →	1.6T?
SW-SW	40G eSR4 QSFP+	100G SR4, CWDM4 PSM4 QSFP28	400G DR4, FR4 SR4.2 QSFP56-DD	1.6T? OBO? QSFP224-DD?
SW-Server	10G AOC SFP+	25G AOC SFP28	100G AOC SFP56-DD	400G OBO? SFP224-DD?
Deployment	2013	2017	2019	2023?

Bankwidth density 40x in 10 years
Doubles - every 2 years

Source: Alibaba, Jefferies

QSFP28 is the smallest 100G transceiver, only a fraction of the size of CFP. According to LightCounting, 100G QSFP28 volume is rapidly ramping up from 2H16. In the longer term, we expect QSFP28 to gradually penetrate the telecom space with 5G rollout, especially in fronthaul.

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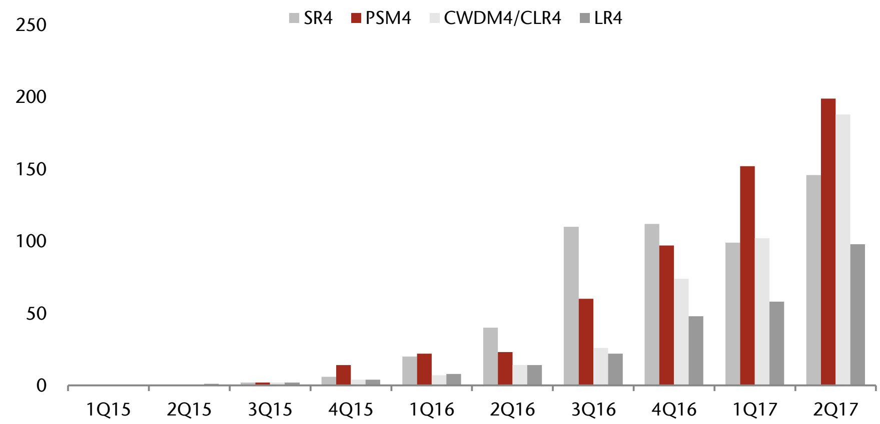
Chart 69: 100G QSFP28 transceiver shipment worldwide



Source: LightCounting, Jefferies estimates

PSM4 use more optical fiber, comparing to CWDM4, which is a cost-saving solution in 500m transport distance.

100G QSFP28 is implemented using four 25Gbps lanes (supporting signal up to 28Gbps). This transceiver keeps all physical dimensions of its predecessors like QSFP/QSFP+. There are four form factors. QSFP28 is also assembled as AOC (up to 70m transmission) and DAC (0~15m transmission), as even more cost effective solutions. AOC/DAC can provide similar performance to discrete transceivers and fiber cables.

- **QSFP28 SR4** is designed to support short distance transmission via multi-mode fiber. It enables 4x25G dual way transmission over 8 fibers.
- **QSFP28 LR4** is for long distance transmission. The transceiver uses WDM technology for 4x25G data transmission, up to 10km over single mode fiber. It requires a multiplexer and demultiplexer.
- **QSFP28 CWDM4** supports four 25G optical transmission over a single fiber for reaches from 150m to 2km.
- **QSFP28 PSM4** (parallel single-mode fiber) operating distance is limited to 500m, over 8-fiber cable. In addition, beside point-to-point links, PSM4 channels can be split out individually. Comparing to CWDM4, PSM4 eliminates the multiplexer and demultiplexer, but higher fiber costs means over longer distance CWDM4 is more cost effective.

Chart 70: 100G QSFP28 transceiver comparison

	PSM4	CWDM4	LR4	SR4
Fiber mode	Single	Single	Single	Multi
MUX/DEMUX	No	Yes	Yes	No
Transport distance	500m	2km	10km	100m
Price (USD)	216	560	912	144

Source: Jefferies

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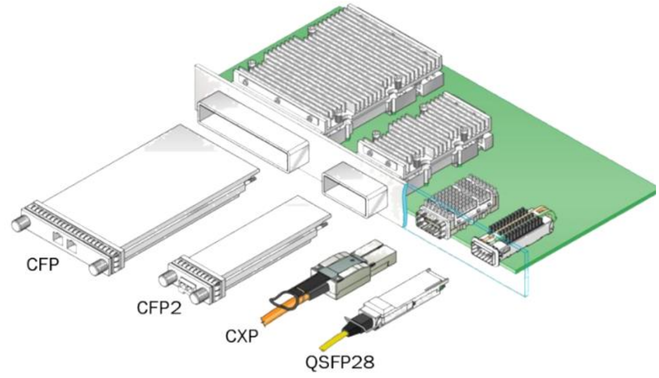
Chart 71: Different form factors of 100G transceivers



Source: Jefferies

Chart 72: 100G transceiver spec comparison

	CXP	CFP	CFP2	CFP4	QSFP28
Lane rate	12x12G or 10x12G	40G/100G	40G/100G	40G/100G	4x25G
Applications	InfiniBand, Ethernet	Ethernet, SONET/SDH, OTN	Ethernet, SONET/SDH, OTN	Ethernet, SONET/SDH, OTN	Infiniband, Ethernet
Dimension (mm)	21x29	82x145x14	41x104x13	22x92x10	18x52x8.5
Max power	6W	8~32W	3~18W	1.5~6W	3.5W

Source: Jefferies

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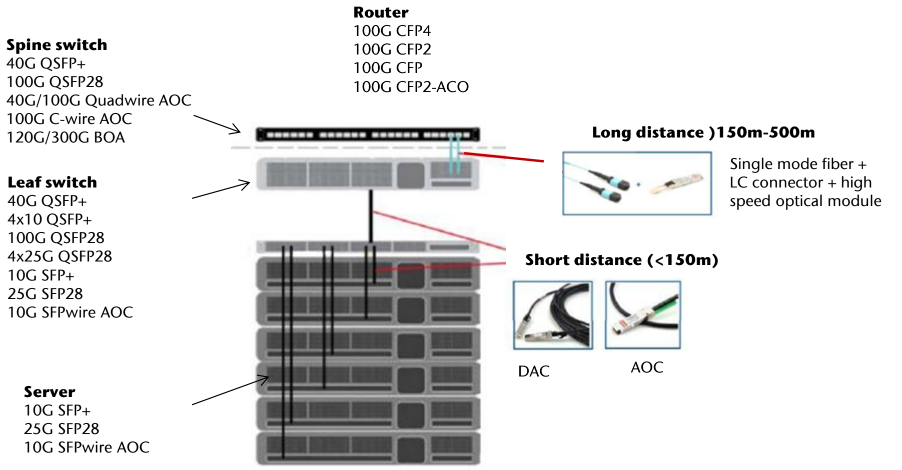
Data Center Transceivers – How it Differs in Spine-Leaf Topology?

Chart 73: Datacom transceivers



Source: Jefferies

In data centers, there are three major cabling solutions:

Optical cabling (AOC) is gradually replacing copper in server-server connection (15~30m). DAC is a better solution in under 10m connections.

- Single mode fiber+ LC/SC connectors+ high-speed optical modules: under scenarios that require high speed and long connection range, the combination of single mode fiber and high-speed optical modules (using DFB, EML narrow linewidth laser) is the only solution, but with high cost. For different optical modules, different fiber connectors are required, e.g. LC connector for SFP package form, and SC connector for GBIC package form.
- Active optical cable (AOC): AOC is a connection product to connect optical modules (using VCSEL etc. wide linewidth and low cost laser) and multiple mode fibers (OM3/OM4 etc.). AOC's linewidth is wide and cost is low, but the transmission distance is relatively limited. It has competitive advantages in cost and performance for 40Gb speed or above and 10Gb speed with 15-30m connection distance.
- Direct attach cable (DAC): there are various standards for direct attach cable. Early stage CAT6 twisted pair products match crystal heads as standard (the same as network cable for computers). Later 10G DAC products are developed to be equip with SFP+ connectors. This product can replace optical modules and AOC below 10m connection distance with only 30%-50% cost.

Chart 74: Cost comparison: AOC vs. DAC

(Rmb)	Distance (meters)				
	3m	5m	10m	15m	30m
10G AOC	300	310	340	370	450
10G DAC	99	160	550 (active)	na	na

Source: Jefferies estimates

Spine-leaf topology will trigger significant new demand for 100G QSFP28 and 25G AOC.

We estimate in a data center with 10,000 servers, approximately 8,000 40G transceivers and 800 100G transceivers are used in the case of the traditional three-layer network; meanwhile, in the spine-leaf network, 25G AOCs will largely replace DAC copper

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connections in server-to-switch and 100G transceiver deployment will increase by 5 times to 4,000.

Chart 75: Optical transceiver demand by network topology

	Three-layer		Spine-leaf
Racks	1,000	Racks	1,000
Servers	10,000	Servers	10,000
10G network cards	20,000	25G network cards	20,000
Acces switch	2,000	Leaf switch	500
40G uplink ports	4,000	100G uplink ports	2,000
Aggregation switch	100	Spine switch	50
100G uplink ports	400		
Core switch	10		
# of transceivers		# of transceivers	
40G	8,000	25G	40,000
100G	800	100G	4,000

Source: Jefferies estimates

We still see that lots of challenges, innovations and breakthroughs that are needed for datacom transceivers:

- Mass production
- Low cost
- Small size & High density
- Low power consumption

Due to the significant bandwidth increase, we see data center optical connections are moving from 1G/10G to 25G/40G/100G now. Alibaba Cloud plans to move from 40G QSFP+ to 100G on switch-to-switch, and from10G AOC to 25G AOC on switch-to-server.

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China On the Rise: Evolving Product Portfolio

Chinese optics companies are mainly in component and transceiver space, which is highly competitive. But they aim to become integrated players through M&A.

Thanks to 5G and data center, we believe China optical component, transceiver module and fiber vendors both will enjoy structural growth in the following years. In the current stage, most local players are poised in the highly competitive passive and active component and 10G/25G/40G transceivers. Potential price competition, inventory overbuilds and faster-than-expected technology migration to 100G+ may significantly impact their businesses. ***We prefer leaders with 1) broad customer base in China and overseas, 2) high vertical integration in the value chain, from chip to component and module, and 3) high R&D intensity as well as good product line visibility.*** We highlight O-Net (from passive to active component and transceivers) and Luxshare (emerging player in high-speed AOC cable).

Chart 76: Global optical transceiver peer comparison

	O-Net	Innolight	Accelink	Finisar	Lumentum	Oclaro	AAOI	NeoPhotonics
Product line	Passve moving to active & transceiver	100G datacom leader, backed by Google	Full product line, first in China with optical chip capability	Full product line, strong optical chip R&D	Full product line, leader in VCSEL	Full product line, specialized in high-speed optical chip	Full product line, high vertical integration	Advanced 100/200/400G coherent, high-end EML chip
In-house lasers	Yes (DFB, EML), IDM	No	Yes (DFB, EML), IDM	Yes, IDM	Yes, IDM	Yes, IDM	Yes, IDM	Yes, IDM
Transceivers product								
10G	x	x	x	x	x	x	x	x
25G	x	x	x	x	x	x	x	x
40G	x	x	x	x	x	x	x	x
100G	x	x	x	x	x	x	x	x
200/400G sample		x		x	x	x	x	x
Customer base	Alcatel-Lucent (~20%) Huawei (<10%) ZTE (<10%) FiberHome (<10%) Microsoft (<10%) Ciena (<10%) Acacia Acacia	Google (~20%) ZTE (15%) Arista (~10%) H3C (9%) Optowiz (6%)	Huawei (31%) FiberHome (14%) ZTE (12%)	Cisco (12%) Huawei (11%) Ciena EMC Ericsson HP Enterprise ZTE	Ciena (18.5%) Huawei (16.7%) Cisco (12.4%) Google Facebook Microsoft Nokia Network	Cisco (18%) ZTE (18%) Huawei (15%) Nokia Network (12%) Amazon Ciena Cisco (18%) Google	Amazon (52.5%) Microsoft (11.6%) Arris (10.4%) Cisco	Nokia Ciena Cisco Huawei FiberHome Acacia Amazon Facebook Google Microsoft

Source: Company Data, Jefferies

- On the product side, local players are mainly in the highly competitive downstream segment of the value chain, including passive components (O-Net), active components (Accelink) and 10G/25G transceivers (Innolight, Hisense). Meanwhile, the high-end optical chip and 100G+ transceiver market is dominated by US and Japan integrated players including Finisar, Lumentum, and Sumitomo. 100G+ coherent chips and transceivers are mostly self-developed by network equipment vendors like Huawei, ZTE and Cisco. We think it's very difficult for Chinese companies to catch up in the near term, but they are making progress in high-end products through their own R&D and vertical integration: 1) O-Net and Accelink currently qualifying 25G chips, and 2) Innolight unveiling 400G transceiver during OFC 2017.

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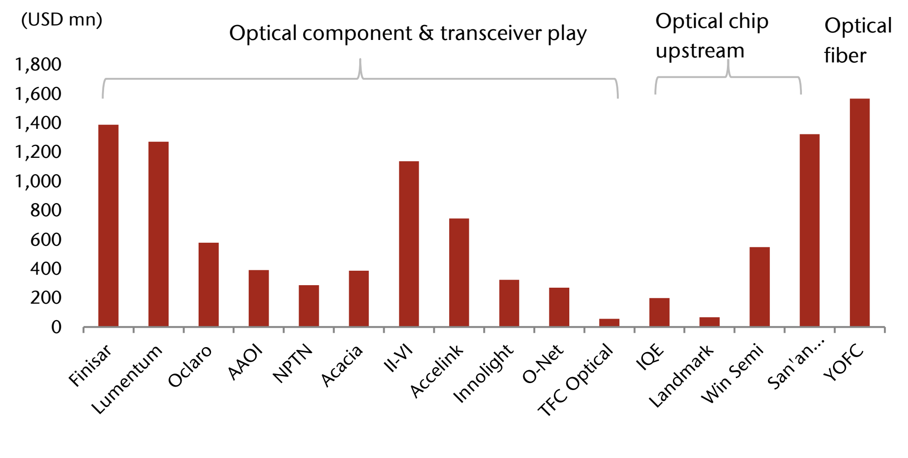
Chart 77: Product mix comparison

	Datacom					Telecom								
	Fiber channel	Ethernet	Optical engines	InfiniBand	Active cable	SONET/SDH	CWDM/DWDM	Wireless	FTTX	WSS	Passive	Optical amplifier	Coherent	High-speed component
Finisar	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lumentum	x	x				x	x	x		x	x	x	x	x
Oclaro	x	x				x	x				x		x	x
NeoPhotonics		x				x	x	x	x		x			x
Source Photonics		x				x	x	x	x					
Sumitomo		x				x	x	x						x
Accelink		x				x	x	x	x		x	x		
FIT	x	x	x	x	x	x		x						x
O-Net		x			x						x	x		

Source: Finisar, Company Data, Jefferies

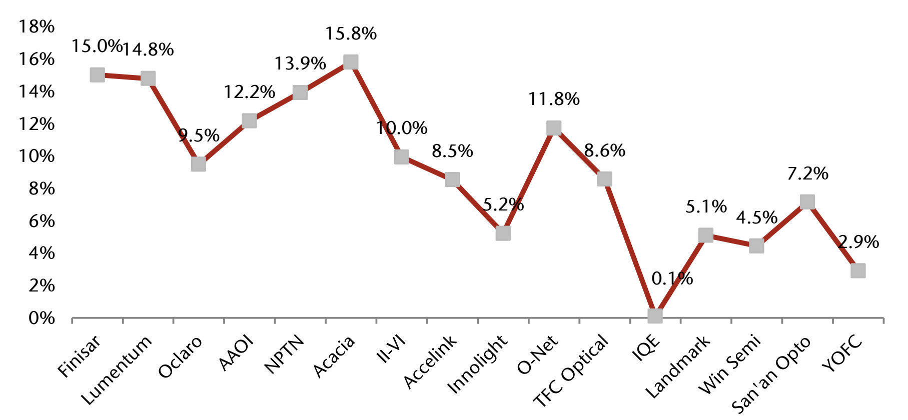
- On the customer base side, we prefer vendors with a balanced mix in China and overseas. Huawei has been very aggressive in stocking upstream optical components for competition. The market weakness in 1H17 was largely due to Huawei's inventory correction.

Chart 78: Optical communication value chain revenue comparison



Source: Company Data, Bloomberg, Jefferies

Chart 79: R&D-to-sales comparison



Source: Company Data, Bloomberg, Jefferies

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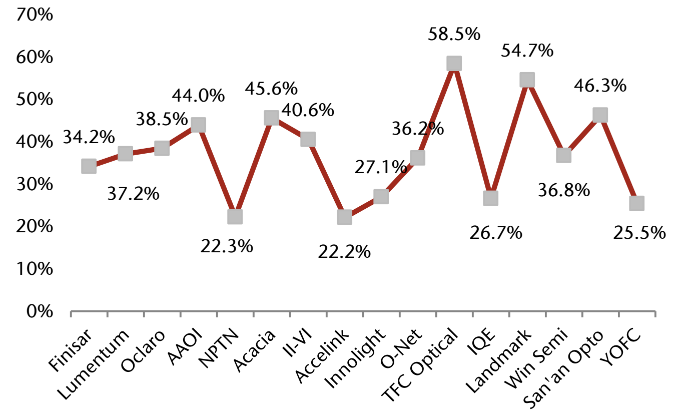
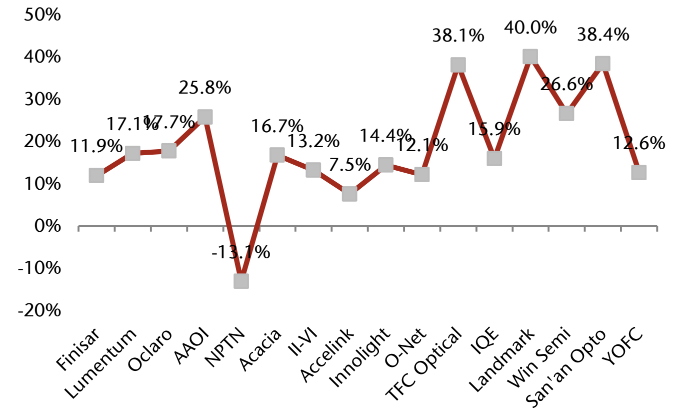
Chart 80: Gross margin comparison



Source: Company Data, Bloomberg, Jefferies

Chart 81: Operating margin comparison



Source: Company Data, Bloomberg, Jefferies

Optics companies are very active in M&A market. Now network equipment vendors step into the space too.

We expect industry consolidation to continue, following recent major M&As like 1) FIT completing the acquisition of Avago's optical transceiver business in 2016, 2) JDSU splitting into Lumentum and Viavi in 2015 and 3) APAT Optoelectronics acquiring NeoPhotonics' low-speed transceiver business in January 2017. Network equipment vendors like Juniper and Ciena also start stepping into this field, mainly in silicon photonics technology. We believe the consolidation will result in better pricing power and more R&D visibilities.

Chart 82: Optical transceiver industry M&As

Time	Company	Target	Business line
May-11	Finisar	Ignis	Tunable laser
Sep-11	NeoPhotonics	Santur	Laser array for long-haul DWDM, Photonic IC
Jan-12	Huawei	Center for Integrated Photonics (CIP)	Photonics research lab
Mar-12	Cisco	Lightwire	High-speed optical connectivity
Mar-12	Sumitomo	Emcore VCSEL-based product line	VCSEL
Apr-12	Broadcom	BroadLight	Photonic IC
Jul-12	Oclaro	Opnext	Optical component and transceiver
Jul-12	Finisar	Red-C Optical	EDFA, Raman amplifier
Dec-12	Accelink	WTD	Optical transceiver
Jan-13	NeoPhotonics	LAPIS Semiconductor	Photonic IC design & manufacturing
Apr-13	Avago	CyOptics	Photonics IC (InP laser and detector)
Sep-13	II-VI	Oclaro Zurich GaAS laser diode business	GaAS laser diode
Nov-13	II-VI	Oclaro amplifier and micro-optics business	Optical amplifier, micro-optics
Jan-14	Finisar	u2t Photonics	100G coherent technology
Apr-14	APAT Optoelec	Avago Taiwan R&D center	10G and 40G laser diode and transceiver design
Oct-14	O-Net	3S Photonics (former Alcatel Photoics)	Laser diode
Oct-14	NeoPhotonics	Emcore tunable laser and transceiver product line	Tunable laser and tranceiver
Nov-14	MACOM	BinOptics	InP laser, silicon photonics
Jan-15	O-Net	ITF Technology	High power laser
Jul-15	JDSU	Split into Lumentum and Viavi	Split into transceiver and optical filter business
Nov-15	MACOM	FiBest	TOSA ROSA
Jan-16	FIT	Avago transceiver product line	Transceiver product line
Jan-16	Ciena	TeraXion high-speed photonics components	High-speed InP and Silicon photonics technology
Aug-16	Juniper	Aurrion	Silicon photonics
Jan-17	APAT Optoelec	NeoPhotonics 10G and below transceiver product line	Low-speed (10G & below) transceiver

Source: Jefferies

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Glossary

Table 1: Glossary

AGC	自动增益控制	**Automatic Gain Control**
APC	自动功率控制	Automatic Power Control
APD	雪崩光电二极管	Avalanche Photo Diode
AWG	阵列波导光栅	Arrayed Waveguide Grating
BBU	基带处理单元	Base Band Unit
BEN	突发使能	Burst Enable
BER	比特误码率	Bit Error Rate
BSD	突发信号检测	Burst Signal Detect
CDR	时钟数据恢复	Clock Data Recovery
CFP	100G 可插拔封装	100Gbps Form-factor Pluggable Package
CID	连续相同数字	Consecutive Identical Digit
CML	电流型逻辑	Current Mode Logic
CPRI	通用公共无线接口	Common Public Radio Interface
CW	连续波	Continuous Wave
CXP	120G 小型化可插拔封装	120G Extended Pluggable
DC	直流	Direct Current
DFB	分布反馈	Distributed Feedback Bragg
DML	直接调制激光器	Direct Modulation Laser
EAM	电吸收调制器	Electrical Absorbing Modulator
EDFA	掺铒光纤放大器	Erbium-doped Optical Fiber Amplifier
EML	电吸收调制激光器	Electro-absorption Modulated Laser
EPON	以太网无源光网络	Ethernet Passive Optical Network
ER	消光比	Extinction Ratio
ESD	静电放电	Electrostatic Discharge
FEC	前向纠错	forward Error Correction
FFS	后续研究	For Further Study
FP	法布里-泊罗腔	Fabry Perot
FPGA	现场可编程门阵列	Field-Programmable Gate Array
FSAN	全业务接入网	Full Service Access Network
GPON	吉比特无源光网络	Gigabit capable Passive Optical Network
IL	插入损耗	Insertion Loss

Source: Jefferies

Table 2: Glossary (cont'd)

Inp	铟磷	**Indium Phosphorus**
LA	限幅放大器	Limit Amplifier
LAN	局域网	Local Area Network
LC	小型标准适配器	Little Standard Connectors
LD	激光二极管	Laser Diode
LOS	信号丢失	Loss Of Signal
LR	长距	Long Reach
MAC	煤质接入控制	Media Access Control
MLM	多纵模	Multi Longitudinal Mode
MMI	多模干涉耦合器	Multi-Mode Interferometer
MPD	背光探测器	Monitor Photoelectric Detector
MSA	多源协议	Multi Source Agreement
NA	不适用	Not Available
NG-PON2	下一代无源光网络第二阶段	Next Generation Passive Optical Network
NRZ	非归零	Non Return Zero
ODN	光配线网	Optical Distribution Network
OLT	光线路终端	Optical Line Terminal
OM	光模式	Optical Mode
OMA	光调制幅度	Optical Modulation Amplitude
ONU	光网络单元	Optical Network Unit
ORL	光回路损耗	Optical Return Loss
PECL	正发射射极耦合逻辑	Positive Emitter Coupled Logic
PLC	平面光波导	Plannar Lightwave Circuit
PON	无源光网络	Passive Optical Network
PRBS	伪随机序列	Pseudo Random Binary Sequence
RF	射频	Radio Frequency
RIN	相对强度噪声	Relative Intensity Noise
ROSA	光接收组件	Receiver Optical Sub-Assembly
RRN	无源拉远节点	Passive Remote Node
RRU	射频拉远单元	Radio Remote Unit

Source: Jefferies

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Table 3: Glossary (cont'd)

RSSI	接收信号强度指示	**Receiver Signal Strength Indicator**
RZ	归零	Return Zero
SAG	选择区域外延	Selected Area Growth
SD	信号检测	Signal Detect
SFF	小型封装	Small Form Factor
SFI	SFP+ 高速串行电接口	SFP+ High Speed Serial Electrical Interface
SFP	小型可插拔	Small Form Factor Pluggable
SFP+	增强型小型化可插拔	Enhanced Small Form Factor Pluggable
SLM	单纵模	Single Longitudinal Mode
SMSR	边模抑制比	Side Mode Suppression Ratio
SOA	半导体光放大器	Semiconductor Optical Amplifier
SOI	绝缘体上硅	Silicon on Isolator

Source: Jefferies

Table 4: Glossary (cont'd)

SR	短距	**Short Reach**
TDP	发送色散代价	Transmitter Dispersion Penalty
TEC	热电制冷器	Thermal Electrical Cooler
TFF	薄膜滤波器	Thin Film Filter
TOSA	光发射组件	Transmitter Optical Sub-Assembly
TTL	晶体管-晶体管逻辑	Transistor-Transistor Logic
TWDM-PON	时分波分复用无源光网络	Time and Wavelength Division
UI	单元间隔	Unit Interval
Vcsel	垂直腔面发射激光器	Vertical Cavity Surface Emitting Laser
VOA	可调光衰减器	Variable Optical Attenuation
WDM	波分复用	Wavelength Division Multiplexer

Source: Jefferies

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(Article 3(1)e and Article 7 of MAR)

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