Open Optics MSA Design Guide

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Contents

1 Overview

The Open Optics MSA[1] specification provides a Wavelength Division Multiplexing (WDM) roadmap to scale data center networks to greater than 1 Tb/s of traffic over a standard Single Mode Fiber (SMF). It allows 100Gb/s networks to interface with 200Gb/s and 400GGb/s networks and build larger networks. Inspired by long haul telecom WDM networks which routinely transmit terabits of data over a single fiber, this architecture is designed to optimize cost and scalability for data center reaches, typically less than 2km.

Historically, data centers have used VCSEL transceivers and Multi-Mode Fiber (MMF) as the most cost effective interconnect solution. The first generation data centers were built using 1Gb/s VCSEL transceivers and the OM2 version of MMF, optimized for 1Gb/s 850nm VCSEL transmission. This combination provided reaches of 500m, long enough for most data center applications.

For the 10Gb/s generation, data centers replaced both the transceivers and the installed fiber with new VCSEL based transceivers and OM3 fiber. The OM3 version of MMF, optimized for 850nm 10Gb/s VCSEL transceivers supported reaches up to 300m.

The 40Gb/s generation did not scale so easily for the following reasons:

- The VCSEL solutions were implemented using four parallel 10Gb/s channels, requiring 4x more trunk cabling and patch panels
- The reach for the VCSEL solutions was only 100m over OM3 fiber, not enough to cover many data center reaches
- Installing new OM4 fiber was expensive with a modest increase in reach of 150m

By contrast, the 40Gb/s single mode transceivers used WDM, combining four wavelength channels onto one single mode fiber. These factors caused many hyper-scale data centers to convert more of their data center fabric to single mode fiber.

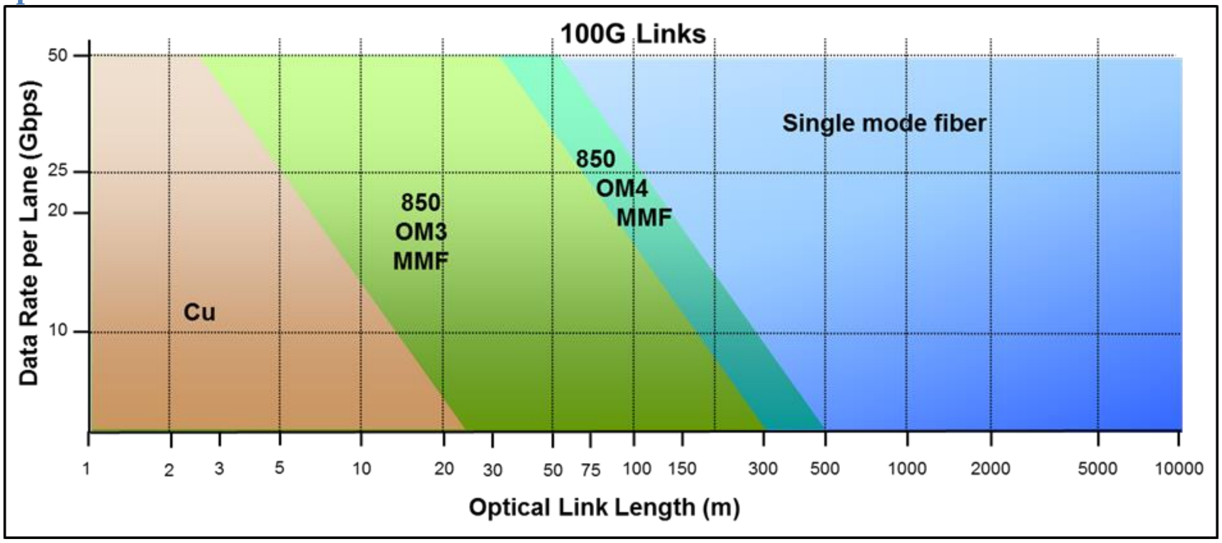
The 100Gb/s generation is scaling even worse:

- The 25Gb/s VCSEL solutions require OM4 fiber for 100m reach
- More large data centers are converting to single mode fiber

Figure 1 highlights the impact of channel speed and the reach of VCSEL based solutions. It is also interesting to note that in spite of predictions of the “end of copper,” direct attach copper (DACs) are widely used, even at 100G, for inside rack cabling where the reaches are less than 3.5m.

[1] http://OpenOpticsMSA.org

Figure 1: At higher lane speeds, single mode solutions cover more of the data center space

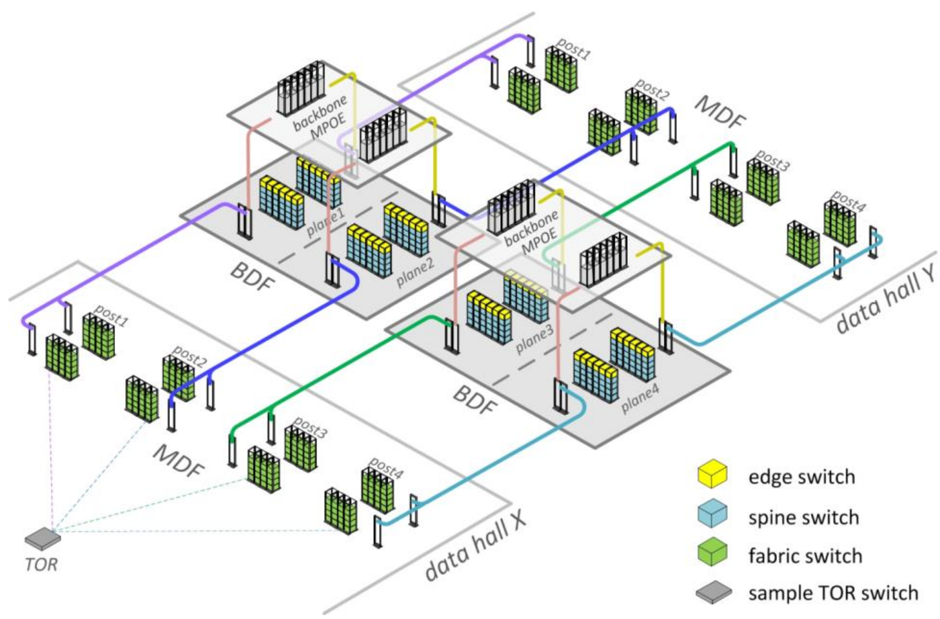


2 Data Center Cabling

Data centers networks are comprised of structured cabling; networks of trunk fibers which terminate on patch panels. The diagram[2] below from Facebook's Alexey Andreyev blog illustrates several standard concepts. The optical trunks are shown in colored pipes and they terminate at patch panels, which are really just a rack of connection points. Not shown are the optical jumper cables which connect the patch panels to switches.

Open Optics address the need to increase the bandwidth of the data center by a factor of 2, 4, 8 or even 32 without installing new trunks, jumpers or patch panels.

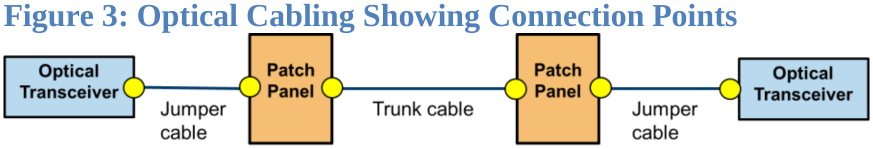
Figure 2: Facebook Diagram Showing Patch Panels and Trunk Cables



2.1 Data Center Optical Link

A typical optical link consists of a transceiver connected by a jumper cable to a patch panel. The trunk cables of the data center terminate at patch panel and the jumper cable connects to transceivers at the switch as shown in Figure 3.

Figure 3: Optical Cabling Showing Connection Points



[2] Andreyev, https://code.facebook.com/posts/360346274145943/introducing-data-center-fabric-the-next-generation-facebook-data-center-network/

The optical link's insertion loss is the sum of the worst case connector losses and fiber attenuation. The IEEE P802.3bs 400G Task Force documented worst case values for estimating the link budget in a submission by Kolesar[3]. Table 1 shows the Open Optics estimate for the worst case link budget for a 2km intra-data center link.

Table 1 – Link Insertion Loss Estimation

Link Items	Insertion Loss			Insertion Loss for Link			
	Mean Loss	Loss at 2.5σ	Units	# items	Mean Loss	Loss at 2.5σ	Units
LC Connector	0.20	0.58	dB/LC	4	0.8	1.55	dB
MPO Connector	0.35	0.98	dB/MPO	2	0.7	1.58	dB
Loss (2km SMF)	0.20	0.30	dB/km	2	0.4	0.60	dB
Total Link Loss					**1.9**	**3.2**	**dB**

Each connector has a mean loss and standard deviation. Kolesar assumes a 2.5σ for the worst case. Since the connector variability is assumed to be randomly distributed and independent, the variances can be summed. The worst case SMF fiber loss is assumed to be ≤ 0.30dB/km over the Open Optics 1550nm wavelength range[4].

The Open Optics MSA specifies an optical link budget of 3.5dB which accommodates worst case assumptions for the previously mentioned six connection points, as well as for 2km of fiber loss with extra margin.

The specification easily ensures operation of a 500m of SMF fiber which covers the vast majority of data center applications.

3 Wavelength Division Multiplexing (WDM)

Wavelength division multiplexing combines multiple optical wavelengths (frequencies) onto a single waveguide or single fiber. Like radio stations broadcasting in air, each optical channel is independent from the others. In an optical network, the separate channels are generated by lasers set at pre-defined frequencies. A multiplexer combines the separate channels into one fiber. The data stream travels over fiber to a demultiplexer where the channels are separated and converted back to electrical signals.

The WDM used in telecom applications, where 80 or more channels are transmitted over a single fiber strand, is called DWDM (Dense WDM). The density of channels (spaced very close to each other) increases the cost and complexity of the transmitters and receivers, yet the benefit of sending more traffic over the same fiber is tremendous. Most DWDM systems are in the 1550 (C-Band) range.

In Datacom applications, CWDM (Coarse WDM) has been popular for 40Gb/s Ethernet applications. CWDM, at 20 nm channel spacing, would only fit 3 channels in the space that DWDM fits 80. With traditional laser assembly technologies, CWDM was low-cost enough to be widely deployed in data center applications.

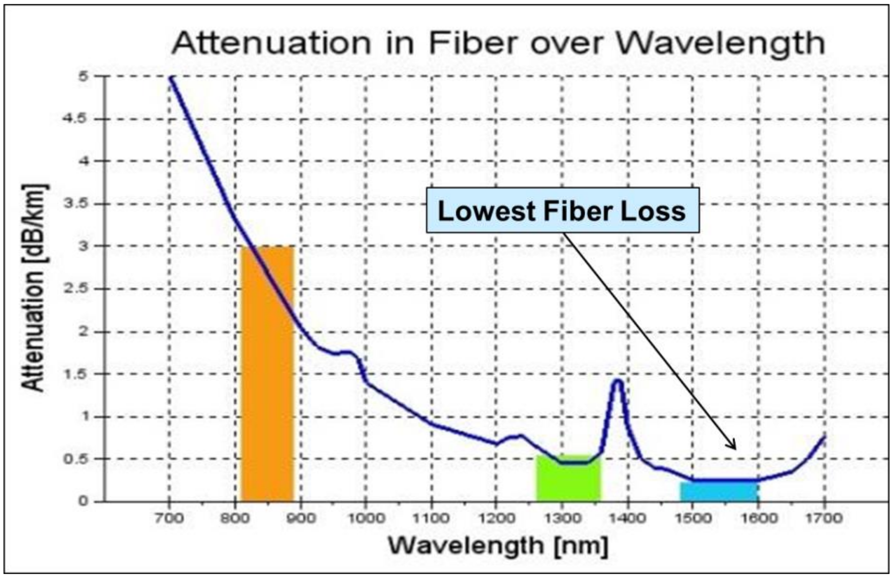
[3] Kolesar, http://www.ieee802.org/3/bs/public/14_05/kolesar_3bs_01_0514.pdf
[4] Anslow, http://www.ieee802.org/3/hssg/public/nov07/anslow_03_1107.xls

The main problem with CWDM is scalability; CWDM does not readily scale to more channels. Lasers across such a broad spectrum are difficult to make into arrays; assembling lasers separately is costly. As of now, none of the major vendors are proposing expanded wavelength plans to the IEEE or Ethernet Alliance.

4 Why C-Band is the Best Choice

C-Band has been widely used for DWDM telecom applications because it has the lowest attenuation loss, and because nearly all fiber amplifiers work in this range, as illustrated in the chart below. It also shows why 1310 CWDM does not easily expand. Scaling to the right hits the “water peak” between 1350 and 1420. Scaling to the left increases the loss, creating other problems.

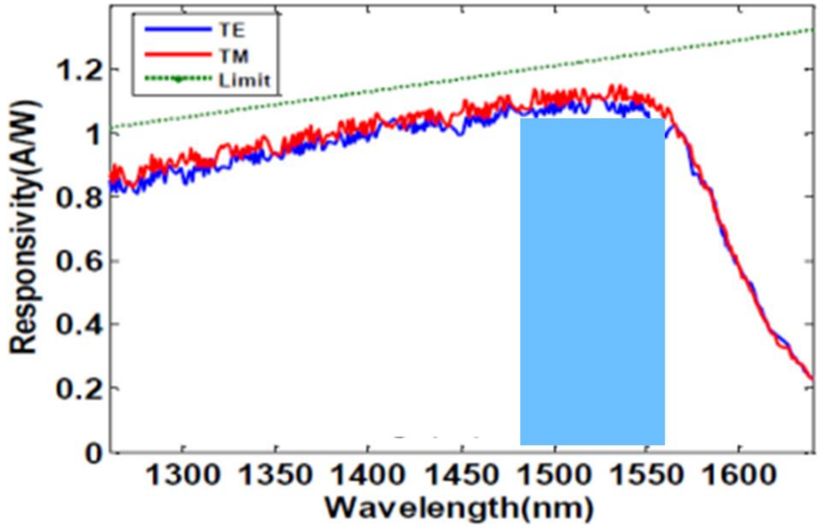
Figure 4: C-Band (1550 region) Provides Best Window for Optical Transmission



C-Band also provides the best region for any technology using germanium detectors. In silicon photonics, detectors are made of germanium for the simple reason that many silicon fabrics include germanium which can be easily incorporated into the chip design. The chart below shows the high responsivity at 1550 from germanium photo diodes integrated in silicon photonics chips[5].

[5]Martin, http://www.ieee802.org/3/100GNGOPTX/public/jul12/martin_01_0712_optx.pdf

Figure 5: C-band (1550) is the Region for the Highest Responsivity for Silicon Photonics Detectors



4.1 C-Band Channel Plan Examples

The figure below shows examples of the flexibility of the Open Optics MSA specifications. Many channel plans can be accommodated. The four channel plans may be used for 4x25G for 100Gb/s transceivers or 4x50G for 200Gb/s transceivers. The eight channel plans may be used for 400Gb/s transceivers. At 50G, the 32 wavelength plan provides for 1.6Tb/s on a single link.

Newer generation of embedded transceivers will increase the need for density and low-cost cabling.

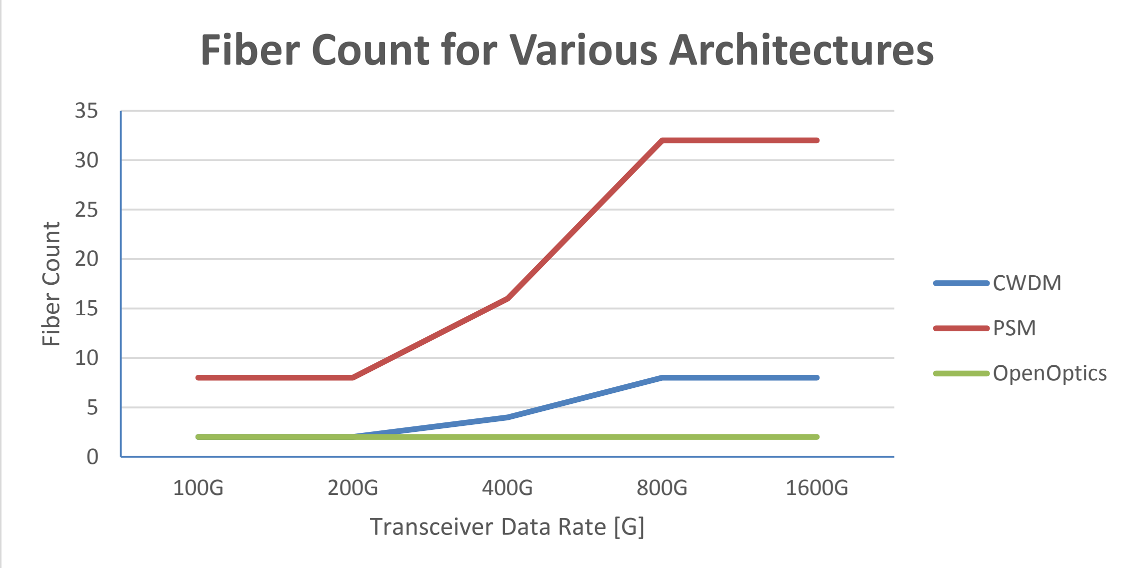
Figure 6: C-band Channel Options for Scalability

Open Optics MSA Channel Specifications							
Wavelength (nm)	Frequency (THz)	4 Ch	4 Ch	8 Ch	16 Ch	16 Ch	32 Ch
1504.23	199.30						
1505.74	199.10						
1507.25	198.90						
1508.77	198.70						
1510.29	198.50						
1511.81	198.30						
1513.34	198.10						32
1514.87	197.90					16	31
1516.40	197.70						30
1517.94	197.50					15	29
1519.48	197.30						28
1521.02	197.10					14	27
1522.56	196.90						26
1524.11	196.70					13	25
1525.66	196.50						24
1527.22	196.30					12	23
1528.77	196.10						22
1530.33	195.90					11	21
1531.90	195.70						20
1533.47	195.50					10	19
1535.04	195.30						18
1536.61	195.10					9	17
1538.19	194.90				16		16
1539.77	194.70			8	15	8	15
1541.35	194.50				14		14
1542.94	194.30	4	4	7	13	7	13
1544.53	194.10				12		12
1546.12	193.90		3	6	11	6	11
1547.72	193.70				10		10
1549.32	193.50	3	2	5	9	5	9
1550.92	193.30				8		8
1552.52	193.10		1	4	7	4	7
1554.13	192.90				6		6
1555.75	192.70	2		3	5	3	5
1557.36	192.50				4		4
1558.98	192.30			2	3	2	3
1560.61	192.10				2		2
1562.23	191.90	1		1	1	1	1
1563.86	191.70						
1565.50	191.50						

5 Link Cost Comparisons

The relative link cost includes two transceivers, SM jumper cables, a portion of two 6-port patch panels (LC/MPO), and a portion of a 24 SM fiber trunk cable as shown in Figure 3. The number of fibers needed is dependent on the transceiver architecture (CWDM, PSM, or Open Optics) and is also dependent on the transceiver's aggregate data rate (100G to 1600G). Figure 8 details our assumptions on how the fiber count scales with data rate across the three architectures.

Figure 7 – Fiber Count for Various Architectures and Aggregate Data Rates

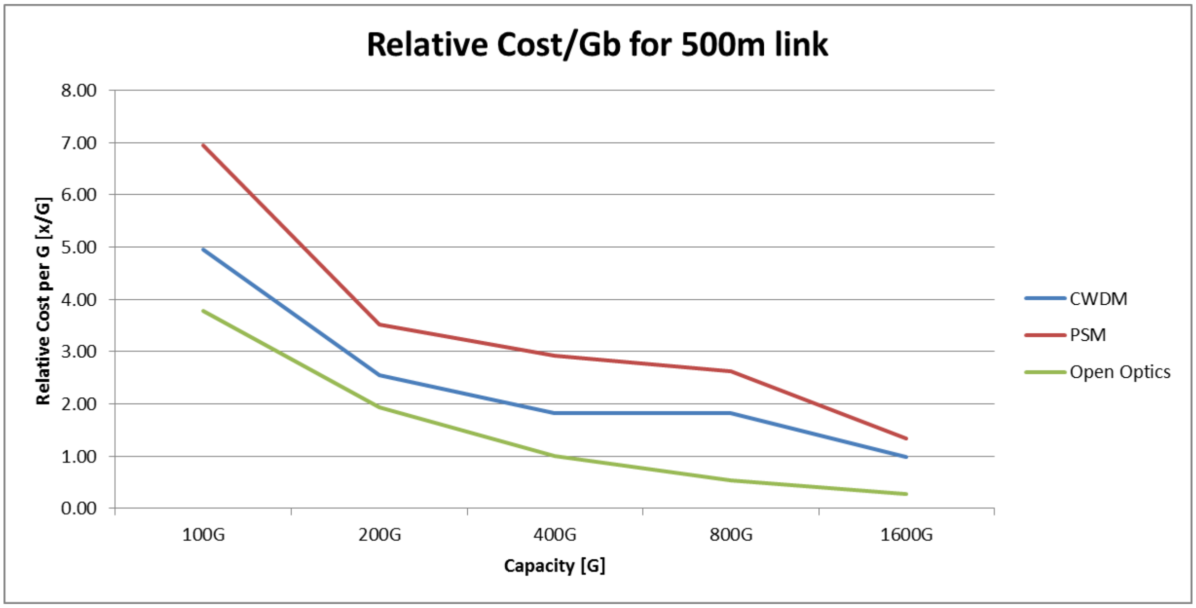


Lane rate for each wavelength starts at 25G for the 100G transceiver and is assumed to progress to 50G for 200G transceivers and eventually reaching 100G for the 1600G transceiver. The CWDM architecture assumes an optical channel spacing of 20nm resulting in a maximum of four wavelengths per fiber being feasible. The PSM architecture assumes one wavelength per fiber. Other proposals at standards organizations assume architectures which lie somewhere in between the pure CWDM and the pure PSM assumptions. Nevertheless, the CWDM and PSM estimates should provide upper and lower boundaries for architectures competing with Open Optics.

Utilizing an inexpensive silicon photonic platform with innovative packaging concepts enables transceiver costs to scale very cost effectively as the transceiver aggregate data rate increases; much better than the traditional 10x the data rate for 4x the cost rule of thumb.

Figure 8 shows the relative cost per gigabit for a 500m link for each of the three architectures as the transceiver aggregate data rate scales from 100G to 1.6T. The cost of the fiber based infrastructure remains a significant portion of the link cost for the CWDM and PSM architectures due to the number of fibers required to carry the optical signals. However, the Open Optics WDM based architecture achieves the lowest link cost since it only needs 1 fiber pair over all data rates.

Figure 8: Dramatic Cost Reduction in Data Center Links



6 Specifications

The Open Optics optical specifications below are grouped into two categories. Foundation optical specifications which are shared across all intra-data center applications and data rates are shown first. The second section highlights key optical specifications for the Open Optics 100G optical link.

Open Optics Intra Data Center	**Open Optics Specifications (FEC)**				**Open Optics Specifications (no FEC)**			
	Min	**Typical**	**Max**	**Unit**	**Min**	**Typical**	**Max**	**Unit**
Open Optics Foundation Specifications								
Operating link reach range	0.002		2.0	km	0.002		2.0	km
Channel wavelength range (nm)		1504 to 1566		nm		1504 to 1566		nm
Channel wavelength range (GHz)		191500 to 199300		GHz		191500 to 199300		GHz
Channel scalability	4		32	λ	4		32	λ
Channel spacing interval (Grid)[1]		200*n		GHz		200*n		GHz
Open Optics 100G QSFP28 Optical Link								
Form Factor		QSFP28				QSFP28		
Signaling rate, each lane		25.78125 ± 100ppm		Gb/s		25.78125 ± 100ppm		Gb/s
BER (optical link)			5.0E-5				1E-12	
FEC Type		IEEE-Std™ 802.3bj, clause 91				None		
Channel Insertion Loss			3.5	dB			3.5	dB
TDP, each lane (for 100Gb/s)			1.5	dB			1.5	dB
Link Budget (including 1.5dB TDP)	5.0			dB	5.0			dB
Tx OMA, each lane (assuming 1.5dB TDP)	-7.0			dBm	-4.5			dBm
Rx Sensitivity (OMA), each lane			-12.0	dBm			-9.5	dBm
Extinction Ratio (ER)	2.5			dB	2.5			dB

[1] n is an interger number

7 Definitions of optical parameters and measurement and measurement methods

All optical measurements shall be made through a short patch cable, between 2m and 5m in length, unless otherwise specified.

7.1 Test patterns for optical parameters

While compliance is to be achieved in normal operation, specific test patterns are defined for measurement consistency and to enable measurement of some parameters. Table 1 gives the test patterns to be used in each measurement, unless otherwise specified, and also lists the IEEE references in which each parameter is defined. Any of the test patterns given for a particular test in Table 3 may be used to perform that test. The test patterns used in this specification are shown in Table 2.

Table 2: Test Patterns

Pattern	Pattern description	Pattern defined in
Square wave	Square wave (8 ones, 8 zeros	IEEE802.3 Clause 83.5.10
3	PRBS31	IEEE802.3 Clause 83.5.10
4	PRBS9	IEEE802.3 Clause 83.5.10
5	RS-FEC encoded scrambled idle	IEEE802.3 Clause 82.2.10 & IEEE802.3 Clause 91

Table 3: Test Pattern Definitions

Parameter	Pattern
Optical modulation amplitude (OMA)	Square wave or 4
Transmitter and dispersion penalty (TDP)	3 or 5
Extinction ratio	3,5
Stressed receiver sensitivity	3 or 5
Calibration of OMA for receiver tests	Square wave or 4

7.2 Optical modulation amplitude (OMA)

OMA shall be as defined in IEEE802.3 Clause 52.9.5 for measurement with a square wave (8 ones, 8 zeros) test pattern or IEEE802.3 Clause 68.6.2 (from the variable measured OMA in IEEE802.3 Clause 68.6.6.2) for measurement with a PRBS9 test pattern.

7.3 Transmitter and dispersion penalty (TDP)

Transmitter and dispersion penalty (TDP) shall be as defined in IEEE802.3 clause 52.9.10 with the exception that each optical lane is tested individually using an optical filter to separate the lane under test from the others.

The optical filter pass band ripple shall be limited to 0.5 dB peak-to-peak and the isolation is chosen such that the ratio of the power in the lane being measured to the sum of the powers of all the other lanes is greater than 20 dB(see IITU-T G.959.1 Annex B). The lanes not under test shall be operating with PRBS31 bit streams.

7.4 Extinction ratio

The extinction ratio of each lane shall be within the limits given in the Specifications if measured using the methods specified in IEC 61280-2-2. The extinction ratio is measured using the test pattern defined in Table 2.

7.5 Receiver sensitivity

Receiver sensitivity, which is defined for an ideal input signal, is informative and compliance is not required. If measured, the test signal should have negligible impairments such as intersymbol interference (ISI), rise/fall times, jitter and RIN. Instead the normative requirement for receivers is stressed receiver sensitivity.

8 Conclusions

The Open Optics approach is the only architecture which provides the lowest link cost even as data rates scale as seen in Figure 8. Other competing architectures which have been proposed fall somewhere in between the pure CWDM and the pure PSM reference architectures.

There are two primary factors which enable this attractive link cost structure:

1. The use of inexpensive WDM techniques so that only a pair of SM fibers are needed
2. The use of inexpensive laser approaches which allows cost effective WDM transceiver implementations

9 References

1. NANOG 48, Steenbergen: *Everything You Always Wanted to Know About Optical Networking – But Were Afraid to Ask* https://www.nanog.org/meetings/nanog48/presentations/Sunday/RAS_opticalnet_N48.pdf
2. Corning, *Corning Specialty Fiber Product Information Sheets* http://www.corning.com/WorkArea/downloadasset.aspx?id=30931&ei=hdD4VLq

zO8XdoASa6IHICg&usg=AFQjCNHjvx1yMWm98Rxagfd3ANNIcV_ioQ&sig2=IVuSIoNzXZn3C2ojDlPNxg&bvm=bv.87611401,d.cGU
3. IEEE802.3, Kolesar, *Loss Budgeting for 400GE Channels* http://www.ieee802.org/3/bs/public/14_05/kolesar_3bs_01_0514.pdf

10 Document Revision History

Table 4: Document Revision History

Revision	Date	Description
1.0	March 08, 2015	Initial Release