SUMMARY

Data center interconnect (DCI) has been one of the fastest growing use-cases for optical networking equipment with ACG Research reporting 63.5% optical DCI revenue growth in 2016 to $1.69 billion. DCI growth has attracted significant vendor investments resulting in optimized technology and solutions. Such solutions range from multi-slot chasses to small form factor (SFF) appliances ("pizza boxes") and in the case of Inphi, a 4.5 watt, QSFP28, fixed-wavelength, PAM4 direct detect, pluggable DWDM module with 80km reach.

In this paper we analyze the capital expenses, the operational expenses and the total cost of ownership (TCO) for ColorZ™ technology in sub-80km metro-distributed DCI applications over a five-year timeframe. We analyze both hyperscale and emerging data center use cases. In building an economic model with over 50 input variables, we leverage ACG Research's knowledge and experience in optical networking as well as information gathered from discussions with vendors and service providers alike.

The results of our economic analysis demonstrate that hyperscale data centers as well as emerging data centers can benefit from deployment of ColorZ technology with TCO savings from 67% to 58%, respectively. While ColorZ consistently demonstrates lower capital expenses, operational expenses are mixed depending upon DCI bandwidth and the need for leased fiber. As a result of our analysis, service providers with metro-distributed data centers less than 80km apart should consider ColorZ technology for their DCI deployments.

REPORT HIGHLIGHTS

- ColorZ reduces TCO by up to 67% for metro distributed hyperscale data centers versus alternative solutions.
- Emerging data centers with N x 100G interconnect bandwidth demands can also benefit from ColorZ metro deployments with 58-60% TCO savings.
- ColorZ low power consumption delivers up to 74% electricity savings over 5 years.
- Capex is the dominant contributor (vs. opex) to TCO in all scenarios including those with leased fiber.

INTRODUCTION

At the 2016 OFC Conference, Inphi announced its ColorZ technology, which delivers 100Gb/s, 100GHz, fixed dense wavelength division multiplexing (DWDM) in a 4.5 watt, QSFP28 pluggable package. Commensurate with that announcement was a public declaration by Microsoft[1] that they intended to augment their existing DCI toolkit - utilizing ColorZ technology to interconnect sub-80km metro-distributed data centers while continuing to use coherent DWDM technology for longer distances. Figure 1 maps ColorZ and the other DCI optical transmission technologies to their respective distances.

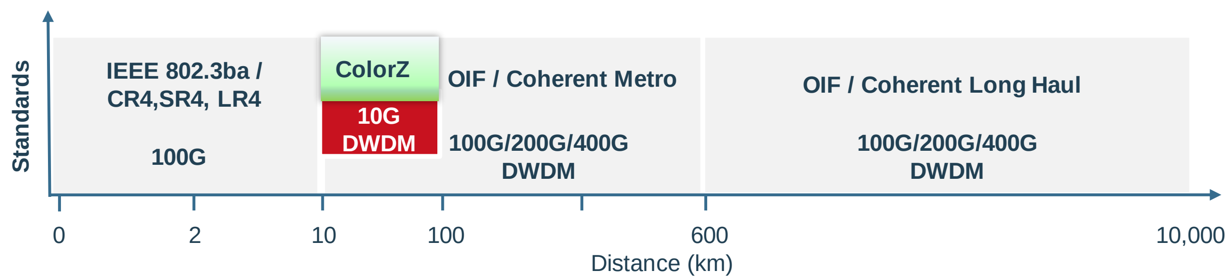

Figure 1. Data Center Interconnect Technology by Distance

As the 2017 OFC Conference approaches, Microsoft has concluded months of live field trials with the ColorZ technology and is preparing for commercial deployment in multiple cities.

In this analysis and report we answer two major questions:

- What are the economic advantages of deploying ColorZ technology to interconnect sub-80km hyperscale data centers such as Microsoft?
- Can smaller, emerging data center providers expect to see similar economic advantages to hyperscale providers if they utilize ColorZ technology in their sub-80km data center interconnections?

Figure 2. Inphi ColorZ QSFP28 Package

[1] Inphi Press Release, March 22, 2016

THE ADVENT OF THE METRO-DISTRIBUTED DATA CENTER

Initially, Internet content providers, cloud service providers and InterXchange providers deployed a small number of mega data centers in major North American markets (for example, NFL cities) and interconnected these data centers with long-haul DWDM transmission systems over fiber optics. Expansion into EMEA, APAC and LAC followed a similar pattern with mega data centers launched in major cities like London, Frankfurt, Shanghai, Sydney or Tokyo.

Because of a number of factors, data center deployment models are changing, and instead of a single mega data center in a geographic market, service providers are deploying multiple edge data centers. By moving data centers closer to the consumer and enterprise customers, latency can be reduced, application responsiveness increased and overall end-user experience improved. One company, EdgeConneX, is focused on making edge data centers a reality and launched “2016: The Year of the Edge” webinar in which the company cited multiple quantifiable examples of consumers clicking more, watching longer and churning less when latency and buffering times are reduced. Reduced latency does not just improve residential or enterprise services. The mobile industry is also embracing the movement of compute and storage resources closer to the edge of the network with the advent of mobile edge computing (MEC), seeking to improve responsiveness for mission-critical mobile applications. In addition to reduced latency, the deployment of multiple metro-distributed data centers increases the level of resiliency/redundancy in the network in the event of a catastrophic site failure. Service providers may also find it easier to acquire multiple smaller parcels of land versus one much larger one. Power can also be easier to obtain from utilities with smaller, more distributed power needs over multiple data center locations than a single mega data center with truly mega-power demands.

An increase in the number of data centers, the bandwidth to data centers and the bandwidth between data centers are all leading to strong growth in DCI solutions. ACG Research’s Optical DCI analysis found that demand for optical DCI solutions led to a 63.5% year-over-year increase in Optical DCI revenue in 2016 with $1.69 billion spend[2].

The Network Architecture

There are a number of ways one might interconnect metro-distributed data centers: optical ring, mesh, or hub-n-spoke architecture. For purposes of our analysis, we have assumed a point-to-point full mesh. A full mesh is simple but has the downside that the number of interconnections required scales as [N x (N-1)/2], where N is the number of data centers. As an example, three data centers require three interconnections; four data centers require six interconnections; and five data centers require 10. The scalability of a full mesh remains manageable as long as the number of data centers stays modest as in our case with three to five data centers per metropolitan serving area.

[2] 4Q16 ACG Optical DCI Market Report.

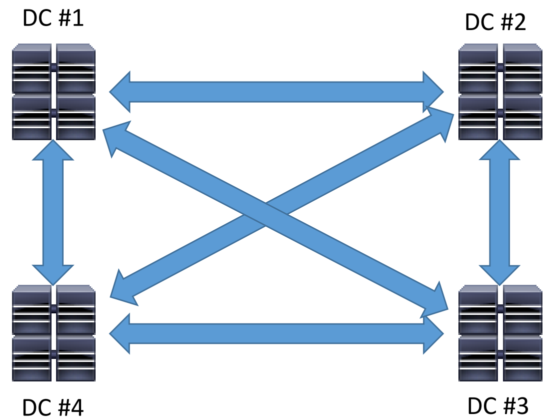

Figure 3. Data Center Interconnect Full-Mesh with Four Data Centers

Economic Measures Included in the Analysis

In this analysis, we developed an economic modeling tool with more than 50 input variables, including the number of data centers, initial inter-DC bandwidth, bandwidth growth rate, labor rates and electricity costs. The duration of the model is five years and the outputs include capital expense (capex), operation expense (opex) and TCO over that time. Two deployment scenarios are analyzed. One is based upon utilization of ColorZ modules plugged directly into data center spine switch ports, which are then connected to an open-line system (OLS) that includes MUX/DEMUX, pre-amplifier, booster amplifier and dispersion compensation for up to 40 ColorZ modules. The alternative solution is based upon the use of SFF optical appliances or “pizza boxes” with Nx100G DWDM coherent technology. Short-reach 100Gb/s grey optics are used to connect the spine switch ports to the SFF optical appliances. Multiple vendors supply SFF optical appliance products with more than 1 Tb/s of line-side capacity. There are variations in SFF product designs with some optical appliances taking a modular approach utilizing pluggable CFP2-ACO DWDM line-side optics with others taking a more integrated approach with onboard DSP and DWDM optics. Some vendors also support an integrated line system with the ability to combine and amplify wavelengths on the SFF appliance itself (sometimes referred to as superchannel support) in order to reduce the need for external OLS equipment in applications with shorter distances (e.g. <120km) and lower capacities (e.g. < 1Tb/s). We did not single out any one vendor’s product but instead selected leading attributes of the collective market in our analysis. We also based our modeling on product capabilities that were deemed commercially available in Q1-2017. We made every attempt to exclude roadmap features/capabilities and products that were not commercially available for deployment in live networks.

Cumulative Total Cost of Ownership

Total cost of ownership is the sum of capex and opex for a given solution. Both capex and opex have their own components and methods of calculation. Cumulative TCO sums TCO components over a period of time. In this analysis, we considered the TCO over five years.

Capital Expenditures

Capex is the cost of purchasing the elements for a DCI solution. In our analysis, we include the cost of the ColorZ module or SFF appliance as well as any OLS components such as MUX/DEMUX and amplifiers needed. In the case of ColorZ, the cost of dispersion compensation as well as pre-amplifier and booster amplifiers is included. We used market-based pricing per element in our capex costs. We assume that capital for an equipment purchase is counted in totality at the time of purchase (did not consider capital depreciation as an example). Incremental equipment is purchased throughout the five-year TCO analysis as needed to support the growing bandwidth demands.

Operational Expenditures

Opex includes the costs of deploying and running the solution. In this analysis, we focused on the foot-print or rack space occupancy costs of the solution, EF&I (engineer, furnish and install) labor costs and electrical power utilization over the analysis period. Every component of a deployed solution is assigned rack space costs, EF&I labor costs and power utilization costs. We purposefully left out any recurring software maintenance or support fees for the solutions as these can differ considerably amongst service providers and vendors. We also included a monthly per fiber-pair lease rate as an input variable in the tool to calculate the recurring cost of leased fiber – which is one of the four scenarios in this document.

DATA CENTER RESULTS

The following section discusses the results of our analysis. We examine two hyperscale data center scenarios and two emerging data center scenarios.

Scenario #1: Hyperscale Data Center with Owned Fiber

In this scenario, we consider four hyperscale data centers in a point-to-point full-mesh configuration with owned fiber. The significant input variables impacting the analysis are outlined in Table 1.

Scenario #1 Hyperscale Data Center	Input Variables
Initial DCI Bandwidth (per connection)	8 Tb/s
Number of Data Centers	4
DCI Bandwidth Growth (annual)	40%
Labor per Port ColorZ (hours)	1.5x Coherent
ColorZ Power (watts)	4.5
SFF Appliance Power per Port (watts)	45.0
Leased Fiber	No

Table 1. Scenario #1 Input Variables

Cumulative TCO and Capex

Because the bandwidth in this scenario is so high at 8 Tb/s, the TCO analysis is dominated by equipment purchases or the overall capex (versus opex) investment. Market price for ColorZ pluggable modules are estimated to be 75% less than coherent DWDM solutions on a per port basis. ColorZ lower price dominates the results of this scenario with ColorZ requiring 71% less capex and delivering 67% TCO savings. Both ColorZ and SFF appliance solutions require MUX/DEMUX hardware to combine/separate multiple wavelengths onto the fibers. The SFF appliance configuration also assumes the inclusion of a single amplifier per fiber pair. Although the ColorZ solution requires additional hardware with pre-amplifier, booster amplifier and dispersion compensation modules per fiber pair, the additional cost of the extra OLS equipment for ColorZ does not significantly alter capex and the impact of the per-port pricing differential between ColorZ and coherent SFF appliances.

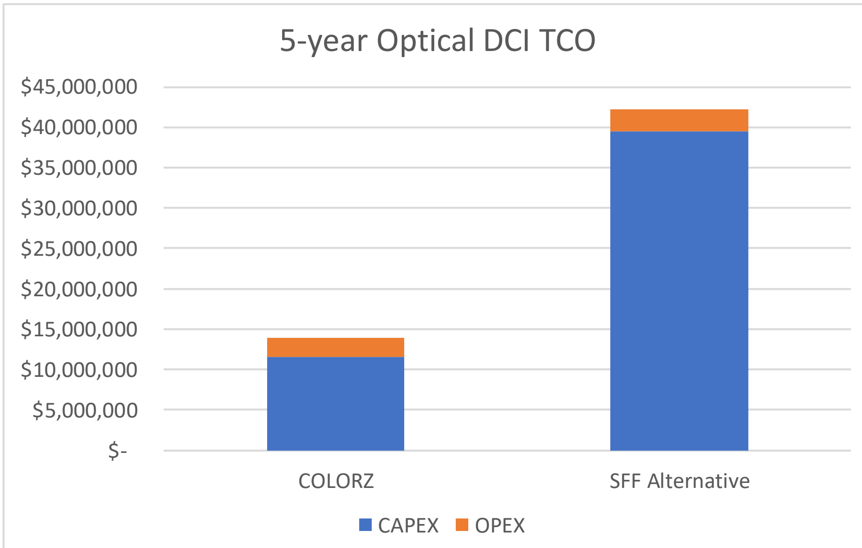

Figure 4. Cumulative TCO Hyperscale with Owned Fiber

Opex Comparison and Analysis

The opex differential between the two solutions is muted compared to capex with ColorZ providing a modest 15% total opex savings. The 74% power savings of the ColorZ solution is offset by 24% higher EF&I cost, which is a direct result of more equipment being deployed due to the lower spectral efficiency (4Tb/s per fiber) of the ColorZ solution as well as the need for pre-amplifier, booster amplifier and dispersion compensation deployments. The use of fixed wavelength modules with ColorZ also results in higher labor costs (used 1.5x that of the coherent SFF appliances in the model) vs. tunable solutions. Fixed wavelength modules increase the amount of deployment coordination required where as an example, 40 wavelengths multiplexed onto a single fiber utilize 40 different fixed modules (one per wavelength) with a mated module required on each end of the connection. In contrast, 96 wavelengths utilizing common infrastructure and tunable hardware with the coherent SFF appliance solutions requires less physical coordination with wavelength assignments and modulation parameters provisioned and modified remotely.

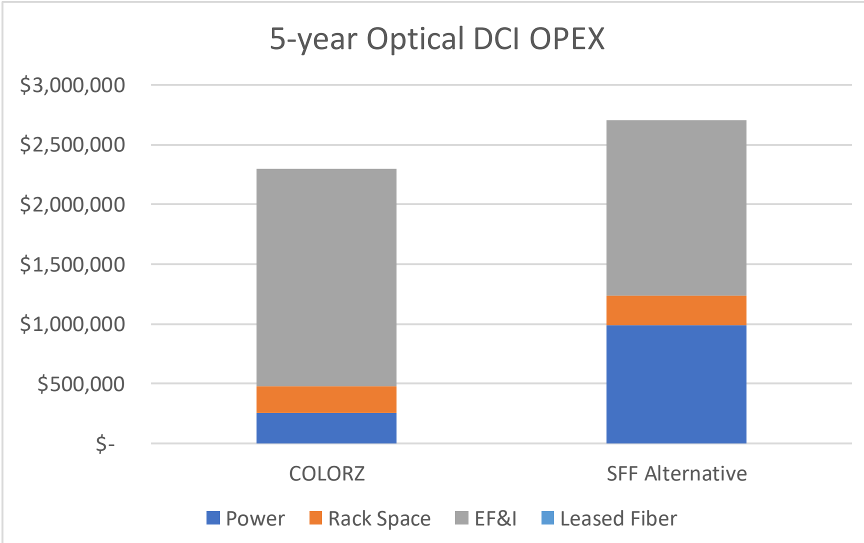

Figure 5. Cumulative TCO Hyperscale with Owned Fiber

Scenario #2: Hyperscale Data Center with Leased Fiber

Once again four data centers are mesh connected, but in this scenario, the service provider leases fiber in the metro area from a 3rd party. While many DCI deployment are not fiber constrained and spectral efficiency is not a top deployment priority, it is important to consider scenarios where leasing costs impact opex and TCO. With the exception of leasing the fiber, the relevant input variables remain the same as outlined in Table 1. Although fiber lease rates can vary widely in different metropolitan areas or countries, we selected $2,000 per month as a typical rate per fiber pair for this analysis. This rate was selected after multiple conversations with service providers and an assumption that we are operating in the 40–80km range. Monthly fiber lease rate is one of the 50 input variables in the model to accommodate the unique situation and lease rate of any particular service provider.

Cumulative TCO

Leasing fiber does not impact capex. Leasing fiber does have a direct impact on TCO by increasing total opex. The ColorZ solution achieves 60% TCO savings versus the SFF optical appliance alternative.

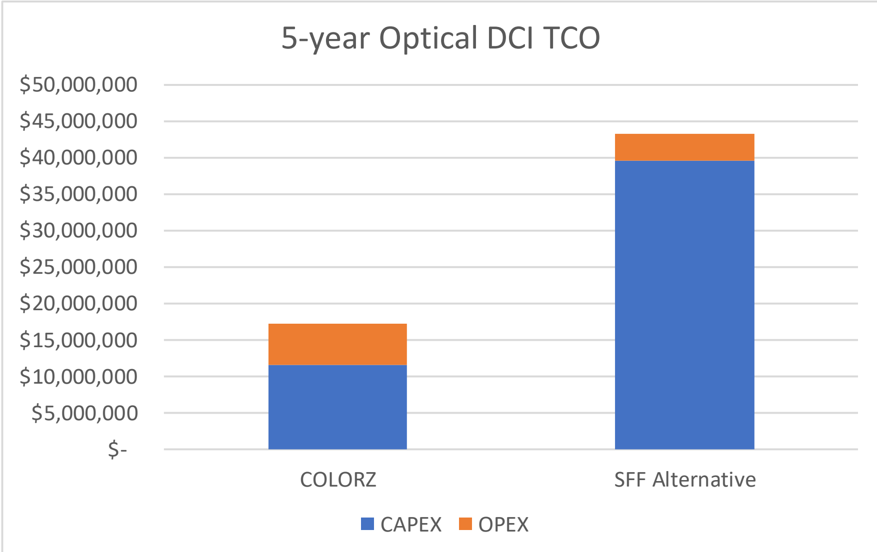

Figure 6. Cumulative TCO Hyperscale with Leased Fiber

Opex Comparison and Analysis

In Scenario #2 we see the impact of coherent DWDM's higher spectral efficiency where a fiber can carry 96 wavelengths at 200Gb/s (16QAM) with 50GHz channel spacing or a transmission capacity of 19.2Tb/s per fiber versus 4Tb/s (40 wavelengths each at 100Gb/s in 100GHz channels) for the ColorZ solution. The 51% higher ColorZ opex is a direct result of ColorZ requiring eight fiber pairs per data center interconnect in year 5; while the SFF appliance solution requires two fiber pairs. More fiber pairs result in higher leasing costs and opex as visible in Figure 7.

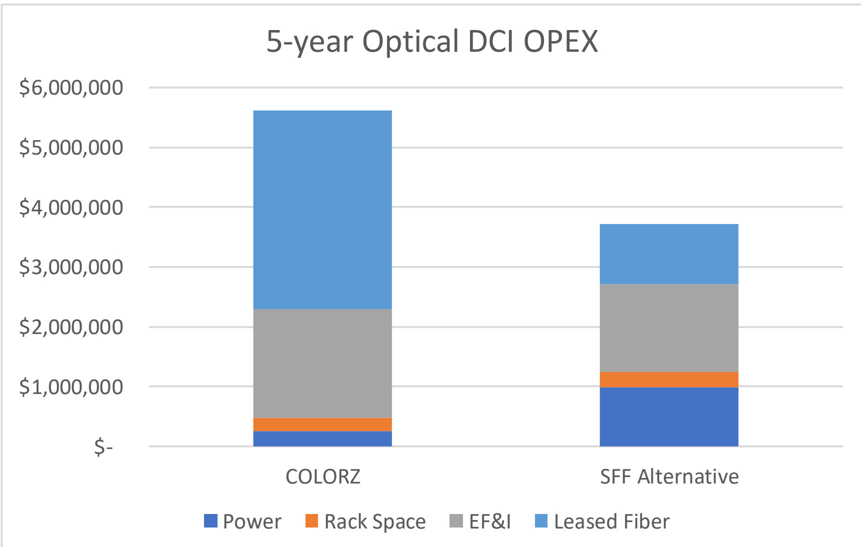

Figure 7. Cumulative Opex Hyperscale with Leased Fiber

Scenario #3: Emerging Data Center

Now that we have analyzed hyperscale DCI deployments, we shift our focus toward emerging data centers with smaller (at least initially) DCI bandwidth demands. We assume that individual capex costs are 35% higher (true for ColorZ and SFF alternative) in the emerging data center scenarios to reflect lower volume and reduced purchasing power versus hyperscale data centers and service providers.

In this scenario, the input variables are outlined in Table 2 where we see the initial DCI bandwidth at 400Gb/s vs. 8Tb/s utilized in the hyperscale scenarios. The SFF appliance solution requires external MUX/DEMUX and an amplifier throughout the deployment lifecycle. ColorZ also requires MUX/DEMUX as well as pre-amplifier, booster amplifier and dispersion compensation modules. We also assume both line systems provide similar network management capabilities (e.g. optical supervisory channel, surveillance & monitoring).

Scenario #3 Emerging Data Center	Input Variables
Initial DCI Bandwidth (per connection)	400 Gb/s
Number of Data Centers	4
DCI Bandwidth Growth (annual)	40%
Labor per Port ColorZ (hours)	1.5x Coherent
ColorZ Power (watts)	4.5
SFF Appliance Power per Port (watts)	45.0
Superchannel (Integrated MUX & AMP)	No

Table 2. Scenario #3 Input Variables, Emerging Data Center

Cumulative TCO and Capex

In this scenario, ColorZ delivers 64% capex savings and 60% TCO savings over the five-year analysis. ColorZ capex savings is reduced from 71% in scenario #1 due to the inefficiencies of deployments with smaller bandwidths. First, the external OLS equipment is underutilized as the DCI bandwidth is relatively low compared to the hyperscale scenarios. ColorZ requires more OLS equipment (two amplifiers and dispersion compensation module) than the SFF appliance solutions. The OLS inefficiency is reflected in 35% of ColorZ capex going to OLS equipment in this emerging data center scenario vs. 20% of capex in the hyperscale scenarios. Another force in reducing ColorZ capex savings in emerging data center scenarios is the cost of sparing. Throughout all the scenarios, we target a 10% sparing ratio (also an input variable in the model). This means that for every 10 unique equipment items purchased for deployment, an additional one is purchased as a spare for use in the event of damage or failure. However, the ColorZ fixed wavelength solution results in the need to stock a spare module per each wavelength utilized. In emerging data center scenarios with low bandwidth, this means one must purchase a spare module for each wavelength utilized even if the wavelength is only used once (or less than 10 times). The result is higher than 10% sparing costs. In this scenario, sparing is 14% of ColorZ capex vs. 10% in the hyperscale scenario where the volume enables one to truly spare individual equipment items at a 10% ratio.

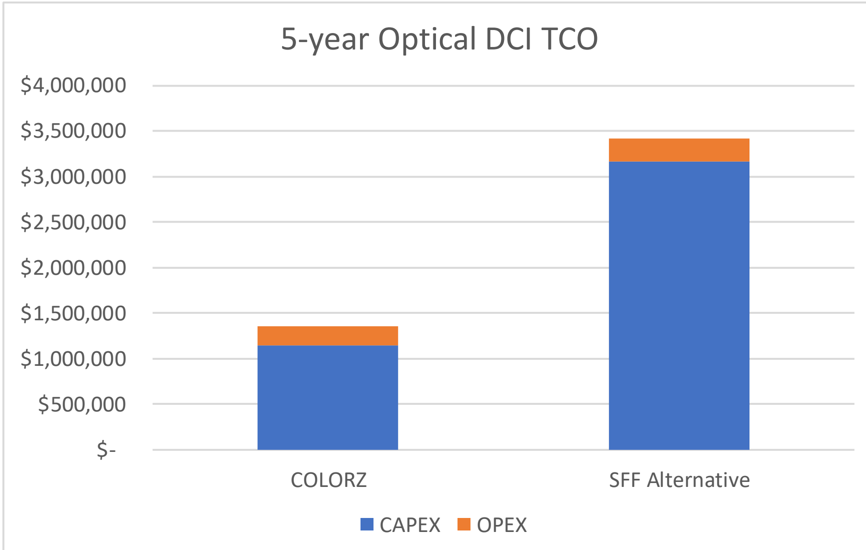

Figure 8. Cumulative TCO Emerging Data Center

Opex Comparison and Analysis

ColorZ delivers a modest 17% opex savings in this emerging data center scenario. ColorZ 47% power savings is partially offset by 9% higher labor cost associate with EF&I for the equipment turn up. By contrast, the hyperscale data center scenario #1 demonstrated 15% opex savings.

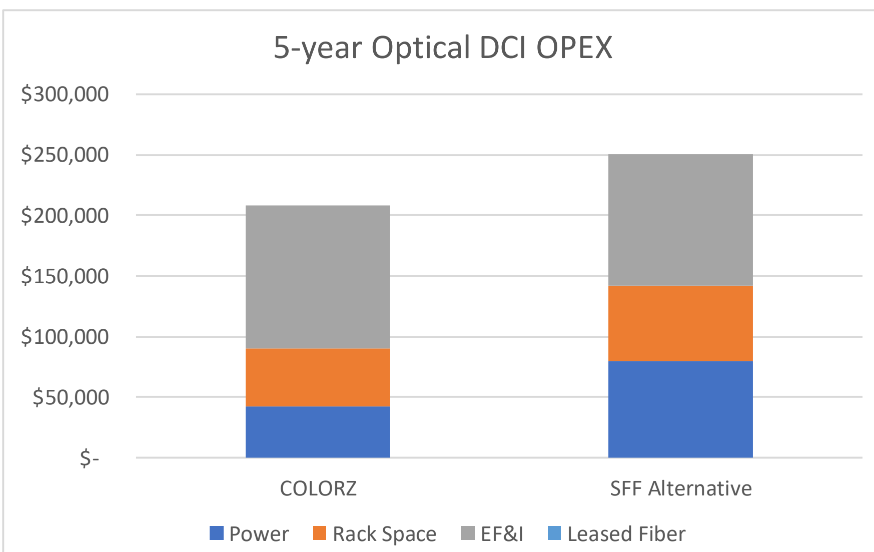

Figure 9. Cumulative Opex Emerging Data Center

Scenario #4: Emerging Data Center, Superchannel Support (Integrated Line System)

The final deployment scenario is similar to Scenario #3, but the SFF appliance solution is assumed to contain integrated multiplexing and amplification (e.g. up to 120km range) capabilities - thus deferring the deployment of external OLS equipment (MUX/DEMUX and amplifier) until the total DCI bandwidth exceeds the capacity of a single SFF appliance.

Cumulative TCO and Capex

With this scenario, OLS equipment for the SFF appliance solution is deferred until year 5 when the total DCI bandwidth demand (>1.5 Tb/s) exceeds that of a single SFF appliance. ColorZ delivers 63% capex savings and 58% TCO savings, respectively. If total DCI bandwidth is kept below the capacity of the SFF appliance with superchannel support throughout the 5-year deployment (e.g. initial bandwidth is 300Gb/s), ColorZ capex and TCO savings are reduced to 53% and 47%, respectively.

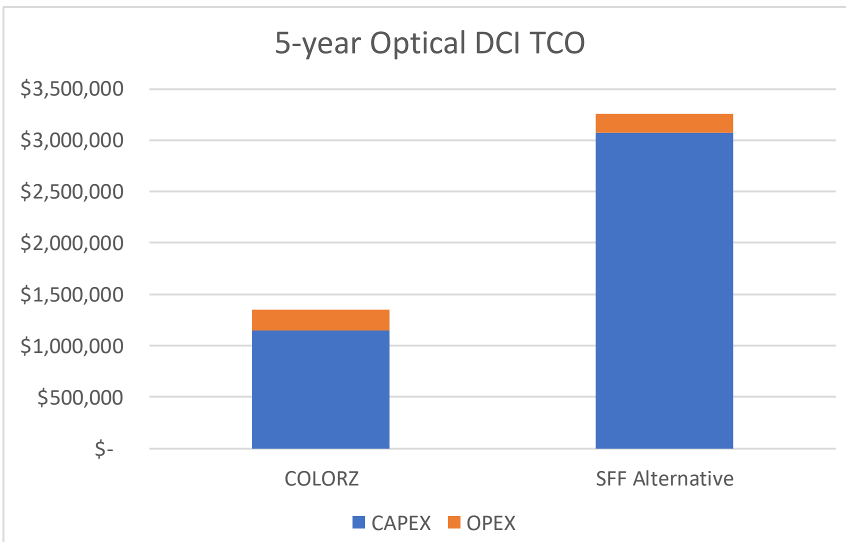

Figure 10. Cumulative TCO Emerging Data Center with SFF Superchannel (Integrated Line System)

Opex Comparison and Analysis

Because the ColorZ solution requires additional OLS equipment from the first year of deployment and the fixed-wavelength, labor-per-port is 1.5 times that of the SFF appliance solution, the SFF appliance opex is 14% lower than that of the ColorZ solution. The SFF appliance solution deploys less OLS equipment and it does so only in the fifth year - thus saving rack space and power consumption for four of the five years of deployment. The ColorZ solution delivers 27% overall lower power, but some of that savings is offset by ColorZ higher rack space occupancy and EF&I labor costs. Spectral efficiency is a nonissue in this scenario as the total bandwidth per data center interconnect remains below the fiber capacity of either solution for the five years of the analysis.

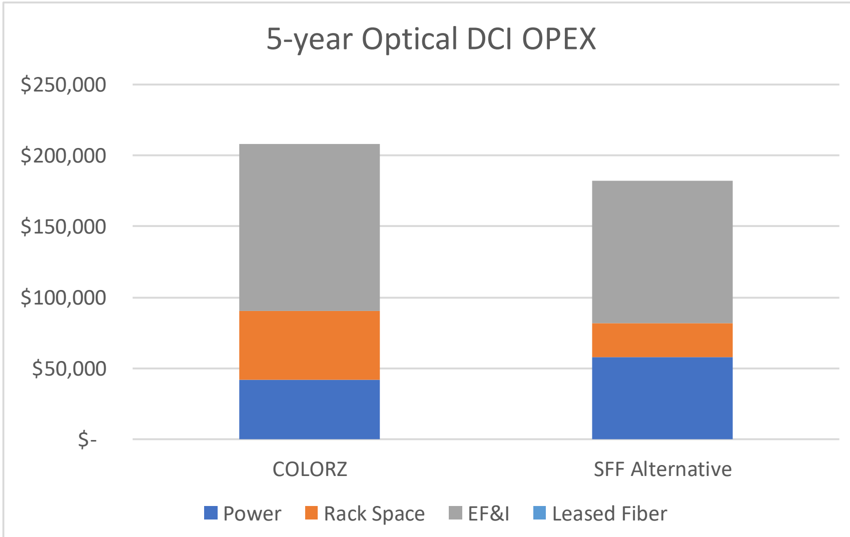

Figure 11. Cumulative Opex Emerging Data Center with SFF Superchannel (Integrated Line System)

OTHER CONSIDERATIONS

It is important to point out some additional considerations to assist data center service providers in making an informed data center interconnect solution decision.

- We did not include the cost of operationalizing or integrating ColorZ into the service provider OSS/BSS. There are ColorZ Simple Network Management Protocol (SNMP) Management Information Bases (MIBs) that need to be read/written. Although we believe this integration work to be modest, each operator will need to take this into consideration when making an informed data center interconnect decision.

- We did not include the cost of annual software maintenance fees for either solution. These can vary significantly among service providers and vendors, and we did not want software maintenance to distort the analysis.

- With fixed wavelengths, ColorZ is a more static approach to optical networking. Those pursuing transport software defined networking and dynamic optical underlay strategies will not further advance those goals with a fixed wavelength deployment model.

- If metro-distributed data center interconnect distances exceed 80km, then coherent DWDM optical technology will need to be used. As new data centers are added to a metropolitan area, then a mixed ColorZ and coherent DWDM deployment model may be needed to cover the entire metro-distributed network.

CONCLUSION

DCI is one of the fastest growing use-cases for DWDM optical equipment. The move toward metro-distributed data centers has created an opportunity for cost optimized solutions that can operate in the sub-80km range. In this paper we analyzed capex, opex and TCO for ColorZ QSFP28, PAM4 pluggable technology and compared the results with alternative SFF appliance solutions. We analyzed both hyperscale and emerging data center use-cases as we answered two key questions.

- What are the economic advantages of deploying ColorZ technology to interconnect sub-80km hyperscale data centers such as Microsoft?
- Can smaller, emerging data center providers expect to see similar economic advantages to hyperscale providers if they utilize ColorZ technology in their sub-80km data center interconnections?

The results of our analysis indicate that sub-80km hyperscale data center deployments can enjoy 60% to 67% TCO savings. Emerging data center providers can also benefit from deployment of ColorZ technology with 58 to 60% TCO savings over a similar five-year analysis period. Service providers that are evolving from 10G metro DWDM DCI solutions or are moving toward a metro-distributed data center deployment model will want to consider adding ColorZ technology in their DCI networking toolkit.

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