Photonic Switching Applications in Data Centers & Cloud Computing Networks
INTRODUCTION

In data centers and networks, video and cloud computing are driving an explosion in network growth and server deployments. According to Bernstein Research (1), between 2009 and 2010 for example, the large mega data centers (Google, Amazon, Apple, Microsoft, Amazon, etc.) experienced a 100% growth in server spending. This growth in server capacity and server numbers is in turn driving tremendous expansion and complexity in data centers, resulting in networking bottlenecks and performance degradation. The overall result is that the performance of new and expensive server resources is being constrained by the traditional data center network architectures and networking equipment. Photonic switching can be deployed within and between data centers to improve performance and to scale to support this rapid growth so that the full value of new server resources can be realized.

Cloud computing has delivered us into the age of the mega-data-center – huge facilities with literally hundreds of thousands of square feet of computing real estate. In these huge data centers the physical and virtual resources and the data flows are becoming extremely complex, almost too complex for humans to negotiate. Network intelligence to analyze and optimize the flows in these large networks is becoming necessary. To this end, photonic switching enables a fully-automated, dynamically reconfigurable, highly-scalable physical layer which can respond to reconfiguration requests on demand.

This paper discusses high-level examples of photonic switching applications and benefits in data centers and cloud computing networks.

INTRA-DATA CENTER APPLICATIONS

Current Intra-Data Center Challenges

Figure 1 depicts a typical multi-layered data center architecture. On the lower level are top-of-rack switches, and below those are banks of servers. The top-of-rack switches are interconnected to an intermediate cluster aggregation layer, and then to a data center aggregation layer at the top, which then connects in to the metro or wide area networks.
The combination of the server growth together with the very complex computational tasks required in modern computing applications means that the needed bandwidth within the data center is increasing two to four times per year. Additionally up to 75% of that bandwidth is actually within the data center running east-west between clusters. Furthermore, the top-of-rack interfaces at the server aggregation layer are rapidly scaling to 10 Gbit/s, 40 Gbit/s, and potentially even to 100 Gbit/s. These factors place tremendous demands on the cluster aggregation layer that has limited ability to scale to support this growth as shown in Figure 2.
This layer of the network is experiencing increased latencies because it has fixed-topologies that are not future-proof. It’s also expensive and labor-intensive to upgrade, and overall it’s not matching pace with the growth and enhancements in servers. Data Center operators typically must plan to upgrade or replace this part of the network frequently and this is unrealistic from a cost perspective. The net result is that the investment in new server resources is not effectively utilized because of performance limitations in the network.

**Emerging Data Center Trends**

To address these concerns, new trends have emerged to facilitate flattening and convergence as shown in Figure 3.

![Figure 3: Data Center Convergence Trends](image)

The first trend is that the servers themselves are getting much more powerful. Multiple blade servers within each rack are common and multiple racks connecting up to top-of-rack switches are becoming the norm. The second trend is that the traditional top-of-rack functionality is actually moving in to the servers themselves. Third, and most importantly, the cluster aggregation layer is converging into the top-of-rack switches. Overall this represents a flattening and simplification of the network architecture. But in order to maximize this simplification, a connection infrastructure that is both low in latency and scalable is needed.

Photonic switching (as depicted in Figure 4) can provide the needed connection infrastructure. Deploying a photonic switching fabric enables a solution that allows every top-of-rack switch to connect directly to any other top-of-rack switch within its cluster or neighboring clusters. It also allows direct optical pass through from top-of-rack switches to the data center aggregation layer. This results in simplification of the network and extremely high-performance low-latency connections between servers.
and switches. This is a powerful solution to the connectivity required to enable cloud computing networks.

![Figure 4: Flat DC Architecture with Photonic Switching Fabric](image)

Furthermore, because this photonic switching layer is transparent to protocols and line speed, it future-proofs the data center network by supporting scaling from 10 to 40 to 100 Gbit/s and potentially beyond without having to replace the network.

**Why Photonic Switching Is Necessary**

The question inevitably arises – this could be done with large numbers of direct fiber connections between top of rack switches and between top of racks and the data center aggregation layer. So why is photonic switching necessary?

Firstly, we previously noted the high level of growth in size and complexity of data centers and the need to reduce human intervention. Photonic switching supports complete automation of single-mode fiber management within the data center. This means that the entire physical network northbound from top of rack switches can be automated. Any connectivity changes can be made on-demand without a technician having to visit the site.

Secondly, the racks and clusters within the data center can be reconfigured either on demand or cyclically to support real-time resource and bandwidth demands. In the following section example use-cases are noted.
Example Intra-Data Center Use Cases

Photonic switching allows the whole physical network within a large data center to be dynamically reconfigured based on a number of different factors. These factors could include instantaneous demand, cyclical patterns throughout a day or a month, or potentially even predictive network traffic algorithms that can predict when specific resources need to be switched around within the data center. This has not been possible in previous data center networks as all physical reconfiguration has required hands-on human intervention at the patch panel.

The dynamic reconfiguration capabilities of photonic switching also enable a range of disaster recovery responses that are not typically available in a manually switched physical network. Example use-cases include: (Please refer to Figure 5 for a basis for understanding use-case examples)

Scheduled Maintenance – the ability to take racks and clusters out of service for maintenance while simultaneously bringing online backup maintenance racks.

Adding Floating Resources – Racks of servers can be added to and removed from clusters to support application demands. These could be based on instantaneous demand or cyclical / time-of-day needs.

Flow-Based Network Flattening – Any Top of Rack switch in any cluster can be directly connected to any other Top of Rack in any other cluster to support application needs. This results in the lowest possible latency and the flattest network.

Reallocation of Inter-Data Center bandwidth between clusters – Optical bandwidth exiting the Data Center can be reallocated internally between clusters to support instantaneous or time-of-day application demands. One example is the typical morning load on email applications where more bandwidth is required temporarily on clusters supporting these applications.

Integrated Photonic-Routing Control Plane

The use cases above facilitate very effective utilization of expensive equipment and bandwidth resources within large data centers. However in order to realize the full benefits, a new integrated photonic-routing control plane is needed. This is depicted in the upper right hand quadrant of Figure 5.
Figure 5: Data Center Photonic Switching Example showing Control Plane

Without a centralized cluster aggregation layer there is no simple way to share the forwarding and routing information between clusters meshed together without paying a penalty on convergence time. The control plane solves this problem by federating the collection and distribution of this information via the management control ports on the TORs. Similarly, a separate control plane would require managing multiple photonic switches connected in clos-architecture for large multi-switch fabrics. Therefore, combining photonic control for the optical switch, together with routing control for the TORs, considerably simplifies the control plane for the end-to-end solution. This would also serve as the interface to the management plane that could provide inter-operability with other parts of the network and business operations systems. The actual implementation of the integrated control plane will vary depending on the specific vendor’s networking products and in most cases will require some collaborative development.

INTER-DATA CENTER APPLICATIONS

We now turn our attention to the potential applications for photonic switching between data centers where the potential value add is maximizing the performance of cloud computing.

Network Resource Optimization

The primary application is resource optimization – the capability to reconfigure resources and to support dynamic network optimization between data centers depending on various network traffic demands.

For example, in a content distribution network (CDN) it may be necessary to need to open up more bandwidth to a certain data center at a specific time of day. Photonic switching gives the capability to do this without having to rely on a network operator.
Let’s review a simple example of this. Figure 6 depicts a network of data centers connected via a MAN or WAN network. The network between the data centers is owned by a service provider with capacity leased by the data center operator.

Under normal loads, traffic passes between all the different nodes of the data centers. This is shown for the Headquarters data center and the remote data centers 1 and 2 with the red, green, and purple traffic paths.

On demand or at a specific time of day, the headquarters data center needs to move a lot more data than usual to data center 2 on the lower left, and this maybe something that is needed for a couple of minutes or an hour or several hours – it is up to the data center operator to determine the duration.

If the data center operator owned the MAN/WAN optical network and if this network consisted of flexible multi-degree ROADMs (Reconfigurable Optical Add Drop Multiplexers) it would be quite realistic to reconfigure the bandwidth as required. However this is typically not the case – in most instances changing the capacity assignment on a service provider’s optical network requires a service order, a scheduled service window, and for the change to stay in place for weeks or months – not hours or minutes, and not cyclically or on-demand.

This is where deploying photonic switches at the edges of the data centers can achieve a similar outcome, without the need to re-arrange the service provider’s network. It gives the data center operator the means to actually reconfigure that capacity themselves.

Photonic switching offers a potential solution in this particular example where we want to get more bandwidth from headquarters to data center two for a short period. This is shown in Figure 7.
Figure 7: Bandwidth Reallocation with Photonic Switching

In this solution a portion of the red bandwidth between HQ and DC1 is looped to pass-through in the photonic switch at DC1. Similarly this pass-through traffic is allocated to a portion of the green path between DC2 and DC3. Capacity has been removed between HQ and DC1, and DC1 and DC2. At the same time an additional purple path has been established between HQ and DC2 providing the additional on-demand bandwidth needed. All of this has been accomplished without any changes on the service provider’s optical network.

This solution can be applied to any of the paths within this multi-data center architecture. This gives a data center operator tremendous flexibility to scale the bandwidth and resources between sites to support different loads on the network in geographically dispersed time zones. It also provides extremely low-latency transit between the data centers.

OTHER BENEFITS OF PHOTONIC SWITCHING IN DATA CENTER APPLICATIONS

Fiber Management & Monitoring

From a management and monitoring perspective, photonic switching adds considerable value to cloud networks.

Firstly, it provides automated local and remote fiber management. Technicians are rarely needed so many data center facilities can be left completely unmanned and operated remotely. The fiber network can be reconfigured remotely as needed.

Secondly, the inbuilt optical power monitoring that CALIENT deploys in all photonic switching systems to optimize path losses can also monitor the health of optical networks within and between the data centers very simply. This provides a very rapid response to a number of failure scenarios including bad connectors, patch cords, and other network equipment.
Lastly, from a disaster recovery perspective, photonic switching offers many switchover and recovery options. For example, the ability to recover from a storage, server, or edge router outage - situations that may be beyond the scope of a simple fiber optic failure and potentially require a coordinated recovery of multiple optical paths. The Photonic Switch provides an optical network fabric that can make coordinated changes across the data center or cloud network in the event of a failure situation.

**Energy Efficiency Benefits**

Data center power consumption is a major challenge, especially with the growth of huge mega data centers and the growth of 10 Gbit/s, 40 Gbit/s, and 100 Gbit/s network deployments. The problem is twofold – the cost and reticulation of the power itself and, secondly, the management of the thermal energy dissipated within the buildings.

The energy consumption of an all-optical switch versus a pure electrical switch or a hybrid optical electrical optical switch is at least in order of magnitude, different. This means that deploying a pure photonic switching fabric can result in significantly lower energy consumption within a large data center, and therefore, sizeable cost savings in power consumption.

**CONCLUSIONS**

Cloud-based video and rich media are driving rapid growth in data center server deployments and the networks they use to transport data. This phenomenon is apparent within the data centers themselves, and also in the networks between data centers which form the basis for cloud computing.

Photonic switching offers significant benefits in these applications.

- It provides scalable and future-proof networking within and between data centers. The photonic switch network is inherently scalable from 1 or 10 Gbit/s to 40 or 100 Gbit/s and beyond
- It facilitates dynamic reconfiguration of data center resources to support maintenance, capacity increments, real time or cyclical demand spikes, reallocation of bandwidth for time of day loads, etc.
- It maximizes cloud performance by reallocating resources between data centers on demand or based on cyclical patterns.
- It offers reduced network power cost due to the inherently low power consumption of pure photonic switching.
- It supports automated fiber management & monitoring, providing low-cost resources to assist data center operators with fault isolation and restoration within and between data centers.
ABOUT CALIENT TECHNOLOGIES

Founded in 1999, CALIENT Technologies is headquartered in Santa Barbara, California. As the global leader in Adaptive Photonic Switching, CALIENT provides systems that build service providers, cloud computing, content delivery and government networks for today's content explosion. CALIENT’s 3D MEMS switches have demonstrated years of reliability, with eight years of successful continuous operation at large companies in diverse markets. With more than 80,000 optical terminations shipped, CALIENT has one of the largest installed bases of photonic switches worldwide. The company designs and fabricates its systems using the state of art MEMS equipment in its own fabrication facility located at its corporate headquarters.

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