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Comparative Study of Modern Optical Data Centers Design

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ABSTRACT

The demand of higher bandwidth is increasing with exponential rise in number of users supported by service providers. In a typical data center, the demand is even more intensified as the number of supported users is humungous. A data center is a collection of servers which are connected in a Top-of-Rack (ToR) configuration. Currently, majority of data centers rely heavily on electronic packet switching technology. The traditional data centers currently employ electronic circuit and switches. Due to slower connections and electronic limitations, these data centers are facing bottleneck problems, in case of high bursts and peak traffic. Thus, a shift is required towards fiber optic technology solutions. The fiber is currently employed in the backbone network, and switching is still performed with electrical components with electrical to optical conversions (E/O) and vice-versa. Researchers thus, proposed the use of hybrid technology supported by both optical and electrical components in switch designs leading to design of Optical Circuit Switching (OCS) and Optical Packet Switching (OPS) as communication mechanisms that can cater to the above need. The limitations of unavailability of Tunable Wavelength Converters (TWCs) and Optical RAM are making the realization and fabrication of an all optical data center difficult. The paper discusses the evaluation of optical data centers over the period of time. This paper reviews both well established and up-coming data centers design which can be considered as near future designs.

Keywords: *Optical Data Centers, OCS, OPS.*

1. INTRODUCTION

Data centers are physical or vital infrastructure used by companies for computers, servers, network devices and IT elements, which generally involve storing, processing and serving large quantities of critical information to customers in a client / server environment [1]. In today's modern era, most data center services are publically available for free, thereby datacenter operators face a major issue of meeting exponentially increasing network bandwidth requirements without an unnecessary rise in energy and infrastructure costs [2][3][4]. A data center currently typically involves tens of thousands of servers forming a massively parallel super-computing infrastructure. Fiber optic technology can play an important part in improving the operations of the data center. In data centers, wavelength routing feasibility relies primarily on wavelength tuning equipment that is omnipresent in the architecture of the wavelength-routing network (WRON). TWCs also enable dynamic routing of optical signals in WRON and cater the demands for tuning variety, velocity, wavelength stability and electronic control. OPS provide many advantages over their electronic counterparts, but a large bottleneck is the lack of optical RAMs. Millions of packets can be stored in electronic RAMs for longer duration, but some hundreds of packets can be stored in fiber delay lines (for temporary optical switching storage) for very short durations. Therefore, a lossless system requires an effective design of the optical switch. Using optical fiber in backbone networks has increased information propagation speed, and huge fiber bandwidth promotes big numbers of channels moving in parallel with WDM technology [5]. It will take much longer, however, before all-optical information centers can be deployed.

In the coming years, therefore, there is a motivation for a paradigm shift towards a hybrid technology that utilizes both electronic and optical technology for effective use in data centers [6][7]. Because internet traffic doubles in every 18 months, and server inputs and outputs double in every 2 years, very fast technological innovations are desirable at a fast rate to satisfy such growing demands. For example, a data center with 50,000 + servers, each fitted with a transfer speed of 40 Gb / s, would need an inner network with a complete transmission capability of 2 Petabits / sec to support complete bandwidth communication between each server. While the innovation on the software [8][9][10] and machinery [11][12][13][14][15] side is obviously exceptional, the scalability is a key issue while considering the current switching and optical interconnects. This motivates research and innovation towards recognizing proper scaling parameters and costing of the switch. Thus an optimal trade-off is required to maintain scalability of users, while at the same time minimizing the computation and communication costs in switches.

In a typical data center, multiplexed parallel servers are required in crosswise de-sign to support various heterogeneous applications and services. The incremental

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expense of scaling the network would involve an adaptability of fine-tuning optical interconnects that must generally scale with high quantities of server installations. An individual rack-house of a data center contains several servers and is associated with a ToR switch through copper connections. The ToR switches further connects to core switch layers through an optical transceiver [16]. To develop the bigger scale net-works, every ToR switch would associate with all accessible core switches. Figure 2(a) denotes the traditional data center design while Figure 2(b) focuses on recent emerging designs.

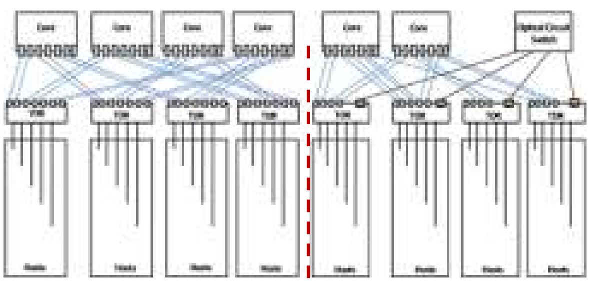

Fig. 1. (a) Traditional Switch Designs **(b) Emerging Switch Designs**

The remainder of the paper is organized into four sections. Section 2 of the paper presents the challenges in data centers. Section 3 of the paper presents comparison of some designs in optical data centers. Finally, section 4 provides the desired conclusions and future research directions.

2. CHALLENGES IN DATA CENTERS

A data center network requires arrangements of components, deployments and optimizing the optics. As indicated in Figure 3, today's network runs on electronics over a 1 Gigabyte Ethernet (GBE). Considering 40 links, the ToR switches connect to server with maximum capacity of 40GB. They further connect to core switches to provide 10 GBE non-blocking connectivity, which may be further aggregated using Dense WDM which multiplexes the above network 4-10 times from the current specifications. Motivated by the above, we point out the major challenges related to data center architectures. The core routers connect data center with the help of internet at the highest level.

The cost and performance of data center systems depends on the distance along with the hierarchy. In addition, spare capacity is over-provided per individual service throughout the data center so that each service can scale out to neighboring servers to react quickly to spikes in demand or failures. Due to this, each service are provided by nearby servers for rapid response but it could lead the adverse effect when the demand of resources increases [27].There are various challenges in hierarchical data center system which are discussed below.

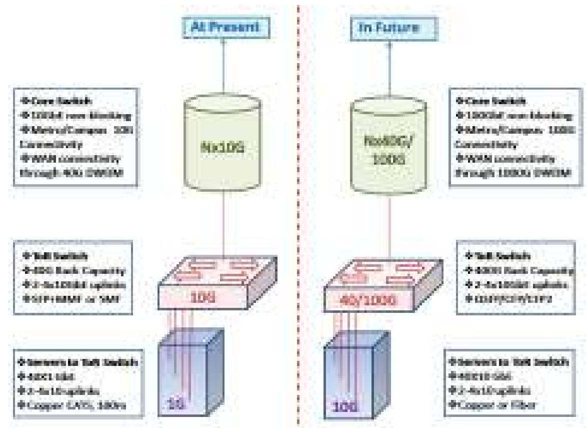

Fig. 2. Technological challenges: At Present and In Future

1. *SCALABILITY*

The hierarchical data center scheme is unable to sustain network traffic's fast development. The Next Generation Data Centers (NGDCs) should allow assistance for millions of microprocessor cores due to the static development in the processing power of multi core servers and the ongoing development of network traffic.

2. *ENERGY EFFICIENCY*

In the deployment of data centers systems power consumption is one of the major challenging issue. The network elements like electronic links, switches are power-hungry. So, in this case, if the power consumption of network elements is saved then it makes a good impact on the overall consumption of data center sites.

3. *SPACE MANAGEMENT*

The data center communicates with millions of server cores, thus issue of non-blocking of data is a prime concern. Thus, connectivity requires a large amount of Ethernet cables which leads to problems like - maintenance issues, implementation of server, management configurations. Due to this, other technologies are very much needed that helps to reduce the cabling requirement in future systems.

3. OPTICAL DATA CENTERS DESIGN : A COMPARISON

In past, Srivastava et.al.[17] proposed a buffer base switch design to mitigate conten-tion of packets re-circulating in FDL. The packets suffer from variable optical delays in the loop, hence the scheme introduced wave distortions. To cater this, Rastegarfar et.al. [18] Proposed an Arrayed Waveguide Grating Router (AWGR) to support wavelength parallelism and design of All-Optical Negative Acknowledgement (AO-NACK) at

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sender side to reduce the transmission of re-circulating packets through a Fiber Delay Line (FDL). The drawback of the scheme is that the design of AO-NACK is complicated in hardware. Bhattacharya et.al.[20] simplified the AO-NACK scheme by proposing algorithms for transmission of optical packets at sender site and at the core network. The paper establishes the fact that a small amount of buffer reduces the cascading effect of retransmission of re-circulating packets via FDL in case of contention at AWGR. Some other notable optical switch designs were proposed by Shukla et. al. [19] [21], and Singh et.al.[22] [26].

Table 1. A comparative review of optical switch and buffer designs in optical data centers

Related Work	Year	Advantages	Limitations
Srivastava *et.al* [17]	2010	Buffer based solution for contention resolution, using a FDL delay of 1 to *B* slots	Each contention packets serves with a variable optical delay introducing wave distortion
Rastegarfar *et.al* [18]	2013	AWGR based scheme with physical layer NACK scheme	The design of NACK scheme in hardware is complicated
Shukla *et.al.* [19]	2016	Flattened data center network designs to support optical parallelism, linear scalability and non-blocking switching.	Congestion and bottlenecks possible at temporal locality positions.
Bhattacharya *et.al.* [20]	2017	Proposed buffer based solutions to the AO-NACK scenarios in re-circulating FDLs	Energy considerations in link level losses were not considered in the design.
Shukla *et.al.* [21]	2018	Simplified switch design parameters in re-circulating FDLs.	Over-subscription of buffer slots is not considered
Singh *et.al.* [22]	2018	Energy consumption analysis over amplified switch	Proper demarcation of context switching from electrical to optical is missing
Singh *et.al.* [23]	2018	Performance analysis against traffic arrivals in electronic and optical buffer	Loading conditions and PLR not discussed at hybrid scenarios of buffer storage
Bhattacharya *et.al.* [24]	2019	Dual buffer based optical design for storage of large number of contending packets in buffer	Simulation regarding power spectral density in case of dual buffer slots is not considered.
Bhattacharya *et.al.* [25]	2019	Dual buffer design with primary and secondary buffer designs for one slot duration in AWG.	Link-level analysis in case of contenting packets is absent.
Singh *et.al.* [26]	2019	A hybrid based buffer scheme for Internet-of-Things (IoT) based environments	Issue to address crosstalk components in AWG is not addressed with optical buffer

To mitigate the crosstalk components and link losses, Singh et.al. [23] provided performance evaluations on energy considerations of an optical switch based on various buffering conditions. A proper demarcation between switching among electronic and optical buffer is not present. The problems are magnified as there is an absence of Optical RAM [21]. A considerable improvement to solve recirculation and NAK issues of bufferless designs is presented by Bhattacharya et.al. [24][25] by proposing a dual buffer based optical switch and simplified AO-NACK mechanism for loss notification. This scheme is beneficial as a large number of packets can move in optical fashion in connected fiber links. Spectral density and power losses in case of dual buffered slots is not considered. Table 1 presents a comparative analysis of related work in Optical Switch designs.

4. CONCLUSIONS

In the near future, optical network is the only viable solution to support the exponential requirements of larger bandwidth at low power consumptions. As the hardware chip size is decreasing to nano-scales, more hardware could be integrated which makes the fabrication of optical switches a possible reality. The use of optical technology is not only limited to switching technology but also in data centers applications. But due to limited technological advances, optical switching cannot be applied. Therefore, both electrical and optical technologies are used simultaneously. The paper investigated the rise in data requirements and challenges in switch design to optimize network performance. From the above discussion, it is conclusive that AWGR will be an integral part of the optical switch and data centers design in future. The commercialization of TWC will be break-through in the field of optical data centers design. In the next a few years both electrical and optical technologies will co-exist. In the

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next generation both techniques OPS and OCS will be used depending on the data rates of arriving traffic.

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