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A SURVEY ON HYBRID DATA CENTER NETWORKS

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Abstract—*Exponential increase in the network traffic demands has led to lot of innovation in the data center networks. The Hybrid Data Center Network (HDCN) which combines the wired and wireless technologies, have emerged in solving many problems faced by traditional data center networks. With increasing traffic demands data centers are suffering from congestion problem. To resolve this issue, Hybrid Data Center Network Architecture was proposed. HDCN support both wired-IEEE 802.3 and wireless-IEEE 802.11ad transmissions. The HDCN employs high speed 60 GHz wireless technology to communicate between the switches there by reducing the complexity involved in electrical connection. Further Hybrid Optical Switches combined with electronic packet switching is used to intelligently manage the on-demand traffic. The data center is reconstructed to Software Defined Data Center with the technical of Software defined network. The services of data center are formed into Virtual Data Center, which is based on the virtual resource collection of the physical network section. Network virtualization techniques have also been considered in realizing the traditional network functions over the virtual machines.*

I. INTRODUCTION

As the global cloud traffic is growing at very high rate, that directly affects the capacity of physical infrastructures of Data Center Networks. This high traffic demand limits the scalability of the classical wired DCN and causing congestion problems. Unfortunately, the fat tree structure architecture of DCN suffers from high over subscription, scalability and cost issues. These limitations are mainly due to the complex wiring and difficult configuration. The enterprise LAN networks faced lot of difficulties with the growth of cloud computing that resulted into increasing size of data centers. The great difficulty was wiring and maintenance for traditional Ethernet solutions that had expensive switches and wires. Unbalanced traffic distributions in data center applications suffer from inadequate network capacity. Typical applications like map-reduce generates traffic with only a few nodes being hot.

To address all these issues, a Hybrid Data Center Network architecture was invented which will improve the network performance in terms of traffic forwarding. Traffic forwarding means to distribute over wireless and/or wired infrastructure. Being free of wiring, the HDCN infrastructure is capable of alleviating the congestion of over-subscribed links and thus increasing Quality of Service of applications. HDCN make use of Optical Transmission techniques that provides high scalability, reduced power consumption using the use of Wavelength Division Multiplexing technique and hybrid optical switches. Virtualization techniques are employed in HDCN which increases scalability that makes data center independent of physical hardware.

II. HDCN ARCHITECTURE

Hybrid Data center Network (HDCN) consists of top-on-rack (ToR) switch which is mounted with a directional antenna, so that physically adjacent ToR switches can directly communicate with each other without any higher layer switches. In this way, the over-subscription problem in higher layer links can be reduced. A typical HDCN is shown in Fig. 1, where directional antennas can automatically rotate to different directions to communicate with different ToR switches. Normally, each directional antenna can support either 8 directions or 6 directions. They illustrated that 60GHz antenna with 8-element Phocus array can provide a stable 1Gbps communication bandwidth between any two adjacent nodes with a distance up to 10 meters in the indoor environment. One clear advantage of adopting a wireless network is that by using directional antenna, wireless links can be established in a flexible and on-demand way according to the real-time cloud computing service demand, which facilitates offloading traffic on the wired links.

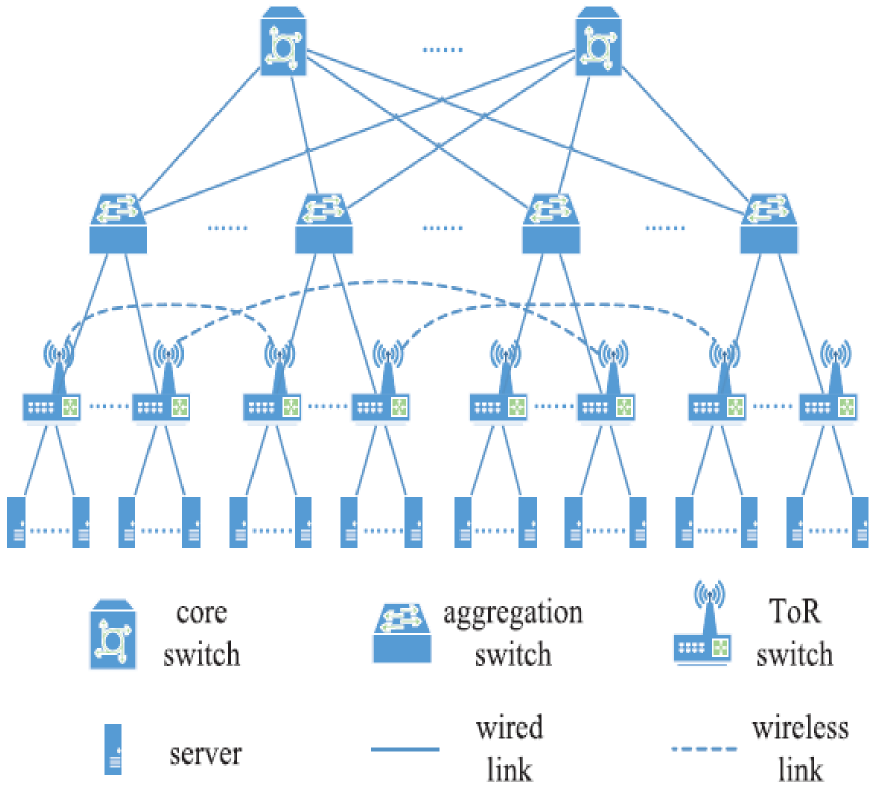

Figure 1: Structure of a hybrid data center network. All ToR switches are equipped with a directional antenna on each to establish a wireless network among ToR switches in an on-demand manner.

III. OPTICAL TRANSMISSION USING HYBRID OPTICAL SWITCH (HOS)

The hybrid optical-electrical data center network architecture becomes a transition solution from the all electrical network architecture to the all-optical one. This is efficient in terms of the operational cost and resource efficiency in data centers. With the emergence of technique the wavelength division multiplexing (WDM) and fiber-optic technology, consumes very little energy and significantly reducing the cabling complexity. WDM- based optical networks provides high bandwidth without using multiple electrical packets. The concept behind optical networks is a light-path which is defined as an all-optical connection routed in the optical domain along one or more fiber links. The light-paths do not add any latency to the data paths. They can be dynamically established on-demand for large volume of data transfer in data centers such as data backup and virtual machine (VM) migration. On the other hand, electrical network are better in multiplexing short and burst traffic. Therefore, hybrid optical-electrical network architecture becomes an attractive solution for data centers. A hybrid data center network thus brings in the flexibility of dynamically connecting ToR switches with high traffic demands using the optical network while maintaining the connections between ToR's with the electrical network for burst traffic.

HOS combines optical circuit, burst, and packet switching on the same network. In this way different data center applications can be mapped to the optical transport mechanism that best suits their traffic characteristics. Furthermore, they proposed HOS network achieves high transmission efficiency and reduced energy consumption by using two parallel optical switches. They demonstrated that the proposed HOS data center network achieves high performance and flexibility while considerably reducing the energy consumption of current solutions.

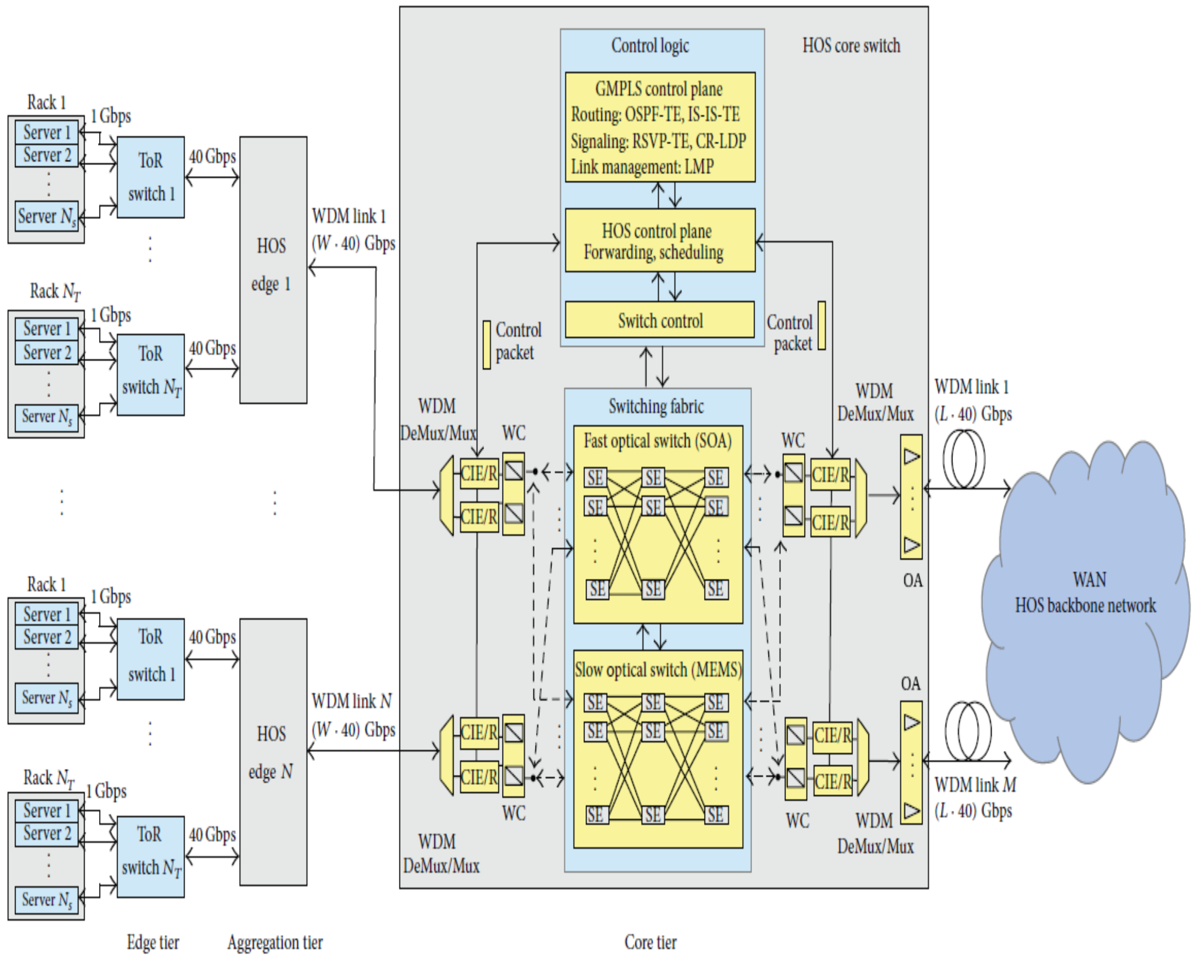

Figure 2: Architecture of a data center employing a HOS interconnection network. CIE/R: control information extraction/reinsertion, WC: wavelength converters.

The architecture of the proposed HOS optical switched network for data centers is shown in Figure 2. The HOS network is organized in a traditional fat-tree 3-Tier topology, where the aggregation switches and the core switches are replaced by the HOS edge and core node, respectively. The HOS edge nodes are electronic switches used for traffic classification and aggregation. The HOS core node is composed of two parallel large optical switches. The HOS edge node can be realized by adding some minimal hardware modifications to current electronic aggregation switches. Only the electronic core switches should be completely replaced with our HOS core node. As a consequence, our HOS data center network can be easily and rapidly implemented in current data centers representing a good midterm solution toward the deployment of a fully optical data center network. When higher capacities per server, for example, 40 Gbps, will be required, operators can just connect the servers directly to the HOS edge switches without the need of passing through the electronic ToR switches. In this way it will be possible to avoid the electronic edge tier, meeting the requirements of future data centers and decreasing the total energy consumption. In the long term, it is possible also to think about substituting the electronic HOS edge switches with some optical devices for further increasing the network capacity. This operation will not require any change in the architecture of the HOS core node, which can be easily scaled to support very high capacities. Furthermore, for increased overall performance and energy efficiency we assume that the HOS core node is connected to a HOS WAN, but in general the core node could be connected to the Internet using any kind of network technology.

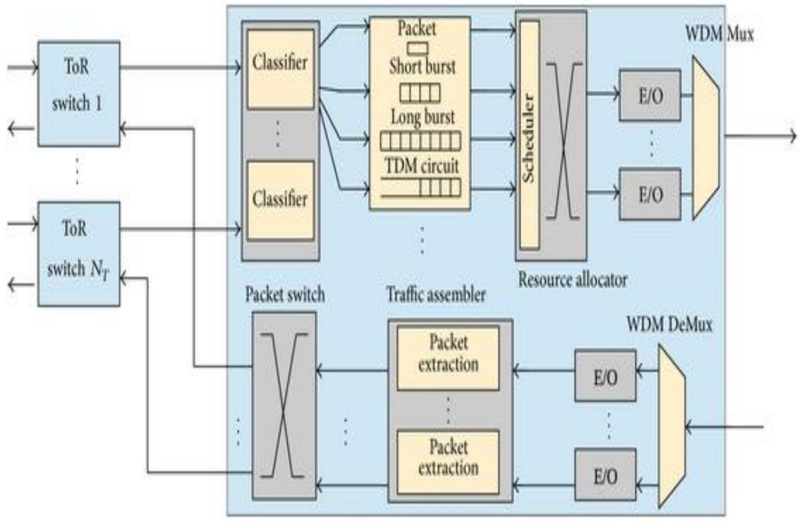

Figure 3: HOS Edge Node Architecture.

The architecture of a HOS edge node is shown in Figure 3. In the direction toward the core switch the edge node comprises three modules, namely, classifier, traffic assembler, and resource allocator. In the classifier, packets coming from the ToR switches are classified based on their application layer requirements and are associated with the most suited optical transport mechanism. The traffic assembler is equipped with virtual queues for the formation of optical packets, short bursts, long bursts, and circuits. Finally, the resource allocator schedules the optical data on the output wavelengths according to specific scheduling algorithms that aim at maximizing the bandwidth usage. In the direction toward the ToR switches a HOS edge node comprises packet extractors, for extracting packets from the optical data units, and an electronic switch for transmitting packets to the destination ToR switches.

As for the electronic core switch, we can divide the HOS core node in three building blocks, that is, control logic, switching fabric, and other optical components. The control logic comprises the GMPLS module, the HOS control plane, and the switch control unit. The GMPLS module is used to ensure the interoperability with other core nodes connected to the WAN. The GMPLS module is needed only if the HOS core node is connected to a GMPLS-based WAN. The HOS control plane manages the scheduling and transmission of optical circuits, bursts, and packets. Three different scheduling algorithms are employed, one for each different data type, for optimizing the resource utilization, and for minimizing the energy consumption. A unique feature of the proposed HOS control plane is that packets can be inserted into unused TDM slots of circuits with the same destination. This technique introduces several advantages, such as higher resource utilization, lower energy consumption, and lower packet loss probability. For a detailed description of the HOS scheduling algorithms the reader is referred to [26]. Finally, the switch control unit creates the optical paths through the switching fabric. The switching fabric is composed of two optical switches, a slow switch for handling circuits and long bursts, and a fast switch for the transmission of packets and short bursts. The fast optical switch is based on semiconductor optical amplifiers (SOA) and its switching elements are organized in a nonblocking three-stage Clos network. In order to achieve high scalability, 3R regenerators are included after every 9th SOA stages to recover the optical signal. The slow optical switch is realized using 3D micro electromechanical systems (MEMS). Finally, the other optical components include WDM DeMux/Mux, OAs, tunable wavelength converters (TWCs), and control information extraction/reinsertion (CIE/R) blocks. TWCs can convert the signal over the entire range of wavelengths and are used to solve data contentions.

IV. VIRTUALIZATION

Considerable expenditure and human power required for maintaining and upgrading data center networks (DCNs). Virtual Data Center (VDC) refers to the data center which applied virtualization technology. The VDC is based on the virtual resource collection of the physical network section including the virtual machines, virtual switches, virtual router and virtual links connected them. Currently, virtualization occupies an important position in the development of data centers, including not only the traditional servers and storages virtualization but also network virtualization, I/O and desktop virtualization, unified communications virtualization and so on.

There are different ways of virtualization -host virtualization and network virtualization. Network virtualization technique allows multiple heterogeneous virtual network architectures to co-exists and share the same physical network with a controlled capital expenditure. Network virtualization in these centers is a promising solution that enables coexistence of multiple virtual networks on a shared infrastructure. It offers flexible management, lower implementation cost, higher network scalability, increased resource utilization, and improved energy efficiency. The emergence and development of the software-defined network (SDN) accelerated the process of network virtualization. SDN focus on centralized management, it decuples the control plane from data plane and moves the control logic to a remote centralized control center which is called SDN controller. Next they focused on network programmability that is automation of network configuration and rapid deployment of new network protocol. Software Defined Data Center (SDDC) has attracted wide attention from academia and industry.

VDC embedding problem is similar to virtual network embedding, but there are still some difference between them, 1)the virtual network embedding is mainly faced to the WAN, and the VDC embedding is faced to the resources allocating in SDDC; 2) the virtual network embedding is only care about the devices of forwarding, but all types of the resources such as hosts, routers, storage, memory and so on in SDDC should be considered in VDC embedding; 3) For one requirement, only one virtual node can be embedded in one physical node in virtual network embedding, but multiple VDC nodes can be embedded to one physical node in the SDDC.

V. TOPOLOGIES IN DATA CENTER

1) Two-Tier topology - shown Fig. 4. The generic topdown tree architecture has the core layer (layer-3) of switches (routers), the aggregation layer (layer-2) of switches, and the edge layer (layer-1) of top-of-rack (ToR) edge switches. The Two-Tier DCNs have only the core and edge layers because the aggregation and edge layers are merged. The core layer switches are connected via high-speed links and control incoming and outgoing DCN traffic. This layer is responsible for routing and balancing traffic load between the core and the aggregation layer. The aggregation layer supports various functions such as server-to-server traffic, default gateway redundancy, spanning tree processing, load balancing, and firewall. At the edge layer, each ToR switch is connected to two core switches for redundancy. Servers are connected via the edge switches.

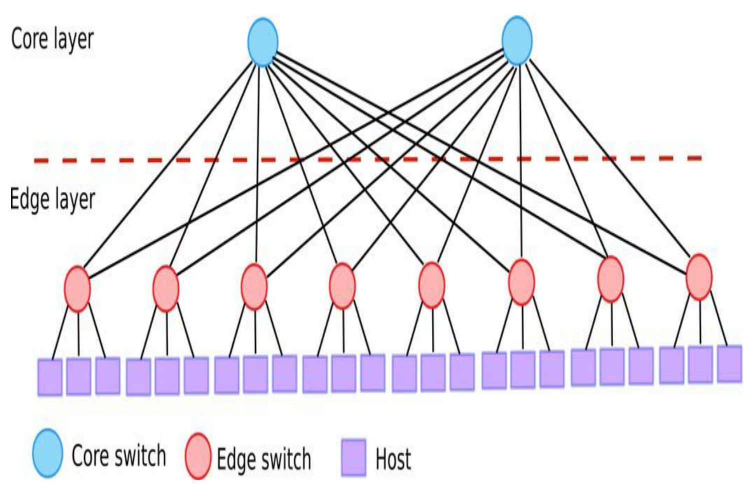

Fig. 4. An example of a Two-Tier DCN with only core and edge layers. It consists of 10 switches, 24 hosts, and 40 links.

2) F2Tree topology- is an enhancement of Fat-Tree, which is based on Clos architecture and was proposed as an early enhancement for conventional DCNs. The Fat-Tree topology is shown in Fig. 5. The F2Tree topology has two additional links added to each core and aggregation switch thus forming rings in each pod , as shown in Fig. 6. It allows immediate access and backup route to the neighbors of the same pod while keeping all benefits of Fat-Tree. F2Tree is designed to ensure fault-tolerance and to maximize bandwidth even Though it has (K2-K) fewer number of hosts than the Diamond topology.

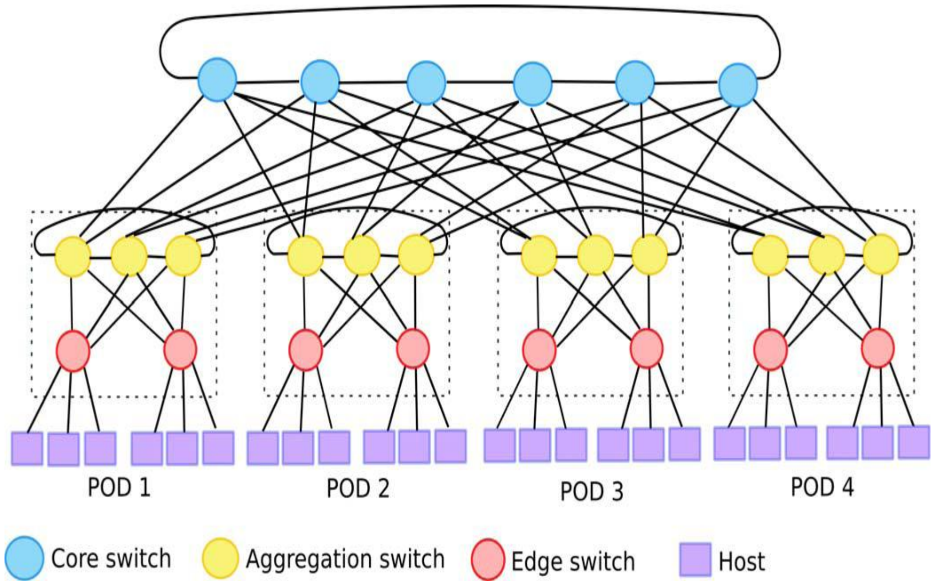

Fig. 5. An example of a Fat-Tree DCN with K = 4. It consists of 20 switches, 16 hosts, and 48 links.

3) Diamond topology- shown in Fig. 4 is a variation of the Fat-Tree. It exhibits a symmetrical architecture where the core switches are placed in two layers. There is no aggregation layer and the core switches are connected directly to the edge layer switches. Consequently, the average path length of interpod routes is shorter than in case of the Fat-Tree topology, which reduces the end-to-end delay.

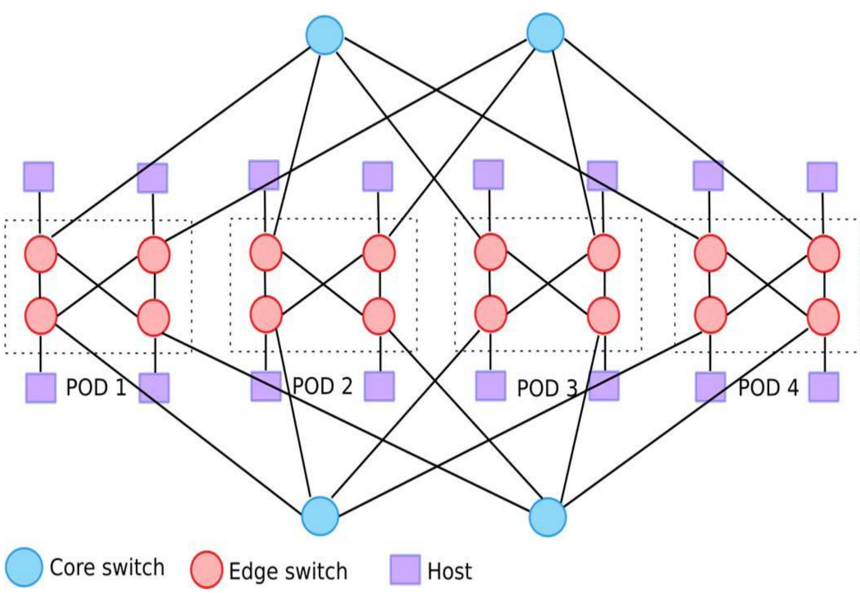

Fig. 6. An example of F2Tree DCN with K = 6. It consists of 26 switches, 24 hosts, and 90 links.

VI. CONCLUSION

This survey helped to understand the changes that Data Center has gone through from traditional one to Hybrid Data Center, from Electrical to Optical and Virtualization implemented in Data Center.Hybrid Data Center Networks adopts to latest technologies in Optical domain, there by solving many issues faced by traditional data centers. Optical based HDCN consume far less power compared to traditional data centers.

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