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On the future integrated datacenter networks: Designs, operations, and solutions

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ABSTRACT

Inter-datacenter networks (Inter-DCNs) and Intra-datacenter networks (Intra-DCNs) are entirely different in communication scales, architecture topologies and sizes, and characteristics of traffic flows. An Inter-DCN is built upon the existing Internet backbone with a fixed mesh topology and is hence difficult to accommodate any physical update or change without significant human intervention. Several core nodes of the backbone network are connecting to Intra-DCNs forming the so-called datacenter (DC) nodes. Different Inter-DCN or Intra-DCN architectures imply different network constructions overhead. An optimized combination of Inter-DCN and Intra-DCN architecture is expected to minimize the construction complexity and cost of DCNs while maintaining efficient network performance. However, research work in this important area has received little attention. In this paper, we study the construction of integrated Inter- and Intra-datacenter networks (integrated-DCN). Specifically, by taking advantages of different optical switching technologies and embedding the new control technology of software defined networking (SDN) in the control plane of integrated-DCN, novel cost-effective DCN architecture will be developed. For the proposed integrated architecture, the important characteristic of traffic asymmetry is investigated and accommodated by developing asymmetric network configuration based on SDN-assisted traffic monitoring/prediction, and the issue of network survivability/availability is explored and addressed by taking into consideration of the unique feature of DCN traffic.

1. Introduction

Datacenters (DCs) serve as a key element for supporting cloud computing services, which provide both real-time access to millions of mobile users and bulk data transfer for distributed storage services. A DC is composed of a core node as a part of the backbone network (e.g., the public Internet), which is attached by one or more intra-datacenter networks (DCN) that carry out the datacenter networking functionalities. The DCs along with general backbone core nodes without connecting to any Intra-DCN (or referred to as non-DC) simply form a virtual network on top of the public Internet, called Inter-DCN. The *Inter-DCN architecture* is the way of interconnection of these DCs and non-DC nodes.

A typical Intra-DCN attempts to interconnect a number of DCs in geographical adjacency. It consists of hundreds of similar pods (or racks), each of which then connects to thousands of 1 GE or 10 GE servers [1–6,8]. For a large Intra-DCN, the number of connected servers is as many as hundreds of thousands, and the peak bandwidth can reach up to Petabps. Some of the bandwidth demand is on the Inter-DCN and may consume a significant portion of network capacity in the public Internet.

Inter-DCN has generally been assumed to be built upon the public Internet backbone with a given mesh topology and Internet protocols which are hard to manipulate and

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modify. Therefore, Intra-DCN has been extensively researched in the past years by taking the Inter-DCN as given and fixed. Nonetheless, since the technology of wavelength division multiplexing (WDM) has been widely applied in backbone networks [17], there still exist extreme flexibilities in constructing Inter-DCN topologies *virtually* via establishing lightpaths. By setting up a set of lightpaths, regular/irregular *virtual* topologies can be developed on the top of physical substrate architecture. On the other hand, as the emergence of software defined networking (SDN) tools [19], real-time modification of Internet backbone services, including switching, routing, signaling, and resource allocation, becomes possible and thus an emerging research dimension of DCNs is on the integrated design of the Inter- and Intra-DCNs. With this regards, this paper focuses on some of the missing pieces from the currently reported research on the DCN architecture, particularly in the aspects of traffic asymmetric characteristic, traffic monitoring and prediction, network survivability/availability. We will provide solutions toward an integrated Inter-/Intra-DCN for achieving better scalability, efficiency, and service availability, via employment of new switching technologies and efficient control schemes appropriate for the Inter-DCN and Intra-DCN.

The contributions of this paper lie in the following aspects. First, we investigate the important feature of traffic asymmetry in DCN which has not been noticed so far and to accommodate this feature, we develop the unbalanced network configuration design based on traffic monitoring/prediction with the assist of software defined networking (SDN). Then, by taking into consideration of the unique feature of DCN traffic demands in terms of requiring both network transmission capacity and computing/storage resources, a novel protection/restoration mechanism is proposed in case of a node failure. Finally, by taking advantage of SDN, we develop quick fault discovery and prediction mechanisms to detour the risky traffic demands in advance so as to improve the network survivability.

The rest of the paper is organized as follows. Section II provides an overview on the state-of-the-art of the DCN architecture design. Section III surveys a number of candidate solutions in constructing integrated Inter-/Intra- DCN architecture. Section IV presents the designs, operations, and solutions for a number of open issues associated with an integrated Inter-/Intra-DCN architecture. Section V outlines a number of future works. Section VI concludes the paper.

2. An overview

The paper studies three important topics in the design of integrated DCNs that are considered as missing pieces of the state-of-the-art: integrated Inter- and Intra-DCN architecture design, traffic asymmetry, and service availability.

2.1. DCN Architectures and switching technologies

Presently available literature mostly considers an Intra-DCN as using three possible underlying switching technologies, namely, electric switching, hybrid electric/optical switching, and all-optical switching. A DCN may be under three possible management structures, referred to as server-centric, switch-centric, and network-centric. Server-centric structures focus on successfully interconnecting a given number of servers via numerous electric switches, however, without consideration on restricting/reducing the number of the required switches, links, transceivers, etc., which always lead to high construction cost and scalability problem. For switch-centric structures, the elaborations are on developing a huge single optical switch with a large number of ports that can be used to connect as many top-of-racks as possible. For network-centric structures, a number of the off-the-shelf small optical switches are connected to form a large optical network which can provide numerous ports to connect a huge number of severs.

Most existing DCNs on electric switching are sever-centric and fall into two tracks, namely, multi-tier based all-to-all non-blocking interconnection architectures, such as Fat-Tree and VLs [1,2], and self-recursive architectures, such as DCell and Bcube [3,4]. Although with the advantage of self-similarity when being scaled to larger degrees, the server-centric architecture based on electric switching falls short of high complexity and cost owing to the restriction in the number of ports that current electric switches can support, which eventually becomes a bottleneck when further scale-up is required.

To extend the scalability of DCNs with electric switches, the hybrid switching architecture that partly employs optical switching elements is considered. To enable flexible accommodation of traffic volumes with different sizes, the reported hybrid architectures, such as Helios and HyPaC [5,6], are switch-centric in order to take full advantage of the multiple switching granularities of electric and optical switches. Specifically, large traffic flows can be switched all-optically as a whole to avoid high switching overhead by using electronic switching. Compared with the electric switching architecture, the use of multi-granularity optical switches provides higher transmission capacity and lower construction cost. On the other hand, the legacy scalability issue still exists due to the dominant number of electric switches and coarse switching granularity of circuit-switching based optical switching technology in the upper layer.

All-optical DCN architecture is employed to countermeasure the inherent scalability issue in the electric and hybrid architectures. Several switch-centric optical architectures have been explored [7], mostly on large-scale optical switches that interconnect all the top-of-racks (ToRs) within an Intra-DCN via one single huge optical switch. Such a design is simple in operation at the expense of high manufacturing cost. An alternative for cost down without loss of performance is the network-centric DCN architecture [8] in which small and off-the-shelf optical switches are interconnected to form an optical DCN of n-cube topology. Results in [8] show that the network-centric optical switching architecture exhibits superior advantages in both network construction cost and network performance when compared to the other counterparts.

An Inter-DCN or Intra-DCN architecture corresponds to specific network construction overhead in terms of complexity and cost. An optimized combination of Inter-DCN and Intra-DCN architecture can help minimize the