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A Cost-effective Low-latency Overlaid Torus-based Data Center Network Architecture

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Abstract—In this paper, we present the design, analysis, and implementation of a novel data center network architecture named *CLOT*, which delivers significant reduction in the network diameter, network latency, and infrastructure cost. *CLOT* is built based on a switchless torus topology by adding only a number of most beneficial low-end switches in a proper way. Forming the servers in close proximity of each other in torus topology well implements the network locality. The extra layer of switches largely shortens the average routing path length of torus network, which increases the communication efficiency. We show that *CLOT* can achieve lower latency, smaller routing path length, higher bisection bandwidth and throughput, and better fault tolerance compared to both conventional hierarchical data center networks as well as the recently proposed CamCube network. Coupled with the coordinate based geographical addresses and credit based flow control, the specially designed POW routing algorithm helps *CLOT* achieve its maximum theoretical performance. Besides, an automatic address configuration mechanism and malfunction detection mechanism are provided to facilitate the network deployment and configuration. The sufficient mathematical analysis and theoretical derivation prove both guaranteed and ideal performance of *CLOT*.

keywords: Data Center Network, Architecture, Torus, Network Topology, Probabilistic Weighted Routing, Deadlock-free

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1 Introduction

Serving as the core infrastructure for the cloud providers as well as large-scale enterprise applications, the data center network (DCN) plays a key role in determining the performance of service provided to users. The traditional hierarchical switched DCN topology, besides being very costly, suffers high oversubscription ratio towards higher layers leading to serious communication bottleneck [1]. Thus, researchers proposed several more cost-effective DCN architectures such as BCube [2], DCell [3], SprintNet [4][5], FlatNet [6], CamCube [7], Small-World [8] and NovaCube [9], where these server-centric architectures abandon expensive high-end network switches by using only low-end switches or even no switches at all. In addition, the forwarding functionality is shifted to the servers, which helps achieve higher bisection bandwidth and better fault tolerance with richer connections [10]. However, they suffer high latencies due to their relatively long routing path length, e.g. in torus-based architectures, and relatively poor path diversity. As a result, some optical DCN topologies like OSA [11] have been proposed. Compared with packet switching, the optical circuit switching can provide higher bandwidth and lower latency in transmission. However, the optics suffer from slow switching speed which can take as long as tens of milliseconds, and cannot achieve full bisection bandwidth at packet granularity.

Based on these observations, in this paper we propose a novel DCN architecture named *CLOT*, which is built on a k-ary n-D torus topology whose various unique advantages have been carefully exploited in [9][12]. Based on torus *CLOT* well implements the network locality forming the servers in close proximity to each other, which increases the communication efficiency. Besides, in response to the serious issue of long routing path length in torus topology, *CLOT* employs a number of low-end switches connecting the most distant node-pairs in each dimension, which largely shortens both network diameter and average path length; this in turn reduces the network latency. Meanwhile, *CLOT* also largely improves the bisection bandwidth, throughput and fault tolerance with better path diversity. Moreover, from the perspective of cost-effectiveness, *CLOT* also far outperforms other hierarchical topologies like FatTree [13] with regard to the network cost. Furthermore, the geographical address assignment mechanism enables content routing such as key-value stores in addition to traditional routing, and works well with legacy TCP/IP protocol. Besides, the proposed automatic address configuration mechanism and malfunction detection mechanism greatly facilitate the network configuration and avoids the human errors.

The rest of the paper is organized as follows. First we briefly review related works in Section 2. Section 3 gives

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