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Power savings in software defined data center networks via modified hybrid genetic algorithm

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Abstract

In modern data centers, power consumed by network is an observable portion of the total energy budget and thus improving the energy efficiency of data center networks (DCNs) truly matters. One effective way for this energy efficiency is to make the size of DCNs elastic along with traffic demands by flow consolidation and bandwidth scheduling, i.e., turning off unnecessary network components to reduce the power consumption. Meanwhile, having the instinct support for data center management, software defined networking (SDN) provides a paradigm to elastically control the resources of DCNs. To achieve such power savings, most of the prior efforts just adopt simple greedy heuristic to reduce computational complexity. However, due to the inherent problem of greedy algorithm, a good-enough optimization cannot be always guaranteed. To address this problem, a modified hybrid genetic algorithm (MHGA) is employed to improve the solution's accuracy, and the fine-grained routing function of SDN is fully leveraged. The simulation results show that more efficient power management can be achieved than the previous studies, by increasing about 5% of network energy savings.

Keywords data center networks, energy efficiency, software defined networking, elastic topology, genetic algorithm

1 Introduction

With the development of cloud and virtualization technologies, data centers are evolving towards large scale and complex structure. Meanwhile, data centers also become quite power-hungry for providing reliable services. Huge and increasing amounts of electricity are consumed by them every year. For example, the energy consumption of global data centers was estimated to be $2.002\,7\times10^{18}$ J in 2010, $2.289\,1\times10^{18}$ J in 2011 and $2.593\,0\times10^{18}$ J in 2012, growing at an average annual rate of about 15% [1]. This energy-guzzling problem becomes one of the crucial limitations for current data center operations. As a vital component of data center infrastructure, the network also consumes an observable portion of the total energy budget (up to 20% [2]), and the proportion even keeps rising due to the improvement and deployment of energy conservation technologies on servers, storages, and hardware designs. Therefore, power optimization for DCNs become a worthy field of research.

To tackle this problem, two typical studies named ElasticTree [3] and energy-aware routing (EAR) [4] were proposed. DCNs typically adopt redundant design to guarantee system stability and reliability. Devices are richly-connected, and the utilization of bandwidth is relatively low most of the time, which may cause extra energy expenditure. The key insight of these energy efficient strategies is to utilize flow routing and consolidation to select a minimum subset of links and switches to forward flows. Then the idle devices can be shut down (or put into dormant mode) on the premise of satisfying network performance.

Such energy efficient routing requires a logically centralized management architecture and strong computing capability. SDN is just well-suited to control DCNs by this way. In SDN-enabled DCNs (SDN-DCNs), the control plane and data plane are decoupled, and network

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intelligence is logically centralized [5]. Powered by the unified management and communication protocols (e.g., the OpenFlow [6]), the networks gain unprecedented programmability and automation. With centralized controlling structure, network topology and traffic loads can also be globally and dynamically obtained in real-time. SDN has fine-grained and straightforward controllability for DCN resources, including bandwidth, ports, switches, etc. Thus, it is convenient to operate DCN devices (e.g., put them to sleep or wake them up) by SDN's customized control protocols.

There are some studies leveraging the innate advantages of SDN to tackle this energy conservation issue for DCNs. Tu et al. [7] proposed an energy-saving model for SDN data center, and the greedy heuristic was particularly analyzed. Li et al. [8] proposed exclusive routing (EXR), an energy-aware flow scheduling method introducing time dimension and using EXR for each flow. Li et al. [9] proposed Willow, a network-limited flow scheduling approach taking both the number of switches and their active working durations into consideration. Wang et al. [10] proposed correlation-aware power optimization (CARPO) algorithm, a power optimization algorithm which applies correlation analysis among flows and integrates traffic consolidation with link rate adaptation for maximized energy savings. Jiang et al. [11] proposed an energy-aware SDN-DCN management scheme in which a requirement of two node-disjoint paths (TNDPs) between the source and destination of each flow is considered. Xu et al. [12] proposed an energy efficient SDN-DCN flow scheduling and routing algorithm, which minimizes energy cost by EXR with flow deadline constraints and increases the utilization of switches. Rodrigues et al. [13] presented a SDN-enabled emulation environment for energy efficiency, and three power-saving protocols can be emulated by operating at corresponding layers of the network. Zhu et al. [14] also presented an energy-aware SDN-DCN management platform in OpenNaaS, and the platform can support different types of OpenFlow controllers. In Ref. [15], Xie et al. considered the energy efficiency of control plane with multiple controllers, and gave a power saving mechanism for the whole SDN architecture.

Most of these prior works just adopt simple greedy heuristic to reduce the computation complexity of their models. However, due to the inherent problem of greedy algorithm, a good-enough optimization cannot be always guaranteed. In this paper, we design a MHGA in the power saving mechanism, and a better solution can be achieved to provide a greater degree of energy optimization. The fine-grained routing function of SDN is also fully leveraged. SDN-based multi-path routing and flow aggregation can be utilized, and switches pool can be elastic along with the demands of network traffic to optimize the energy efficiency in SDN-DCNs. The mathematical model is combined with typical energy consumption characteristics of switches and MHGA to make a refined calculation. A subset of devices is selected to keep alive or wake up, and then other idle devices can be put into dormant mode via management interfaces of SDN. There are no topology limits for modern DCNs to employ this energy saving mechanisn. We conduct the simulations based on Poisson process and real datasets of data center traffic. And the simulations show that the power saving is more efficient and suitable for various topologies.

The remainder of this paper is organized as follows: Sect. 2 presents the background on DCN topologies and energy characteristics of switches, and describes the SDN-DCN structure in the simulation and modular architecture. The power saving mathematical model of SDN-DCNs and the MHGA to solve the problem are present in Sect. 3. Sect. 4 setups the simulation and evaluates the simulated results. Finally, Sect. 5 concludes the paper.

2 Background and system architecture

In this section, we first provide the background on modern DCN topologies and the power consumption characteristics of switch. Then introduce the typical SDN-DCN environment and the model.

2.1 DCN topologies

Three examples of typical DCN topologies are shown in Fig. 1. The traditional DCN topologies mostly are treelike structures, one of which is 2N-tree consisting of three layers of switches (Fig. 1(a)). Since service demands always scale up to its capacity limits, numerous new topologies were proposed [16–19]. These new designs can be mainly divided into switch-oriented and server-centric approaches. In switch-oriented topologies, such as fat-tree (Fig. 1(b)) and VL2, switches are still the core devices to provide high capability for routing. In server-centric