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Routing Techniques based Optimization of Energy Consumption in SD-DCN, Review Paper*

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In light of the ultra-low latency of advanced communication technologies and the advantages of leveraging and/or expressing network softwarization/virtualization, a wide range of use cases in the realm of computer networks is now possible. In this context, Software Defined Networking (SDN) is accelerating network innovation due to the inherent programmability it produces. Due to the unprecedented energy crisis in Europe, power consumption is receiving increasing attention. SDN plays a crucial role in minimizing the power consumption in data center networks, which can be achieved through efficient traffic engineering and routing schemes. In this paper, the problem of optimizing data center power consumption using SDNs is discussed. We then review the state-of-the-art studies highlighting the two common routing techniques, namely the *flow aggregation* and *flow scheduling* techniques. Finally, we present several challenges, open issues, and future directions that are worthy of conducting further research in the area of data center power consumption.

1. Introduction

Large-scale alternatives to fossil fuels that are secure, affordable, and low-carbon are lacking around the globe. The connection between access to energy and green-

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house gas emissions is the aspect of energy that draws the greatest attention. However, there is another major global energy issue that has to be addressed: hundreds of millions of people do not have access to enough electricity, which has dreadful repercussions for both their personal well-being and the environment, particularly in nations with fragile economies. On the other side, the problem did not stop at that.

Europe's energy grid is facing an unparalleled crisis. Since early 2021, wholesale costs of electricity and gas have increased by as much as 15 times, having devastating consequences on both individuals and companies. This challenge has received considerable attention and the motives of this paper is to review the most recent contributions in the area of Software-Defined Data Center Networks (SD-DCN).

As an information technologies community, we should help by shedding more light on the electricity used by data centers network (DCN) worldwide. According to a report in [3], the increase in power consumption in DCN is 56% from 2005 to 2010 and is prone to further increase in the future.

This study highlights the energy efficiency capabilities that can be utilized in emerging software-defined networking (SDN) to optimize power consumption of traffic-aware aspects. Software-Defined Networking appeared as a critical paradigm for achieving such Network Resources Optimization (NRO) and dynamically optimizing the network based on load and state. This is the most common carrier use case as it optimizes the network using the near-real-time state of traffic, topology, and equipment. NRO uses a variety of southbound protocols (for example, NETCONF, BGP-LS, or OpenFlow) depending on the underlying network [4].

According to the literature, researchers address the problem in both directions, hardware and software. Shortly, the energy-saving technologies of hardware are summarized in frequency scaling (i.e., changing clock frequencies), where the power is consumed as a function of the working clock rate [6]. In the same context, other researchers optimize the performance of the power ratio by consolidating multiple virtual machines (VM) in one physical machine [2]. All the mentioned approaches are subject to multiple constraints to keep the quality of service (QoS) acceptable. On the other hand, routing-aware approaches have appeared in recent years. Since the DCNs topologies (i.e., fat-tree, Bcube, etc) come with rich connections and can achieve high network performance by balancing the workload of the DCN, however, such structure of the DCNs topologies waste energy due to traffic volume does not proportional to energy consumption to the DCNs equipment, especially in the traffic valley time [5]. This paper will provide a comprehensive and novel classification of software-based energy efficient solutions into subcategories of traffic-aware approaches.

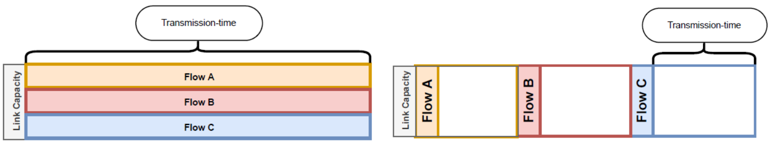
2. Routing Optimization Techniques

The power consumption of the SDN-based DCN's routing mechanics relies on the set of switches that forward the flows between the sources and destinations. Furthermore, the power consumption of those switches is either *dynamic* or *static*. The static part composes sum of the power that distributes on *chassis*, *fans*, *switching fabric*, etc. While the active *links* are usually alluded to as the dynamic portion. Technically, each link consists of two ports, sending and receiving. Therefore, the working ports should be considered in designing power-efficient routings. The formula for computing the network power consumption (NPC) is shown in (1).

$$\mathrm{NPC} = D_p \sum_{s_i \in \mathbb{S}} B_i + S_p \sum_{e_{ij} \in \mathbb{E}} L_{ij}. \quad (1)$$

B_i and L_{ij} denote the state of a corresponding switch (s_i), and link (e_{ij}), i.e., ON/OFF state, respectively. D_p and S_p denote the state of the power consumption, dynamic or static.

The study in [1] analyzes the traffic of a wide range of DCN network datasets belonging to different layers of DCN topologies. The result reported that the link utilization was low and varied from one layer to another. The low-utilization links motivate researchers to propose new approaches that are more energy-aware than commonly used routing algorithms, such as Equal Cost Multiple Path (ECMP), where an active switch consumes the same energy with low or high traffic, which cannot make full use of network energy consumption. Two types of methods come to address this problem: (1) flow aggregation techniques and (2) flow scheduling techniques.



(a) A simple example of flow aggregation.

(b) A simple example of flow scheduling.

Figure 1. Routing optimization techniques.

Flow aggregation techniques consolidate data flows into fewer links and switches that are sufficient to support existing data traffic demand. Then to achieve minimum power consumption for a specific traffic matrix, the other switches and ports should be put into sleep or shutdown mode. Figure 1a shows how three flows share one link fairly. The disadvantage of the mentioned techniques is that the subset of the switches and links (i.e.,sub-topology) may come at the cost of performance degradation (i.e., the quality of service), a significant increase in the delay time, and unreliable (e.g., shutdown) links with higher utilization. For that, the researchers have to keep an acceptable trade-off between energy saving and the quality of service. We will explore many of the major algorithms (such as [5]) and platforms that study these techniques in the full version of the current paper.

Since the SDN controller has a global view of the underlay infrastructure of a DCN, it can calculate the deadline and size of a flow. These characteristics of SDNs stimulate researchers to propose new *scheduling algorithms* to manage the transmission of the flow through a sequence of queues. Therefore, The algorithm sends the flow one by one, thus allowing the flows to monopolise all the links of the respective path with full capacity under the constraints of the deadline and size of a flow. Figure 1b shows how three flows are scheduled in the queue for transition with a full bandwidth. The disadvantage of the mentioned techniques is that they do not fit to time-sensitive traffic (i.e., streaming and real-time traffics), and the flows with higher priorities can preemptively route along the paths of other flows with lower priorities. In the full version of the current paper, we will discuss forwarding cases [7].

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