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Incorporating energy and load balance into virtual network embedding process

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ABSTRACT

Virtual network embedding has propounded as one of the most important techniques to address the issue of Internet architecture ossification. Previous studies on virtual network embedding algorithms focus primarily on the revenue of service providers (SPs) and the acceptance ratio of virtual network requests (VNRs), regardless of the energy consumption for substrate nodes and substrate links. To deal with this issue, some of researchers proposed energy-aware virtual network embedding algorithm to do a tradeoff between the revenue and energy consumption. However, the problem of virtual network embedding is a multi-objective optimization problem, which should take into account the multiple factors such as revenue, energy consumption, quality of services (QoS), load balancing of nodes and links, and so on. In this paper, we incorporate node energy consumption and node resource utilization into the embedding potential computation for substrate nodes, and propose a comprehensive node ranking method called CNRM to measure the substrate node importance. In addition, we utilize an improved differentiated pricing strategy to assign different weights to substrate links according to their resource utilization ratios, adopt the shortest path algorithm to select substrate path with the minimum energy consumption for virtual link during the link mapping process. Extensive simulation results demonstrated that our algorithm achieves a better tradeoff among the acceptance ratio, revenue/cost ratio, energy consumption and network load balance.

1. Introduction

With the advancement of science and technology, many Internet end-users have the demand of deploying new protocols or installing new services on the existing network architecture. Unfortunately, the current Internet architecture cannot meet the increasing demands of these end-users, and the architecture of current Internet appears to be ossification. Network virtualization technique has been propounded as one of the important techniques to fend off the Internet ossification. Through the technique of network virtualization, Service Providers (SPs) can provide different services for different users by means of sliceable management of the existing substrate network resources, and can improve the resource utilization of substrate network and reduce the wasting of substrate network resources. Virtual network embedding is the core component of the network virtualization, it concerns mainly on the allocation of substrate resources and it leads to the virtual network embedding algorithm to be a hotspot of the research.

Due to the fact that the problem of virtual network embedding is proved to be an NP-hard problem, therefore, domestic and overseas scholars have proposed some of heuristic algorithms to address this issue or carried out the simulation under the small scale of network topology using the optimization tools. As mentioned earlier, the issue of virtual network embedding is a multi-objective optimization problem. It involves how to maximize the revenue of InPs, how to minimize the cost of accommodating virtual network requests, how to minimize the energy consumption of servers and equipment, and how to balance the workload of substrate networks. However, the prior studies concentrated primarily on the maximization of revenue by accommodating more virtual network requests or increasing the network resource utilization through optimizing virtual link mapping solutions. Fortunately, some researchers begin to study the energy-aware and security-aware virtual network embedding algorithms. In the subsequent section, we will introduce these two kinds of virtual network embedding algorithms.

In recent years, energy-aware virtual network embedding algorithms [1–5] have received considerable attention because the power consumption of an average data center is the same as 25,000 households [6] and it is becoming the major energy cost of network operators

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which almost account for 42% of the total operating costs. In addition, the security vulnerabilities caused by network virtualization technologies have been attracted great attention from researchers. The security-aware virtual network embedding algorithms have been deeply investigated in the literature of [7–11]. The issues of network fragmentation and load balance can affect the acceptance ratio of VN requests and the Quality of Services (QoS) of the networks, and can equally affect the revenue of SPs since some high level customers are willing to pay the extra price for high quality of services.

However, these aforementioned algorithms involve two objective optimization. Therefore, there are some room for improvement by consideration more objectives on virtual network embedding algorithms. The main difference between our paper and previous works is that we take into consideration of energy consumption and load balance into virtual network embedding. This involves three objective optimization including revenue/cost, energy consumption and load balance, since our work is on the foundation of the classical heuristic algorithm which is the default consideration of revenue/cost. In our work, we investigated the multi-objective virtual network embedding algorithms, especially studied the energy and load balance aware virtual network embedding algorithm. Specifically, we first incorporate the node resource utilization and node energy consumption into the node ranking method aiming to give a comprehensive node ranking approach during the node mapping process. Then we utilize an improved differentiated pricing strategy with the purpose of selecting the substrate path with the minimum link consumption for virtual links. Finally, we take into account the node resource utilization to balance the node load in the node mapping stage, and adopt the improved differentiated pricing strategy for assigning different weights to different virtual links to balance the link load in the link mapping stage.

The main contributions of this paper can be summarized as follows:

1. We introduce a comprehensive node ranking approach based on node available resource, node resource utilization and node energy consumption. The node ranking method not only takes into account the node energy consumption, but also takes the node resource utilization into consideration.

2. We leverage an improved differentiated pricing strategy to set different weights for different substrate links according to their bandwidth resource utilizations with the purpose of balancing the link load of substrate network, and employ the shortest path algorithm aiming at selecting the substrate path with the minimum link consumption for each virtual link from VNRs to perform the link mapping procedure.

3. We conduct extensive simulations and evaluate our proposed algorithm compared with the other state-of-the-art algorithms in terms of the acceptance ratio of VNRs, the long-term average revenue, the revenue to cost ratio, the standard deviation of node resource usage ratio, and the standard deviation of link resource usage ratio.

The remainder of the paper is organized as follows. In Section 2, we briefly review the related works that associated with multi-objective virtual network embedding issues. We describe the system model and problem statement in Section 3. In Section 4, we elaborate our proposed algorithm E-LB-VNE in details. Experimental results and analysis are illustrated in Section 5. Section 6 concludes this paper.

2. Related works

In recent years, the problem of virtual network embedding has received considerable attention from domestic and overseas researchers. However, most of previous studies do not consider it to be a multi-objective optimization problem while at most do a tradeoff between two objectives. The main goal of prior work with single objective is to maximize the revenue of SPs by accommodating more virtual network requests and reducing the bandwidth utilization of substrate links [12–16]. The main drawback of these single-objective algorithms is that they did not realize the issue of virtual network embedding is a multi-objective problem, since a large amount of energy consumption can lead to reducing the overall revenue for ISPs, high quality of QoS will increase the extra incomes of ISPs. To address these issues, two-objective virtual network embedding algorithms attract great attention from many researchers. The most representatives of these algorithms with two objectives are energy aware virtual network embedding algorithms, security aware virtual network embedding algorithms, and load balance aware virtual network embedding algorithms.

2.1. Energy aware VNE algorithms

Due to the exponentially growing amount of physical machines for service provisioning in data centers, the energy consumption caused by a large amount of servers has been becoming a crucial issue, and it has attracted significant attention in recent years.

Two approaches with two objectives that heuristic-based algorithm and particle-swarm-optimization-based algorithm are presented in [2], the authors traded off between energy consumption that is consumed by supporting VN requests and revenue that obtained from accommodating VN requests, and proposed an energy cost model and formulated the energy-aware virtual network embedding problem as an integer linear programming problem. The authors formulated a discrete-time model to capture the concrete values of electricity price to deal with electricity price fluctuation issue, classified the substrate nodes into active nodes and inactive nodes, and separated the substrate nodes into host nodes that can be running some computing tasks and router nodes that only perform forwarding tasks so as to further quantify the server energy consumption. However, the formulated mathematical model is based on the experimental simulation system, it cannot reflect the genuine network environments.

The power consumption that is consumed by data centers can be decomposed of three parts: the first part is the communication energy consumption that is consumed by substrate links, the second part is the server energy consumption that is consumed by substrate nodes, and the third part is the other energy consumption that caused by cooling and power distribution systems. In the literature of [1], the authors formulated a power-efficient VN provisioning issue into a mixed integer linear programming problem to address the first two parts of energy consumption problems. The contributions of this paper is to give the refinement of communication energy consumption by means of modeling the substrate links as wavelength-division multiplexing (WDM) network which is much closer to the genuine network environments, and employed an improved differentiated pricing strategy for choosing the routing paths. The proposed framework achieved a better tradeoff between the energy consumption and the blocking ratio of virtual network requests. However, the disadvantage of this paper is that the proposed algorithm is based on two steps which cannot coordinate the two mapping stages, the main improvements lies in the improved differentiated pricing strategy in the link mapping stage while ignoring the enhancement of node mapping algorithm for facilitating the subsequent link mapping, and it can be further improved and intensified.

The author of [4] proposed a memetic multi-objective energy aware virtual network embedding algorithm, in this paper, the author formulated an energy-aware virtual network embedding model and devised some of metrics for evaluating the embedding algorithms. This paper proposed a multi-objective particle swarm optimization algorithm to do a tradeoff among all of the optimization objectives, used the local search technique to accelerate the convergence of the proposed algorithm. Extensive simulations shown that the proposed algorithm outperforms the other existing algorithms in terms of increasing revenue and decreasing energy consumption. Nevertheless, the suggested algorithm does not consider the communication energy consumption that is consumed by substrate links.

The main differences between the work [1] and our work are summarized as follows. The first difference is that our proposed algorithm takes into consideration of both energy consumption and load balance. The second difference is that our method improved the