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Optimal virtual network embedding: Energy aware formulation

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ABSTRACT

Network Virtualization is a key component of the Future Internet, providing the dynamic support of different networks with different paradigms and mechanisms in the same physical infrastructure. A major challenge in the dynamic provision of virtual networks is the embedding approach taking energy efficiency into account, while not affecting the overall Virtual Network (VN) acceptance ratio. Previous research focused on either designing heuristic-based algorithms to address the efficient embedding problem or to address the energy impact.

This paper proposes an integer linear programming formulation, Energy Aware–Virtual Network Embedding–Node-Link Formulation (EA–VNE–NLF), that solves the online virtual network embedding as an optimization problem, striving for the minimum energy consumption and optimal resource allocation per VN mapping. Two different objective functions are proposed: (i) addressing primarily the resource consumption problem – Bandwidth Consumption Minimization (BCM); (ii) addressing primarily the energy consumption problem – Energy Consumption Minimization (ECM).

The performance of each objective function is evaluated by means of simulation and compared with an existing objective function, Weighted Shortest Distance Path (WSDP), that is considered state of the art of the resource allocation problem. The simulation results show that the objective function BCM reduces the energy consumption of the physical network by 14.4%, and improves the embedding factor by 4.3%, consuming almost the same amount of resources as requested, and slightly worsening the VN acceptance ratio by 2.3%. ECM reduces the energy consumption of the physical network by 31.4% and improves the embedding factor by 4.1%, without affecting the VN acceptance ratio when compared to WSDP.

1. Introduction

Nowadays, network operators are required to pay more attention to the power consumption of their networks, either due to environmental policies imposed by the local governments or due to energy costs [1]. In fact, the power consumption of the data plane in idle mode is 90% the one in busy mode [2,3], while the power consumption of the control plane, i.e. of the Central Processing Units (CPUs), in idle mode is about 70% [4] the one in busy mode.

Several procedures can be taken to reduce the energy consumption, such as turning nodes that are not being used into sleep mode or by using "green" protocols. In [5] the impact on network protocols by turning network interfaces and components into sleep mode for saving energy is discussed, and in [6] power management schemes that reduce the energy consumption of networks are presented and evaluated. Not

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only the power consumption of each network equipment *per se* is important, but also the power consumption of the service itself. The energy consumption of the data plane can be derived from the virtual links allocation, and the one of the control plane can be derived from the virtual nodes, if we consider the data and control planes as two different power consumption sources.

Network virtualization will trigger the development of green protocols and will facilitate an optimal load distribution in the network: virtual nodes may be concentrated on certain physical nodes, thereby creating unused resources which can be turned into sleep mode. It is important that all provisioned services, i.e. virtual networks, are provisioned in the smallest number of physical nodes and links to save energy, and therefore, to reduce the CO_2 footprint, without affecting the reliability of the network.

One of the major obstacles for operators lies in the energy efficient embedding[1] of a Virtual Network (VN) onto a physical network, while maintaining the same levels of VN acceptance ratio. This problem requires the simultaneous optimization of: (i) resource allocation and (ii) energy consumption. Previous research works, such as [7–12] focused on the efficient embedding, while some recent research works, such as [13,14], focused on the energy consumption aspects. However, most of them either do not take into account both objectives, or do not solve them as an optimization problem, leading to non-optimal embedding solutions.

This paper focuses on the online embedding of VN requests in the physical network taking energy constraints into account. An Integer Linear Programming (ILP) formulation, the Energy Aware–Virtual Network Embedding–Node-Link Formulation (EA–VNE–NLF), is used to solve the VN assignment problem on the basis of an optimization of resource allocation and energy consumption. In addition, different cost functions are proposed and analyzed, which either primarily enforce bandwidth consumption minimization or energy consumption minimization. The performance of each objective function is evaluated by means of simulation and compared with an existing objective function, WSDP, that is considered as the state of the art of the resource allocation problem. The simulation results show that the objective function ECM significantly reduces the energy consumption of the physical network at similar VN acceptance ratios.

Compared to our previous work in [12], this paper:

(i) extends the mathematical formulation to support energy parameters;
(ii) proposes two cost functions, Bandwidth Consumption Minimization (BCM) and Energy Consumption Minimization (ECM) that take into account the energy consumption minimization;
(iii) provides a performance comparison with an objective function, i.e. Weighted Shortest Distance Path (WSDP), which is a state of the art approach for virtual network embedding;
(iv) evaluates the scalability of the proposed approach.

The rest of the paper is organized as follows. After summarizing the related works in Section 2, Section 3 describes the virtual network embedding problem and the evaluation metrics. Section 4 describes the Energy Aware–Virtual Network Embedding–Node-Link Formulation (EA–VNE–NLF) and the applied constraints, while Section 5 describes the VN embedding and discusses different objective functions. Section 6 analyzes the performance of the EA–VNE–NLF with different objective functions, and Section 7 concludes the paper.

2. Related work

The VN embedding problem can be formulated as an unsplittable flow problem [7] of resource allocation and energy consumption optimization. In order to solve this problem, several approaches have been suggested, mostly considering the resource consumption aspect.

Zhu et al. [7] proposed a heuristic based on a centralized algorithm to deal with VN mapping. The goal of the algorithm is to maintain a low and balanced load of both nodes and links of the substrate network.

The work in [15] defined a set of premises about the virtual topology, i.e. the backbone nodes are star-connected and the access-nodes connect to a single backbone node. Based on these premises, an iterative algorithm is run, with different steps for core and access mapping. However, the algorithm can only work for specific topologies.

Yu et al. [8] proposed a mapping algorithm which considers finite resources in the physical network, and enables path splitting (i.e. virtual links composed by different paths) and link migration (i.e. change the underlying mapping) during the embedding process. However, this level of freedom can lead to a level of fragmentation that is unfeasible to manage in large scale networks.

In [16], a formal approach is taken to solve the on-line VN embedding problem using a mixed integer programming formulation. Chowdhury et al. applied a two steps approach to embed VNs on the substrate. In the first step, the virtual nodes are assigned to physical nodes, and in the second step the virtual links are assigned to physical paths. Compared to the previous state of the art heuristics, i.e. [7,8], the formulation proposed by Chowdhury et al. provides a better coordination of the two phases, since an “augmented substrate graph construction” is used. Chowdhury et al. [11] extended their preliminary results [16] and included a generalized window-based VN embedding to evaluate the effect of look ahead on the mapping of VNs.

Butt et al. [17] proposed a topology-aware heuristic for VN mapping, and also suggested algorithms to avoid bottlenecks on the physical infrastructure, where they consider virtual node reallocation and link reassignment for this purpose. Nogueira et al. [10] proposed a heuristic algorithm that takes into account the heterogeneity of the VNs and of the physical infrastructure. The heuristic is evaluated by means of simulation and also on a small scale testbed, where it achieves mapping times on the order of tens of milliseconds.

A distributed algorithm was studied in [18]: it considers that the virtual topologies can be decomposed in hub-and-spoke clusters, and each cluster can be mapped independently, therefore reducing the complexity of the full VN mapping. This proposal has lower performance when compared with centralized approaches.

[1] The terms embedding, mapping and assignment are used interchangeably in this paper.