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Adaptive multi-objective artificial immune system based virtual network embedding

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ABSTRACT

In network virtualization, there are two decoupled roles involved: (i) infrastructure providers who manage the substrate network, and (ii) service providers who request virtual networks to the infrastructure providers. Embedding virtual networks to a shared substrate network, which is termed as virtual network embedding problem, is widely believed as one of the most significant challenges in such context. For this problem, prior work primarily focuses on either (i) maximizing the revenues by accommodating more virtual network requests or (ii) minimizing the energy consumption by consolidating the virtual networks into minimum number of substrate nodes. In this paper, we aim at achieving these two goals simultaneously. We first formulate the virtual network embedding problem into a multi-objective integer linear programming. We then design an artificial immune system based algorithm to solve this programming. In this algorithm, (i) we design a discrete approach to encode the virtual node mapping solution as an antibody; (ii) to initialize the antibodies, we design two adaptive revenue and energy aware strategies for the node and link mapping, respectively, to strike a balance between revenue and energy costs; (iii) we design corresponding customized strategies in the cloning, crossover and mutation process of artificial immune system in virtual network embedding context; (iv) for the generated antibodies, we leverage the Pareto optimality for evaluating their quality. Through extensive simulations, we show that our algorithm outperforms the state-of-the-art algorithms in terms of the revenue and the energy consumption.

1. Introduction

1.1. Background and motivation

Recently, network virtualization has emerged as the promising paradigm for the future Internet. In such context, there are also two decoupled roles involved: (i) i.e., infrastructure providers (InPs), who manage the substrate network (SN), and (ii) service providers (SPs), who request virtual networks (VNs) to InPs. A VN request generally includes two categories of constraints: node constraints and link constraints. The node constraints are typically on capacity of nodes (such as CPU computing power, memory and storage capacity) and location. The link constraints are typically on communication bandwidth and delay. When the InP receives VN requests from SPs, the InP needs to map the virtual nodes and links of the VN requests to the substrate nodes and links, which is well known as the VN embedding problem.

1.2. Limitation of prior art

The VN embedding problem, which is widely believed as one of the most significant challenges, has received significant attention in recent years. In Yu et al. (2008), Chowdhury et al. (2009), Houidi et al. (2008), Lischka and Karl (2009), Zhu and Ammar (2006), Lu and Turner (2006), Fan and Ammar (2006), Cheng et al. (2011, 2012), and Chowdhury et al. (2012)), the main goal aims at designing efficient embedding methods to increase revenues by accommodating more VN requests in the shared SN. In particular, the most recent studies (Cheng et al., 2012; Zhang et al., 2013; Chowdhury et al., 2012) propose to maximize the revenue by minimizing the resource cost (e.g., CPU and bandwidth) of embedding each VN request and thereby saving more resource for the incoming VN requests. However, all these early studies ignore the energy-related costs consumed by the SNs for accommodating VN requests. To study the energy issue in the VN embedding context, in our prior effort (Su et al., 2012, 2014), we mainly focus on abstracting the energy consumption model and designing energy

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aware VN embedding algorithms to optimize the energy cost. However, all these aforementioned studies mainly focus on pursuing only one objective, i.e., either maximizing the revenues or minimizing the energy consumption, when carrying out VN embedding.

1.3. Proposed approach

In this paper, we study the multi-objective VN embedding problem. In particular, we formulate the VN embedding problem to an integer linear programming (ILP) with maximizing the revenues and minimizing energy consumption as the two objectives. To solve this programming, we design an adaptive revenue and energy aware VN embedding algorithm called RE-AIS-A, which is based on artificial immune system (AIS) technique. The main idea of this algorithm is as follows. We first apply a discrete approach, which encodes the virtual node mapping solution as an antibody. Then, in the initialization of antibodies, in order to increase the number of feasible and energy efficient antibodies in the populations, we design an adaptive revenue and energy aware local selection strategy for node mapping, and design an adaptive revenue and energy aware shortest path algorithm for link mapping, respectively. To further improve the performance of the algorithm, we also design cloning, crossover and mutation strategy for employing AIS in VN embedding context. Finally, we leverage the Pareto optimality for evaluating the quality of the generated multi-objective antibodies. By leveraging AIS in our context, we can achieve a better VN embedding solution in terms of the revenue and energy consumption in the evolution process.

1.4. Summary of experimental results

We carry out extensive simulations and show that our algorithm outperforms the state-of-the-art algorithm and other metaheuristics in terms of long-term average revenue and energy consumption. In particular, our algorithm can generate 15% more revenue and conserve 28% energy consumption at the same time.

1.5. Key contributions

We make the following major contributions in this work:

1. To the best of our knowledge, we make the first attempt to adaptively maximize the revenue and minimize energy consumption simultaneously in the context of VN embedding to economically benefit the InPs.
2. We design an adaptive AIS based VN embedding algorithm, i.e., RE-AIS-A, to simultaneously optimize the revenues and the energy consumption so as to maximize the profit for the InPs.
3. We conduct a thorough numerical comparisons between our algorithm and the state-of-the-art algorithms. They show that our algorithm outperforms the state-of-the-art algorithms in terms of long-term average revenue and energy consumption for InPs.

1.6. Roadmap

The remainder of the paper is organized as follows. Section 2.1 presents the network model and the multi-objective problem formulation. In Section 3, we present our adaptive artificial immune system based VN embedding algorithm called RE-AIS-A. Section 4 is devoted to evaluate our proposed VN embedding algorithm. Section 5 reviews the related work. Finally, Section 6 concludes this paper.

2. Network model and problem formulation

In this section, we first present the network model and problem description of VN embedding in Section 2.1. Then, we present the performance metrics in Section 2.2. Finally, in Section 2.3, we formulate this problem to a multi-objective integer linear programming.

2.1. Network model and problem description

Substrate network: A substrate network (SN) can be represented by a weighted graph $G_s = (N_s, L_s, A_s^n, A_s^l)$, where N_s denotes the set of substrate nodes, L_s denotes the set of substrate links, and A_s^n and A_s^l denote the attributes of the nodes and links, respectively.

For a node, typical attributes include processing capacity (i.e., CPU), storage, and location. For a link, typical attributes include bandwidth and delays.

Similar to most of previous studies (Yu et al., 2008; Cheng et al., 2011, 2012; Chowdhury et al., 2012; Su et al., 2012), we consider the CPU and location attributes for nodes and the bandwidth attribute for links as our main focus. Other attributes can be easily incorporated into the network model and the algorithm presented in this paper. As shown in Fig. 1(b), an SN is presented, where the numbers in rectangles represent available CPU capacities and the numbers over the links represent the available bandwidth capacities, respectively. Similar to Su et al. (2012), to estimate the energy consumption of the SN, we also consider the power state (with a value of *active* or *inactive*) of the substrate nodes. As shown in Fig. 1(b), the substrate nodes in *active* state are drawn in transparent while the nodes in the *inactive* state in grey.

Virtual network: Similarly, a virtual network (VN) can also be represented as a weighted graph $G_v = (N_v, L_v, R_v^n, R_v^l)$, where N_v denotes the set of virtual nodes, L_v denotes the set of virtual links, and R_v^n and R_v^l denote the requirements of the nodes and links, respectively.

Figure 1(a) presents a VN request with both CPU and bandwidth requirements.

A VN request can be defined by $VNR(G_v, T_a, T_d)$, where T_a denotes the arrival time and T_d denotes the duration of the VN request staying in the SN.

VN embedding: The VN embedding problem is defined as a mapping M from a VN to an SN without violating the node and link constraints of the VN. Naturally, the mapping M can be decomposed into two stages: the node mapping M_n and the link mapping M_l.

(i) M_n maps each virtual node $u \in N_v$ to a substrate node $i \in N_s$ while satisfying the location and CPU constraints of u. These substrate nodes are responsible for hosting virtual nodes, which are referred to as *hosting nodes*.

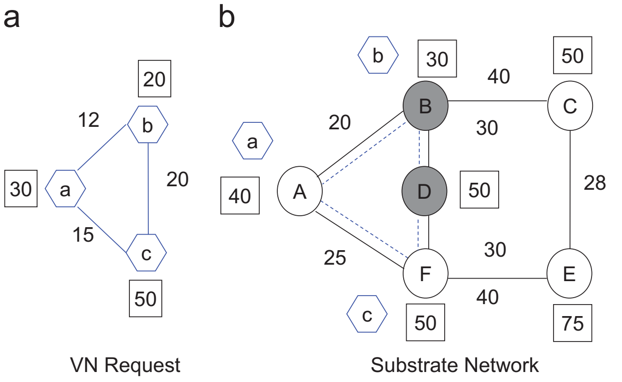

Fig. 1. Example of VN embedding.