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Novel methods for virtual network composition

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ABSTRACT

Network virtualization has been proposed as a technology that aims to solve the Internet ossification. Central to the network virtualization is a virtual network composition mechanism providing an efficient mapping of virtual nodes and links onto appropriate physical resources in the network infrastructure.

This paper proposes a novel backtracking heuristic algorithm for virtual network composition. Based on this algorithm, two approaches with two different objectives are presented. The first approach (Backtracking-CR) aims to compose a virtual network using the least amount of network resources, while the second (Backtracking-LB) applies load balancing for virtual network composition. Furthermore, a linear programming approach that optimizes the virtual network composition with an objective of using the least amount of network resources is presented and used to bench mark the heuristic algorithm. Simulation results show that using less network resources by applying linear programming or Backtracking-CR does not produce higher number of successfully mapped virtual networks when is compared to load balancing approach. Results also show that the proposed heuristic algorithm is scalable to large physical and virtual networks with respect to the computation time.

1. Introduction

Future Internet services are characterized by global delivery of high-performance applications over a high-capacity dynamic network. This is mainly driven by the emergence of ever more bandwidth demanding, dynamic and heterogeneous e-services such as cloud computing, HD gaming, HD/UHD video on demand streaming, and IPTV. Internet has started to face technical problems and suffer from ossification in supporting these types of heterogeneous and network-based applications [1]. A key challenge for network operators is deployment of dynamic infrastructures capable of supporting heterogeneous and network-based applications with several network resource usage patterns. Network virtualization has been proposed as a technology that aims to solve the issue of Internet ossification and provide flexibility for future Internet. It enables infrastructure providers to partition their physical network infrastructure into multiple application/service specific and customized virtual networks without significant investment or change in the physical infrastructure. In addition to the infrastructure provider, the role of service provider has emerged in the network virtualization business model. A service provider can lease a virtual network from one or several infrastructure providers and use it to deploy various protocols and offer services to the end users. [1–4].

The main advantages of applying network virtualization can be summarized as below:

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- Each Virtual Network (VN) can have different network architecture including network protocols. As a result, network virtualization provides heterogeneity and can support the trend to the Internet pluralist model [1].
- Dedicated VNs can be used to test the new technologies, protocols, network architectures and applications by developers and researchers. Therefore, Internet innovation is easier with network virtualization [5].
- Network virtualization can be used to support QoS over network by dedicating a separate VN for each service class or application type [6].
- Network virtualization can minimize the cost of owning physical network elements [7].

Network virtualization is defined as composition of isolated VNs simultaneously coexisting over a shared physical infrastructure. A VN is a set of virtual nodes interconnected by virtual links. Virtualization of network nodes and links is achieved by partitioning and/or aggregation of physical network resources i.e. routers and links capacities.

VN composition is the process of mapping a VN onto a physical infrastructure, and it comprises two main actions: virtual node mapping where appropriate physical nodes must be reserved, and virtual link mapping where virtual links must be assigned to suitable physical paths. Since VNs share the same infrastructure resources, an efficient VN mapping approach is essential to accommodate as many VNs as possible.

This paper introduces a novel heuristic mapping algorithm for VN composition suitable for packet networks (e.g. IP network). The important features of the proposed algorithm are: on demand and real time VN mapping, VN mapping with network constraints on both virtual nodes and links, one stage mapping of nodes and links as well as VN mapping with arbitrary topology e.g. star, mesh, ring, etc. Furthermore, a new integer linear programming (ILP) approach for optimal mapping is presented. Finally, performance of the proposed approaches are compared.

The rest of this paper is organized as follows. Section 2 provides an overview of related works. Section 3 describes the network model used in this paper. In Section 4, the proposed heuristic mapping algorithm and its two variations are presented. Section 5 introduces our new ILP approach. Performance evaluation of the proposed approaches is presented in Section 6. Finally, Section 7 concludes this paper.

2. Contribution and overview of related work

VN mapping problem is considered as NP-hard problem [8–10] and therefore many of the proposed approaches restrict the solution space and solve part of the problem in order to reduce its complexity. There are two main categories of approaches that deal with VN mapping: (1) approaches with coordinated node and link mapping and (2) approaches with independent mapping of nodes and links in different stages. The first category is more flexible in selecting different node and link mapping options and optimizing this selection to suit a predefined objective, and it has been proved to be more efficient [8]. However, many of the existing algorithms apply node mapping before link mapping with no coordination between the two stages [5,9,11,10].

Very few research works have been published on coordinated mapping of virtual nodes and links such as [8,12]. Authors in [8] propose an approach with an objective of improving the VN acceptance ratio and balancing the traffic load on the network. They use a linear program to find an optimal solution for node mapping as first stage. Multi-commodity flow algorithm is used to map the virtual links in the second stage. Although node and link mapping are coordinated, they are still two consecutive stages. Authors in [12] propose an algorithm with the goal of minimizing the mapping cost. Choosing the virtual nodes and links for mapping is done by an optimization process that considers the constraints and available resources as inputs and returns a set of preferred mapping options. Processing capacity of node and data rate capacity of link are the considered constraints in evaluating this algorithm.

Authors in [13] present a path-based linear programming model for solving the VN mapping problem. In this model, a set of paths that can be used to accommodate each virtual link is predefined, which leads to restriction in the solution space. Therefore, they propose a column generation process which attempts to find optimal solutions by gradually incorporating new paths into the solution base. Authors in [14] propose a pro-active and a hybrid policy heuristic to solve the survivable VN embedding problem which takes into account that the physical network might not be fully operational all the times. Single link failures are considered, and the proposed heuristic implements backup policies to handle these failures.

Other relevant published research works are mainly based on using two separate stages for node and link mapping. For instance, the authors in [5] propose mapping algorithms with the goal of minimizing congestion at the physical nodes and links. They address the problem generally without considering constraints like packet processing capability and geographical location of node, and bandwidth of link or interface. The proposed mapping approach in [9] uses path splitting by which virtual link can be mapped onto multiple substrate paths. This approach maps a set of VN requests together by mapping the nodes first and then the links. The authors in [10] propose an offline distributed VN mapping where all VN requests are known in advance and network resources are unlimited. The VN mapping in [11] is restricted to backbone-star VN topology. In addition, the possibility of rejecting requests due to unavailability of resources is not addressed in [11], and link bandwidth is the only considered constraint.

A framework for VN mapping where various mapping algorithms can run in a distributed and parallel way is introduced in [15]. This framework aims to spread the computation load across the network while keeping the mapping cost comparable to other centralized approaches. Authors in [16] investigate how a VN mapping algorithm can be modified to consider energy-efficiency with the goal to have minor impact on the performance regarding other optimization criteria.