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An automated approach to dependability evaluation of virtual networks

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A B S T R A C T

Network virtualization has been pointed as a promising approach to solve Internet's current ossification. A major challenge is the mapping of virtual networks (VNs) onto the substrate network due to its NP-hard nature, and, thus, several heuristics have been proposed aiming to achieve efficient allocations. However, the existing approaches only focus on performance, and dependability issues are usually neglected. Dependability involves metrics such as reliability and availability, which directly impact the quality of service, and a limitation is the absence of mechanisms for estimating dependability metrics in virtual networks. This paper proposes an automated approach for estimating dependability metrics in virtual network environments and a mapping algorithm based on GRASP metaheuristic. The approach is based on stochastic Petri nets (SPN) and reliability block diagrams (RBD), and a tool is also presented for automating model generation and evaluation. Experimental results demonstrate the feasibility of the proposed technique, as well as the trade-off between VN's availability and cost.

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1. Introduction

Internet has a vital role in modern society, enabling the existence of a wide variety of business applications in several areas such as entertainment, education and health. Although Internet has evolved significantly in terms of capacity and speed, important innovations in its architecture (e.g to better support mobility) suffer particular resistance due to its current structure [20]. As a consequence, barriers are created to the introduction of technological innovations and improvements, resulting in the current ossification problem [1,2].

In this context, network virtualization has received special attention from the scientific community, as it allows the coexistence of multiple instances of virtual networks (VN) in the same physical infrastructure. Their dynamic aspects allow several possibilities, such as instantiation according to different design criteria, with customized administrative control. Furthermore, virtual networks have prominent properties, such as the resource partitioning, traffic isolation, abstraction and concurrent use of shared resources. [1,3,5,16].

Over the last years, several techniques [5,18,25,26] have been proposed to achieve efficient allocation of the physical infrastructure elements to VNs, considering performance metrics. Mapping and allocation of VN requests are very important [20], but dependability issues are usually not taken into account by those approaches. Dependability involves metrics that directly impact quality of service (QoS), such as availability and reliability. The evaluation of these metrics is especially important, since the infrastructure components are failure-prone, which can affect virtual network operation. Using such a technique, VN providers can assess if a VN mapping is able to meet the constraints imposed by a customer request for high availability, for instance.

A major problem associated with dependable VN mapping is the absence of mechanisms for estimating availability in virtual network. This paper proposes an automated approach for estimating dependability metrics in virtual

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network environments and a mapping algorithm based on GRASP metaheuristic. The approach is based on stochastic Petri nets (SPN) as well as reliability block diagrams (RBD), and a tool is also presented for automating model generation and evaluation. The experimental results demonstrate the feasibility of the proposed models and mapping algorithm, as well as the trade-off between availability and cost. The proposed technique allows other algorithms to consider dependability metrics in the mapping, and enable them to assess the impact of different redundancy techniques.

This work is organized as follows: Section 2 presents related work. Sections 3 and 4 introduce the concepts of network virtualization and dependability, respectively. Section 5 discusses about the proposed method, and, Section 6 presents the optimization problem formulation. Section 7 describes the proposed dependability models, and, Section 8 presents the adopted evaluation environment. Section 9 explains our GRASP algorithm for virtual network mapping, and, Section 10 presents the experimental results. Finally, Section 11 concludes this work and presents future works.

2. Related work

Over the last years, techniques have been proposed to deal with VN allocations in shared infrastructures, aiming at improving important metrics, such as acceptance rate, network resource utilization, and cost [5,10,18]. However, few works deal with dependability issues.

Szeto et al. [5] presents a technique for VN mapping to maximize the number of virtual networks that can be simultaneously allocated on a shared physical infrastructure, using a preallocation mechanism. Experimental results indicate better utilization of physical resources, but this work simplifies the constraints of physical resources, assuming infinite capacity in each physical node.

In [27], VN mapping takes place into two phases: (i) mapping of the nodes; and, next, (ii) the links. In the first phase, they adopt a greedy approach to map the virtual nodes, in which the selected physical nodes are those with more free resources. Subsequently, the virtual links are mapped onto physical paths, using a shortest path algorithm. Results demonstrate the benefits of such an approach, which makes the problem more simple and computationally efficient. However, nothing is stated about dependability.

Melo et al. [28] present an approach based on integer linear programming (ILP) [63], considering the minimization of physical resources and load balancing as the objective function. Experiments demonstrate prominent results for performance metrics, such as acceptance rate and physical resource utilization. However, only performance metrics are adopted.

Koslovski et al. [6] present an allocation framework for virtual networks, taking into account mean time between failures (MTBF) associated to network nodes. Besides, such an approach does not present the mechanism for estimating MTBFs and maintenance is not considered. In [16], the authors consider survivability (which encompasses failures in network virtualization) and heuristics for mapping redundant routes (links) for node communication. However, that work does not consider failure events in the physical nodes. In addition, failures in software components (such as operational system and virtual machine) are not considered. Finally, The approach proposed does not allow customer to specify a minimum level required for the virtual network availability or reliability. Therefore, this technique does not guarantee that SLAs levels based on such dependability metrics are met.

In this context, dependability modeling is an important task and some studies have been proposed for evaluating dependability metrics in virtual computing systems. Xiaojing Hu et al. [9] adopt stochastic Petri nets models to assess such metrics in virtual machines and operating systems. In [7], Sun et al. present a dependability model for cloud computing. Similarly, Saripalli et al. [8] proposed a methodology for risk assessment in cloud computing environments, focusing on security risks.

Unlike the aforementioned works, this paper proposes a mapping approach that considers dependability issues, including redundancy policies for achieving high availability. Furthermore, mechanisms are proposed for automatic modeling and evaluation of VN's availability using stochastic Petri nets (SPN) and reliability block diagrams (RBD).

3. Network virtualization

Network virtualization is a promising approach to deal with Internet's ossification problem. This concept allows the coexistence of multiple instances of virtual networks on a single shared physical infrastructure, in addition to enable network traffic isolation, full administrative control and customization of VN instances More specifically, the benefits include:

- **Flexibility** in the topology, routing and control protocols, since virtual networks are independent of the adopted physical network and other allocated VNs.
- **Manageability,** as each virtual network is independently managed and fully customized.
- **Scalability,** since the infrastructure providers can easily increase the number of coexistent virtual networks.
- **Isolation** between virtual networks in the same physical infrastructure, ensuring security, privacy and improving fault tolerance issues.
- **Heterogeneity,** in the sense that both the physical and virtual networks may be composed of heterogeneous technologies (e.g., optical and wireless).

In this context, the following business roles (Fig. 1) are usually taken into account: physical infrastructure provider (PIP), virtual network provider (VNP), virtual network operator (VNO) and service provider (SP). PIP owns and manages the infrastructure, in addition to provide services that enable network virtualization. VNP is responsible for mapping resources of one or more PIPs on a virtual topology. VNOs are responsible for installation and operation of a virtual topology provisioned by VN provider. Finally, service provider adopts the allocated virtual network to offer a specific service.

Network virtualization involves several challenges, which has been tackled by the scientific community in recent years [5]. In general, the challenges include [29]: (i) the interface between PIP, SP and users; (ii) resource and topology discovery; (iii) quality of service (QoS) assurance; and (iv) resource allocation. This work is concerned with resource allocation

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