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A new virtual network static embedding strategy within the Cloud's private backbone network

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ABSTRACT

Cloud computing is a promising paradigm which has emerged to overcome the main issues of the computational world. It acts as a torchbearer technology for realising a new computing model in which resources can be acquired and released on demand. However, a fundamental issue in the instantiation of resources is how to afford optimal allocation so that the service provider fulfils the users' service level agreement while minimising its operational cost and maximising its revenue. In this paper, we tackle the problem of networking static service provisioning within the Cloud's private backbone network. This requires the embedding of virtual networks in which edge routers are directly connected to data centres. Our objective is to map online virtual networks in the private substrate backbone network using the minimum physical resources but while still satisfying the required QoS in terms of bandwidth, processing power and memory. This in turn minimises the reject rate of requests and maximises returns for the substrate network provider. Since the virtual network embedding problem is NP-hard, we propound a new scalable embedding strategy named `VNE-AC` to deal with its computational hardness. This is based on the Ant Colony metaheuristic. Extensive simulations are used to evaluate the performances of our proposal. These show that `VNE-AC` minimises the reject rate of virtual networks and enhances the cloud provider's revenue.

1. Introduction

The computational world has seen impressive progress in recent times, which is leading it to become larger and more complex. Cloud computing has emerged to tackle its main difficulties. This new paradigm provides end-users with utility computing via the Internet using a Web browser. More than twenty definitions of cloud computing have been proposed by the research community [1,2]. However, a consensus has been reached the definition that is given in [3]: "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." Cloud Providers ($\mathcal{CP}$) such as Google, Amazon and Microsoft compete to satisfy clients' demand by providing geographically distributed data centers connected with their private and/or public backbone network. A client communicates with data centers through its Internet connexion.

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In spite of its great success, many of the issues surrounding Cloud computing remain open such as: interaction between Cloud users and $\mathcal{CP}$ [4], privacy and data confidentiality [5], service availability and reliability [6], and energy management [7]. As a consequence, $\mathcal{CP}$ must put forward and prove the major benefits of adopting Cloud in order to attract those clients who are overwhelmed with uncertainties related to using new innovations. To eliminate the reluctance of these clients, $\mathcal{CP}$ must provide high-guarantees concerning service availability and ensure better performances in terms of (i) respecting the negotiated Service Level Agreement (SLA) and (ii) maximising revenue.

Actors involved in Cloud computing model are different from those in the traditional network model. Indeed, within Cloud computing, the service providers do not own the physical infrastructure. The ***user actor*** can be decoupled into two actors: ***Service providers*** and ***Clients***. Service providers create and run applications on the physical infrastructure offered by ***Cloud Providers*** ($\mathcal{CP}$). As a consequence, the clients buy services from service providers who will be $\mathcal{CP}$'s clients.

As described in [8], a cloud can deliver many services that can be classed in three main groups: (i) Software as a Service (SaaS), (ii) Platform as a Service (PaaS), and (iii) Infrastructure as a Service (IaaS). In this paper, we address the IaaS providing physical computational resources to cloud users, such as processing power, storage, and routers. In this respect, clients are free to install and manage their own software stack (operating system, application, routing protocol, etc.) as super-users. It is worth noting that IaaS can be supplied thanks to virtualization technologies (OS virtualization, para-virtualization, and hardware-assisted virtualization), which guarantee isolation between virtual instances sharing the same physical resources. For instance, Amazon's Elastic EC2 [9] is a well-known cloud offering IaaS.

Private Virtual Networks ($\mathcal{VN}$s) provisioning is considered as IaaS offered by the cloud infrastructure architecture. As depicted in Fig. 1, the cloud infrastructure architecture consists of a set of geographically distributed data centres interconnected with a Private Substrate backbone Network ($\mathcal{SN}$). The latter is formed by a set of geographically distributed routers interconnected with wired broadband connections (e.g., optical fibre). Moreover, the cloud provider contains one or more *Centralised Controllers* (CC) which are used to (i) monitor the infrastructure, (ii) embed applications in data centres, and (iii) embed $\mathcal{VN}$s in the substrate backbone network, etc.

Thanks to virtualization technology, many independent applications can be hosted in data centres [10]. Similarly, an application can be deployed in many geographical sites, making use of a private $\mathcal{VN}$, mapped in the Cloud's private backbone $\mathcal{SN}$, to interconnect all the geographical sites. In this respect, an end-user can (i) build any $\mathcal{VN}$ topology, (ii) install any routing protocol within the allocated $\mathcal{VN}$, and (iii) be responsible for network administration (i.e., IaaS). Since virtualization technology offers isolation, an end-user can only manage their own $\mathcal{VN}$ (i.e., instance) and cannot deteriorate the rest of the $\mathcal{VN}$s hosted in the $\mathcal{SN}$.

In this paper, we investigate the issue of $\mathcal{VN}$ static provisioning within the cloud's private backbone in which network performance and the cloud provider's economic returns depend strongly on its success. In fact, our proposal is run in the Centralised Controllers to manage the resource allocation of the Cloud's private backbone network. We assume in this work that there is no physical failures within the substrate backbone network. It is worth noting that data centers can communicate over the *Internet*. However, in this work we study the resource allocation within the *Cloud's private backbone* connecting data centers. Indeed, cloud providers can use both networks (i.e., private backbone and Internet) to guarantee the communication between the data centers. We mean by static provisioning that the embedding strategy does not reconfigure and migrate the virtual routers and links once they are mapped in the physical cloud's backbone network. Each virtual router must be assigned to only one substrate router. Also, each virtual link must be mapped into a substrate path. In fact, the virtual network can be seen as an overlay deployed in the Cloud's private backbone network. Specifically, our objective is to increase the private substrate cloud provider's revenue by reducing the reject rate of $\mathcal{VN}$ requests, while also satisfying the required physical resources in terms of bandwidth, processing power, and memory. The key issue addressed in this paper is the provisioning cost optimisation within the private backbone network. Indeed, our main motivation is to maximise the revenue of Cloud providers by maximising the acceptance rate of virtual networks. To do so, the objective is to generate the best virtual network embedding in aim to maximise the residual physical resources. Thus, an intelligent resource provision strategy is necessary. Note that the mapping of virtual routers is proved to be NP-hard in [11]. Additionally, virtual link assignment can be formulated as an unsplittable flow or a multi-way separator problem which is also NP-hard [12,13].

Since the $\mathcal{VN}$ embedding problem is computationally intractable in large-scale, the optimal solution could only be generated in small-sized instances of $\mathcal{VN}$ and $\mathcal{SN}$. We therefore propose a new scalable $\mathcal{VN}$ mapping strategy based on a Max–Min Ant System (Ant Colony metaheuristic) [14], denoted by `VNE-AC`.[1] The main idea behind our proposal is to take inspiration from the behaviour of collective ants in finding the best path between their nest and a food source. To do so, `VNE-AC` first divides the $\mathcal{VN}$ request into a set of sub-problems, denoted by solution components which are sorted and then sequentially assigned to form the sequence of mapping transitions. Then, `VNE-AC` launches the artificial ant colony and ants perform a parallel search. To this end, each ant iteratively builds a piece of the solution (i.e., transition) where each solution component is embedded according to the available resources and the artificial pheromone trail in the $\mathcal{SN}$. It is worth noting that each substrate router is associated with a pheromone trail value for each transition. Once all the candidate solutions (i.e., full $\mathcal{VN}$) are mapped, `VNE-AC` updates the pheromone trail in the $\mathcal{SN}$. The pheromone trail is evaporated in all substrate routers. Nevertheless, it will also be reinforced in the contributing substrate routers to build the best mapping topology. Indeed, the solution component is likely to be embedded in the substrate router with the highest

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[1] Preliminary results of `VNE-AC` are accepted for publication in IEEE ICC'11.