OptiCloud: Development of a Private Cloud Infrastructure to optimize Workload Placement using Software Defined Networks based on OpenStack

Research-in-Progress

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Abstract

Cloud computing offers great opportunities for its adopters. But due to a lack of trust and effort in workload migration, the adoption of public cloud infrastructures is not always the preferred option for organizations. The application of a private cloud infrastructure combined with software defined networking (SDN) provides the potential to mitigate few drawbacks of public clouds. For this reason the development of an optimized private cloud infrastructure applicable particularly for small and medium enterprises is investigated. This paper provides an overview of the cloud platform used for that purpose, the cloud setup, and required optimizations needed for an effective private cloud. An optimized workload placement algorithm is introduced that combines information gathered from data available through the use of SDN.

Keywords

Cloud computing, cloud infrastructure, private cloud, software defined network, software defined networking, SDN, OpenStack, optimized workload placement.

Introduction

Cloud computing, as an alternative to traditional information technology (IT), has become one of the most important IT issues during the last couple of years (Park and Ryoo 2013; Won 2009). The use of internet-based technologies to conduct business found its way in organizations through the main areas related to information systems (IS) and technologies, such as operating systems, application software and technological solutions (Low et al. 2011). In a need to improve the IT performance of organizations, cloud computing has already changed their information infrastructure and associated business processes as well as business models (Wu 2011). Science and practice are therefore equally challenged to deal with these new concepts, architectures and technologies.

Possible drivers for cloud adoption among organizations can be found in enhanced business flexibility and agility and cost savings in terms of software licensing as well as personnel resources (Weinhardt et al. 2009; Altaf and Schuff 2010). Even though obvious benefits exist, there are still perceived risks that prevent organizations from taking advantage of these novel and innovative technologies. Threats for data integrity and availability due to outages and security breaches, unclear status of outsourced data or even cover-up of data loss incidents to maintain a reputation have given especially data storage in the cloud a bad name (Wang et al. 2010). These problems mainly affect public cloud adoption. In a public cloud setting the infrastructure is provisioned for open use by the general public on the premises of a cloud provider (Mell and Grance 2011). In contrast to that, a private cloud infrastructure is provisioned for exclusive use by a dedicated organization (Mell and Grance 2011).

The public cloud adoption problem due to a lack of trust on the one side and the increasing awareness of the basic advantages of cloud computing among organizations on the other side drive the interest in private cloud infrastructures. Many distributed private clouds however do not run efficiently out of the box. In addition, especially small and medium sized enterprises (SMEs) often do neither have the knowledge nor the resources to assess the benefits of a private cloud infrastructure. On the other hand, cloud computing is especially of interest for the SMEs segment due to the relatively low demands on the company's on premise IT infrastructure, high scalability and high flexibility. Hence, SMEs have a particular demand for a private cloud infrastructure that fulfills their business needs. According to the European Union, SMEs are defined by several criteria whereof the size of the company which is limited by 250 employees, is the most customary one (Europäische Kommission 2003).

In the course of a 2.5-years research project called "OptiCloud", researchers from America (California), Europe (Austria), and Asia (India) are working on a private cloud infrastructure to determine feasibility and improve corporate use for SMEs. This international and interdisciplinary project takes an IS research view on cloud computing. The technical challenge lies in an optimization task with respect to workload placement using software defined networking (SDN). SDN is a concept which provides organizations the flexibility to manage their networking equipment using software running on any internal or external server (Azodolmolky et al. 2013).

The goal of this paper is to explore the possibilities of flexible workload placement using the concept of SDN in a private cloud infrastructure. As the focus thereby is set on the technical perspective, the authors aim at the identification of design characteristics of optimized workload placement that supports the needs of organizations for flexible data and service placement in the cloud. The following section motivates the need for SDN in today's cloud infrastructure. Afterwards the development of the proposed cloud infrastructure (OptiCloud) is described. Insights into hardware, networking infrastructure and software equipment are provided. The paper concludes with contributions to research and practice and directions for future work.

Background on software defined networking

Prior to planning the development of a private cloud infrastructure, it is crucial to take critical success factors and current limitations into account. In general, the decision to adopt a particular technological innovation depends on its availability and compatibility with existing technologies (Tornatzky and Fleischer 1990) and needs (Rogers 2003). Furthermore the probability to adopt a technology decreases with increasing complexity (Tornatzky and Fleischer 1990). A high level of ease of use causes the reverse effect (Davis 1987).

A recent exploratory study on cloud adoption in 9 SMEs showed that moving infrastructure to the cloud is directly related to the expectation of cost reduction which is, especially for SMEs, critical due to non-achievement of economies of scale (Stieninger and Nedbal 2014b). Another critical issue, according to this study, is security and trust (Stieninger and Nedbal 2014b). Depending on the particular attitude towards cloud computing, the statements spread throughout literature differ fundamentally. While the supporters of cloud computing believe devoutly that cloud computing improves security (Buttell 2010), the opponents criticize deficits in privacy management and data security (Stieninger and Nedbal 2014b).

In order to fulfill the claim of the currently most widely used definition (Stieninger and Nedbal 2014a) of cloud computing, the NIST definition of cloud computing (Mell and Grance 2011) for high flexibility, rapid scalability, and optimize resource usage, a new network architecture is needed. As a novel and innovative mechanism, software defined networking (SDN) currently is the most promising candidate to provide proper solutions for the following trends and issues (Open Networking Foundation 2012):

- Changing traffic patterns: Today's applications access different servers across various enterprise data centers before returning the data to the end users device. This creates a lot of additional machine-to-machine traffic that has to be transferred to connecting devices from anywhere, at any time.

- Consumerization of IT: IT departments are increasingly confronted with employees using their personal devices such as smartphones, tablets, and notebooks to access corporate applications while on the other side they have to secure corporate data and protect intellectual property.
- Availability of cloud services: Organizational units that have already adopted public and private cloud services now want self-service provisioning of their applications, infrastructure, and other IT resources. Taking into account additional security, compliance, and auditing requirements, along with business reorganizations, consolidations, and mergers, this is a complex challenge.
- Big data: Processing large scale datasets, so-called "big data", on thousands of distributed servers demands more bandwidth. Additional network capacity is needed in the enterprise data centers.

SDN is a new approach to network architectures that "has the potential to enable ongoing network innovation and enable the network as a programmable, pluggable component of the larger cloud infrastructure" (Kobayashi et al. 2014). It "provides the network operators and data centres to flexibly manage their networking equipment using software running on external servers" (Azodolmolky et al. 2013). The network management, which is usually implemented in software, is decoupled from the data tier which enables cloud services to self-adapt according to changes in the network context (Rubio-Loyola et al. 2011). SDN enables organizations to gain better insight of where which workloads and data reside. Utilizing this knowledge can be used to make better decisions where data should reside and thus eliminate major security concerns of public clouds previously discussed.

OptiCloud infrastructure design and architecture

This section discusses the design and architecture of the proposed private cloud infrastructure. It starts with an overview of the cloud test platform and the infrastructure. This is followed by the hardware and networking equipment and the software used for the setup.

Cloud test platform overview

When deciding on which cloud infrastructure to choose, OpenStack and OpenNebula are currently the two major open source platforms available (Wen et al. 2012). Although released in public two years earlier, we chose OpenStack as (i) more than 150 companies collaborated in its development, (ii) its number of participants grew faster bypassing OpenNebula one year after its release, and (iii) it supports almost all available hypervisors including Hyper-V, whereas OpenNebula currently only supports three (Xen, KVM, VMWare) (Wen et al. 2012). OpenStack is widely used in private as well as in public clouds. It is massively scalable and adopted both in academia and in industry (Corradi et al. 2014). OpenStack provides an Infrastructure as a Service (IaaS) solution through a set of interrelated services. Each service offers an application programming interface (API) that facilitates its integration into the solution (OpenStack documentation: http://docs.openstack.org/havana/install-guide/install/apt/content/ch_overview.html [20.2.2014]).

Figure 1 shows the underlying infrastructure for the OptiCloud test platform. It has all OpenStack services installed and runs on a single physical machine called "Controller". This accommodates for an entry-level private cloud which can still consolidate several traditional physical servers into virtual machines (VMs) depending on the number of available hardware resources. To get best performance it was found beneficial to have larger numbers of CPU cores, RAM and a fast hard drive. For scaling to larger deployments, more physical servers can be added as compute nodes. On those Open vSwitch, Hypervisor, Neutron and Nova-Compute services would have to run.

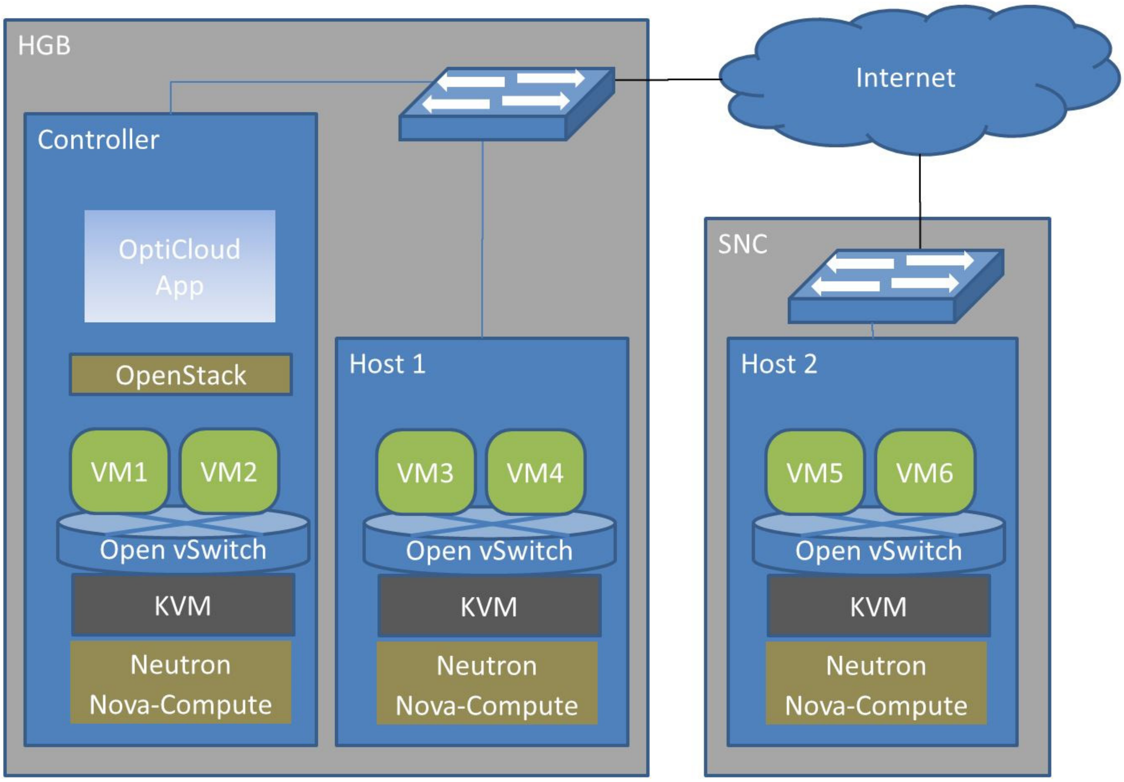

Figure 1. Architecture of server, network components and software of the cloud test platform.

Neutron is used for providing networking services. It enables OpenStack to delegate network provisioning for VMs to an SDN controller. It further avoids the need for physical network changes as VMs go through their lifecycle of being created, paused and destroyed. As such it helps scaling a private cloud up and down without the need to understand the individual VM's networking needs (Neutron documentation, https://wiki.openstack.org/wiki/Neutron [26.2.2014]).

Neutron provides different plugins for OpenFlow and SDN. It gives cloud tenants an API to build rich networking topologies, and configure advanced network policies in the cloud. Tenants for Private Clouds can be mapped to departments or groups for example to ensure clear segregation of traffic driven and defined in software.

OptiCloud hardware and networking setup

Virtualization allows for overcommitting CPUs and memory. In that case, more virtualized CPUs and memory are allocated for VMs than are available on the physical server. Operating Systems inside VMs typically do not utilize all allocated memory and CPUs all the time, so it is a good way to improve server utilization. However, it can also have negative impact on performance when the hypervisor has to frequently switch between VMs sharing same resources. To avoid such impact, this setup was aiming at making enough physical resources available for VMs.

It was also accounted for modeling slow and fast physical network links between VMs. This will become important once we discuss the problem of VM placement. Current cloud scheduling algorithms do not take network related information into account. If VMs then land far apart in terms of their physical location and distance, the communication overhead may become bigger in private clouds because physical servers may not be interconnected with high-speed links.

The two physical hosts “Controller” and “Host 1” in Figure 1 are located in the Hagenberg (HGB), Austria, data center. Through the internet these two servers are able to communicate with “Host 2” located in Santa Clara (SNC), California.

Controller and Host 1 have four CPUs (Intel Xeon E5-4607) with 6 hyper threading cores each. This amounts to 24 Cores and 48 hardware threads and 64GB RAM. Host 2 has a single four Core CPU with 8 hardware threads (Intel Core I7-3770) and 16 GB RAM.

Host 1 and Controller are interconnected through two 1 Gbps networks one for management and the other for VM connectivity as well as a 10 Gbps link for VM networks. VM networks inside HGB have ping latencies of less than 0.5 ms. The link speed between HGB and SNC through public infrastructure was measured at 500 Kbps and shows ping times of 170ms and more. The different speeds and latencies will be used to determine the communication efficiency between VMs.

Such variations of 20x network throughput and 340x network latency support the findings of Corradi et al. They found that while experimental results show that VM consolidation is an extremely feasible solution to achieve cloud business drivers, it has to be carefully guided to prevent excessive performance degradation (Corradi et al. 2014). In the subsequent chapter we present the OptiCloud Application on the Controller to counter these negative side-effects.

Controller runs all OpenStack services including nova-compute. As such it is the central point for provisioning VMs as well as virtual networks. It further acts as a compute node and can run VMs on the same hardware. KVM is used as hypervisor and VMs that are created will be inter-connected via Open vSwitch. The default Linux Bridge is not used for VM communication. The OptiCloud App also runs on the Controller and performs optimization tasks with respect to the location of VMs, observed network communication, and additional factors like temperature and power consumption.

The present working setup allows for creating virtual networks, defining subnets in the network and spawning VMs, which will be assigned an IP address within the range of subnet that is created. Intra-VM communication can be monitored using neutron APIs where statistics about interactions within the network can be gathered.

OptiCloud software to approach the optimization problem

Previously it was explained that VMs in distributed private clouds will have non-uniform network traffic characteristics due to differences in cabling, locality and other devices network devices sitting between them. Further, power, cooling and other environmental factors account for changing efficiencies of a cloud. Translating these variations into Figure 1 obviously VMs 1 through 4 will have less bandwidth and exhibit higher packet latencies when exchanging information with VMs 5 and 6. If for example a web server (VM1) with corresponding database (VM5) would be distributed across SNC and HGB locations, the overall application experience would most probably suffer. It seems therefore desirable to influence VM placement decisions with awareness about network characteristics among other factors. OptiCloud is intended to approach this optimization problem. The current research has validated that the following information is available as input to OptiCloud:

- location of a VM (host)
- cost/benefits associated with a location (temperature, power, cooling)
- connectivity to virtual switch port
- list of flows established from one VM to other VMs
- volume of data exchanged via flows between VMs
- cost/benefits associated with a path between VMs (latency/throughput)

These inputs will have to be gathered with reasonable but varying frequencies and a model has to be derived about the current communication efficiencies. Improvement suggestions will be the result of OptiCloud. A suggestion is then translated into a VM migration with the intent to bring VMs closer together.

In the example above the web server (VM1) will experience a network latency of 170ms for retrieving information from its database located on VM5. Reed et al. suggest that 150ms should be the upper bound on response times for web servers (Reed et al. 2013). This however, is the time it should take to load a full web page, which requires establishment of a TCP connection and exchanging multiple packets.

It would be desirable to migrate either VM1 from HGB or VM5 to SNC. Modern hypervisors support live VM migration across locations without incurring VM downtime. We use this functionality to achieve this optimization without incurring a downtime neither for VM1 nor VM5. However, the hypervisor functionality does not guarantee that the VM is reachable from outside the cloud when it arrives at its destination. The use of SDN and its networking overlays is required to keep the network up after VMs have been moved. This is achieved by creating a virtual internal network using Neutron and connecting that to a virtual router. Through the use of publicly addressable floating IP addresses the VM stays reachable even when migrated across locations.

The combination of hypervisor live migration and SDN allows for OptiCloud to dynamically place VMs where they are found to interact better with its environment. Web site users would after the migration perceive a much better response time after the migration without the need for scheduling down times.

Conclusions

This research-in-progress paper discussed a private cloud infrastructure based on OpenStack that explores the possibilities of flexible workload placement using architectures and technologies like SDN and automated workload migration. Especially for SMEs with limited IT resources, automation is key for driving operational cost down. Cloud computing promises operational benefits and reduced costs. Private clouds however can cause performance issues because SME networks are less likely to exhibit uniform data center characteristics. Private cloud tenants should therefore have workloads provisioned automatically without the need for IT to change compute, networking or storage. Distributed locations are beneficial for SMEs with branch offices where (i) branch locations have different characteristics for energy cost, time of the day, etc. (ii) communication across locations may need long paths through the internet cause varying network latencies and throughput, (iii) traditional enterprise networks are much more expensive to operate, and (iv) existing clouds are not optimized for ideal placement of workloads.

The benefits and practical implications can be summarized as follows:

- private clouds are attractive especially to SMEs due to lack of trust in public ones and operational benefits over traditional enterprise data centers
- deployment of an OpenStack based private cloud across SME branch offices is possible using open source software
- the combination of compute and network virtualization allows for true workload flexibility in placement
- placement algorithms have been developed but lack flexibility to take into account location dependent factors
- the OptiCloud workload placement approach currently shows feasibility and one straight-forward algorithm to place VMs based on network communication

Although IS research is intensely discussing the topic of cloud computing, the more specific topics of SDN and the cloud platform OpenStack described in this paper are not covered at all. As per Feb. 2014, the AIS Electronic Library (aisel.aisnet.org) does not list any paper containing the terms "software defined network" or "software defined networking" when searching within “All Fields”. The term “OpenStack” also only delivers one search result, a paper on the status-quo of cloud computing in German language (Fischer et al. 2013). As for the critical success factors described in this paper, the authors believe that these topics are noticeable when building a private cloud infrastructure. The main contribution for IS researchers therefore is to show how such a platform is designed, taking the needs of organizations into account.

The main drawback of the paper is that results from simulation and monitoring of the workload placement and optimization are subject to future work. The next step in the experiment therefore is to connect Host 1 and Host 2 to the Controller and derive all inputs required for generating the cloud efficiency model. The OptiCloud software application can then migrate the VMs from one host to another based on the traffic conditions or other factors like temperature and power.

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