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OpenStack in Enterprise

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The goal of the project is to set a private cloud infrastructure based on OpenStack and VMware, which can be replicated to the set of demilitarized commodity hardware and used for system engineering and testing. The project aims to explore features, benefits and challenges of different virtualization stacks and particularly network functions virtualization and their implementation in the commodity hardware.

The project has a specific set of requirements regarding software in use, especially regarding capabilities for a military-grade security, ease of system engineering, overall maturity and availability of an enterprise support. Therefore, the enterprise-grade OpenStack distributions will be considered, like VMware integrated OpenStack, Red Hat OpenStack and Mirantis Fuel.

Furthermore, the project will consider usage of connected software routers, including Juniper, Cisco and open-source SDN solutions.

The cloud infrastructure will be heterogeneous, with various Linux, Windows7/8.1/10 and Windows Server systems running sanitized copies of business-critical applications like Active Directory. The Linux systems will be based on Centos as a free alternative to enterprise-level Red Hat Linux systems and Windows systems will utilize MSDN licenses.

The result of this project will be an inhomogeneous private cloud infrastructure being implemented on the server, with a system which allows changes to the server-based infrastructure both on the OS and the network topology level to be rapidly pushed to the commodity LAN cluster. The project has to confirm the following things: 1) OpenStack can be utilized for the system engineering in an enterprise environment in a comfortable and, importantly, "batteries included" manner and 2) an OpenStack-based setup and/or various network topologies can be pushed to commodity hardware.

Keywords	Enterprise, OpenStack, SDN, Microsoft

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Acronyms and abbreviations

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AD	Active Directory
API	Application programming interface
AWS	Amazon Web Services
B2B	Business-to-Business
CLI	Command Line Interface
CMDB	Configuration management database
CERN	European Organization for Nuclear Research
DDR SDRAM	Double data rate synchronous dynamic random-access memory
DNS	Domain Name System
DHCP	Dynamic Host Configuration Protocol
ESXi	Elastic Sky X i
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
IaaS	Infrastructure as a Service cloud delivery model
IP	Internet Protocol
ISO	archive file of an optical disk
KVM	Kernel-based Virtual Machine
mATX	micro Advanced Technology eXtended
NSX	Network Virtualization Platform
NDA	Non-disclosure agreement

OS	Operating System
OVG	Open Virtualization Format
PaaS	Platform as a Service cloud delivery model
PXE	Preboot eXecution Environment
QoS	Quality of Service
REST	representational state transfer
SQL	Structured Query Language
SNMP	Simple Network Management Protocol
SCP	Secure Copy
SCCM	System Center Configuration Manager
SCOM	System Center Operations Manager
SSH	Secure Shell
SLA	Service-level agreement
SSD	Solid state drive
UI	User Interface
VM	Virtual Machine
WAN	Wide Area Network
WWW	World Wide Web

1 Introduction

1.1 Purpose of the project

The project goal was on demand and regarding the industrial needs of an Airbus Defence and Space (DS) GmbH company, department of Border Security Solutions. The major sales factor for the department is integration of various surveillance sensors, including radars, infrared video cameras, laser distance meters, majority of which operate over Simple Network Management Protocol (SNMP) protocol, with traditional, although security-wise hardened, corporate IT infrastructure, including network, data processing storage solutions and large-scale fiberoptic networks. Since the typical scope of client's solution is in range of hundreds to thousands workstations, virtualization is used to speed up integration procedures. The final aim is to evaluate alternative system engineering approaches to deployment and testing of client's infrastructure. The end-product, if it meets industrial capabilities, could be used to test and virtualize the surveillance infrastructure for handling immigration crisis in Europe.

1.2 Overview of the company

Airbus DS was formed in January 2014 as a merger between European Aeronautic Defence and Space Company and Airbus Military. The company is present on six continents [1], has 40 thousand employees and the revenue of €14 billion per year. The company is listed on Euro Stoxx 50 index made out of 50 largest European companies, which "provides a representation of Supersector leaders in the Eurozone" and directly represents the state of European economics. Airbus DS is the world's second largest space company and the 7th largest military company, with large projects like EuroFighter, Euro Hawk and Airbus A400m. Airbus DS is a strategically European company, fulfilling the requests of the European governments in the areas of internal and external security.

It is not possible to include an overview of the company's existing solutions in the thesis due to NDA (non-disclosure agreement).

2 Theory background

2.1 Cloud computing

With new business requirements emerging even for the non-IT centered corporations, like market analysis with Hadoop clusters, where is an increasing demand in cutting expenses and increasing performance by outsourcing IT infrastructure to the third parties. Therefore, corporations turn to cloud computing as a way to achieve these goals. Cloud computing lately has been summarized as "just somebody else's computer". It refers to the fact that instead of converging infrastructure on the locally-placed commodity hardware, the computational tasks are performed in the (typically) more secure location on the third-party premises or deeper within the company itself. Cloud computing systems typically offer data replication redundancy, copying sets of data to different physical storage locations according to predefined policies. With the growing value of corporate data, cloud dramatically reduces expenses of hardware failure. This gets to the point where the smaller companies and even medium enterprises cannot compete with the market leaders, when the Amazon, Google and Microsoft basically damping down the hosting prices to the ground. Therefore, the competition on public Infrastructure as a Service (IaaS) layer is almost non-existant. However, the positive side it that it boots the innovation on the software layer.

Cloud gives the IT companies a agility to adapt to rapidly shifting demands of the modern workspace. This is also emphasised by enabling shift from monolithic (single-host application, like Microsoft Exchange) to distributed applications, making the system more resilient to a single component failures. This is especially important since expansion of IT infrastructure naturally leads to the higher amount of hardware failures.
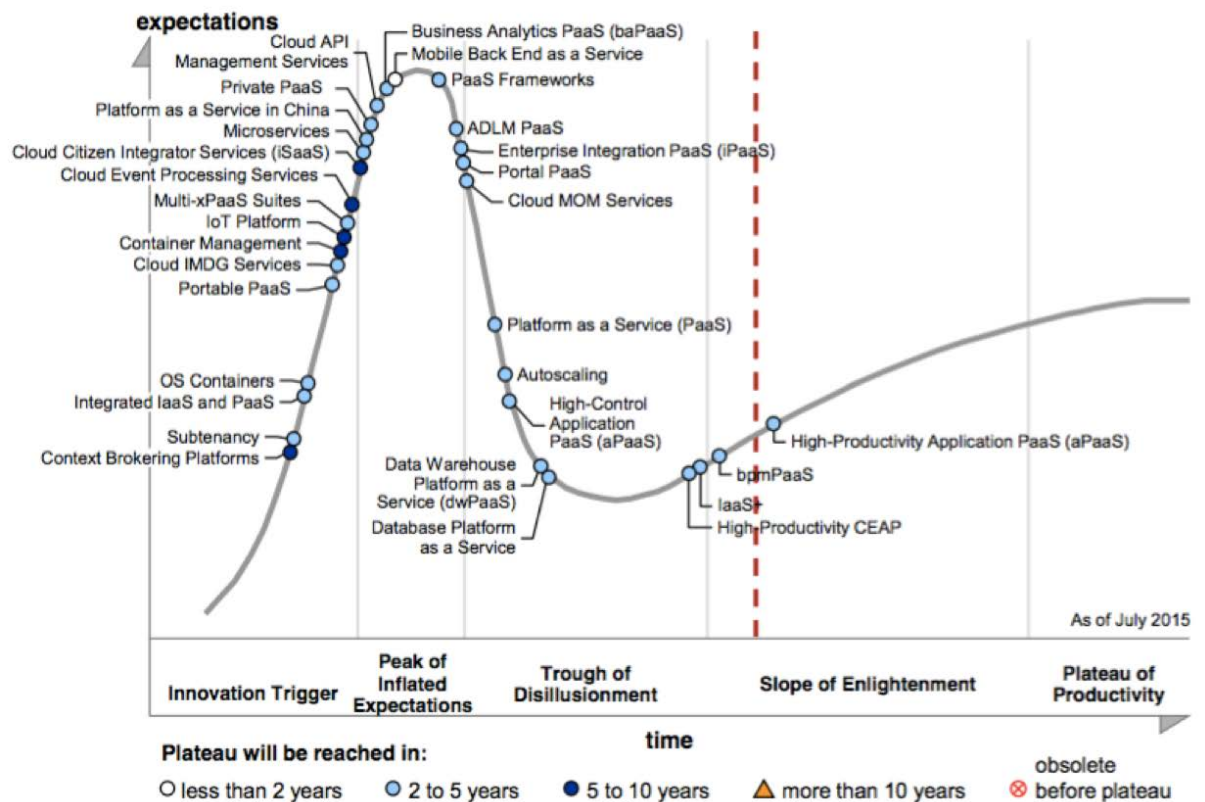
Figure 1: Gartner hype cycle for PaaS technologies. Reprinted from Johan den Haan, Mendix [2]

As shown in Figure 1, a clear correlation is exhibited between expectations and applicability in the production of emerging technologies. OpenStack falls into PaaS (Platform as a Service), Operating System (OS) Containers, IaaS, Private PaaS, Multi-xPaaS Suites (multi-hypervisor deployments) and other categories, meaning it ranges in applicability for different tasks from "usable" to "very promising".

2.2 Virtualization

Virtualization is an approach to run both hardware and system architecture in software. Also, typical virtualization units are more powerful, improving service stability, productivity and reducing overhead (% of the hardware which stays unused). Typically on the highest system level, virtualization is classified by functions into network, storage and server virtualization.

Typically virtualization solutions are divided into two categories: type-1 and type-2 hypervisors. Type-1, also called bare-metal hypervisor, includes solutions like XenServer and ESXi. In OpenStack program, sub-project called Ironic offers bare-metal hypervisor capabilities. Mirantis OpenStack v8.0 includes Ironic. Type-2 hypervisor runs on top of an operations system like a regular program. This includes VMware Workstation, VirtualBox and QEMU. Nested virtualization allows multiple Virtual Machines (VMs) and even hypervisors to run within one another.

Virtualization allows more "effective" backups with the snapshot capabilities, storing the whole state of the virtual machine and the programs running on it for faster reproduction of the desired system state. A snapshot also increases the system flexibility, allowing the VMs to be easily moved on re-deployed between separated physical machines and even data centers. In addition, even in the case of a hardware failure, so-called failover mechanisms allow VMs to be instantly restored on another hardware server from pre-replicated copy (usually stored on the separate storage server), preventing data loss.

Virtualization can be ubiquitously utilized even outside of the datacenter environment. For example, Airbus DS is using Bromium software on all office machines. Bromium is B2B (Business-to-Business) software founded by creators of the popular Xen hypervisor. Bromium provides so-called "micro-virtualization", allowing each PC program, web-link or an email-attachment to run in a separate VM sandbox, an environment which allows the program only to utilize the resources assigned to it by Bromium. The sandbox is also specifically hardened again. It is considered that even without the virus database for heuristical (behavioral) analytics; Bromium is as efficient against all viruses and human-performed hacking attempts as traditional antiviruses and certainly integrates well as a complementary product with no zero-day security issues. Unlike traditional hypervisors, the process of creating and starting the VM is completely hidden from the user, preventing the issues with "security vs usability" scenario. [3; 4]

2.3 Role of virtualization in business
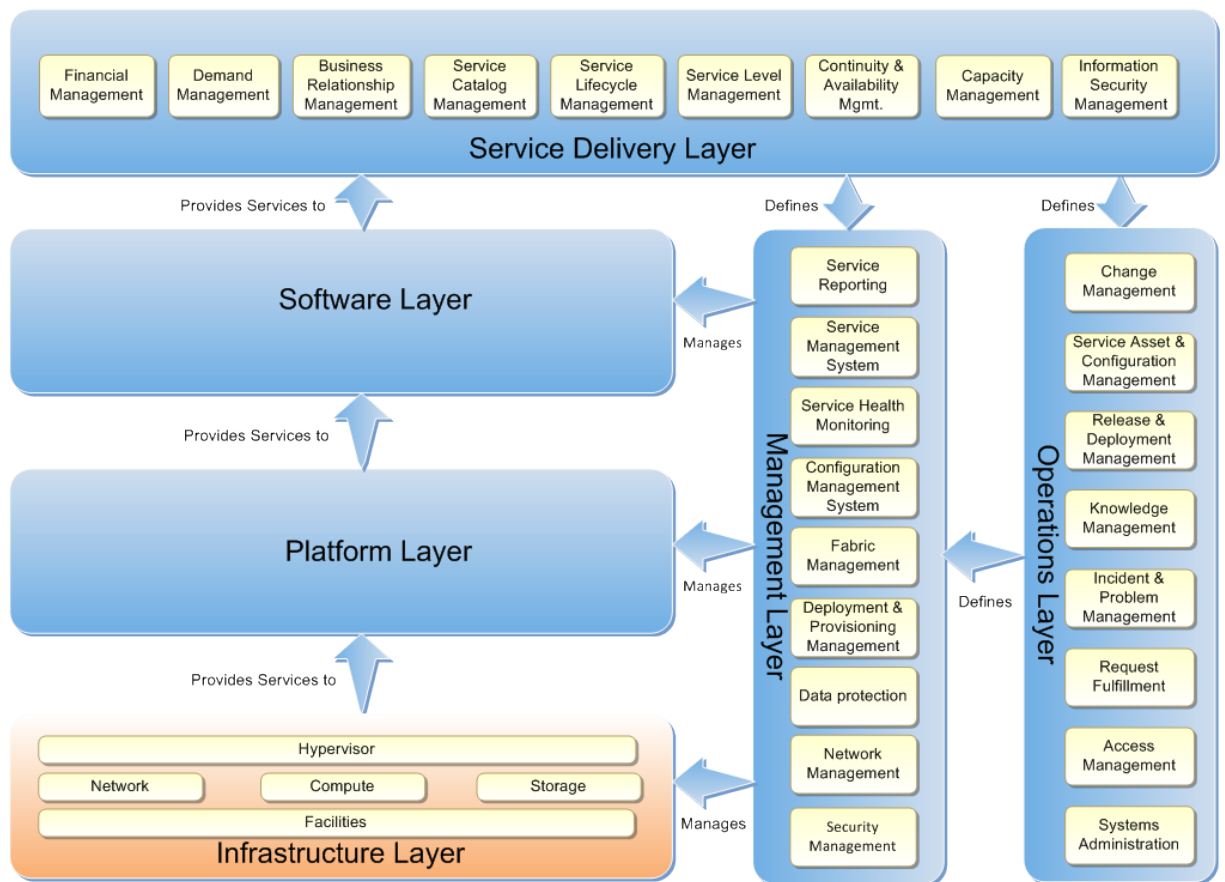
Figure 2: Private Cloud Planning Guide for IaaS. Reprinted from Bill Loeffler, Microsoft (2014) [5]

Figure 2 illustrates which services an infrastructure layer enables in an enterprise and what are the input regulations for it. According to the NIST definition of cloud computing, cloud computing is associated with three service models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). [6] Virtualization can be utilized in a various services, for example Bromium, mentioned in section 2.2 utilizes Security as a Service business model.

2.4 Private and public cloud

The private and public clouds serve fundamentally different purposes. The private cloud limits physical access to infrastructure from hundreds of end nodes to potentially just a dozen specific machines which can access the backend hardware using

specialized software, while the public cloud typically offers a higher degree of access to services via the browser. Different cloud models also represent different pricing and income models. In the private cloud, an infrastructure represents an expense area, costing the company money without generating an income by itself; while in the public cloud an infrastructure is an income area, generating money from the customers who use the services. A list of available OpenStack-powered clouds is available [7] in OpenStack Marketplace, allowing quick evaluation and analysis on the potential scalability.

2.5 Private data centers

Innovation in the private datacenter sector is primarily driven by companies with exceptional internal requirements for the internal infrastructure. It is estimated that an average internet user can bear a maximum of 5-8 seconds before he closes the page, and every millisecond of delay repels the existing users, reducing corporate income. [8] Nowadays cheap broadband internet access makes the users even more demanding. The data center infrastructure of internet companies has to take such aspects of modern life into consideration by design.

Google is extensively building new datacenters around to provide global fast low-latency internet access to its services. They have an exceptional degree of security inside them. Back in 2014, then Google's vice president Vint Cerf, also known as "the father of the internet", visited Finland to oversee the new datacenter built in Hamina, he was denied access to the premises since he did not have the security clearance. Google has a history of being hideous about its internal projects, only revealing projects like B4 (SD-WAN (Software-defined Wide Area Network)) and Google File System (a highly available commodity-based distributed data storage system) after they have been in operations for several years.

Figure 3: Reprinted from The Tech, Google (2016) [8]

As illustrated in Figure 3, Google Data center network facilities are utilizing commodity hardware with exceptional computational density (four hardware switches per server unit).

Facebook currently processed more than a trillion page views a month and processes 9% of overall internet traffic. [9] However, even if physical access is limited and some of architecture is undisclosed, some are not. Companies clearly see the benefits from open-sourcing hardware development, allowing programs like Open Compute Project to exist. Open Compute Project addressed issues of pushing the limits of computing components (data transfer speed, amount of storage), at significantly lower prices per gigabyte (GB)/GB per second/megahertz (MHz) than the typical hardware provider equipment (like HP or Cisco). Facebook engineers achieved $2 billion reduction of expenses on data center infrastructure due to internal and Open Compute Project hardware utilization. [10; 11]

Figure 4: Facebook's "Yosemite", the world-first open source modular chassis servers. Reprinted from Hu Li, Facebook (2015)

Noticeably, Yosemite allows to insert 192 System on Chip (SOC) server cards (shown in Figure 4) into a standard 24-slot server rack, compared to the regular solution of 24 dual-motherboard solution used, for example, in The European Organization for Nuclear Research (CERN). [12]

2.6 OpenStack (software platform for cloud computing)

OpenStack is the second-largest open source project after Linux. It is a free and cross-platform software solution for cloud computing. It is very market-driven, with more than 500 companies backing it and dozens providing commercial products on its basis. It is also driven by the academia, with CERN migrating the majority of its computational infrastructure from OpenNebula to OpenStack. [13]

OpenStack supports all major virtualization platforms, including Xen, Kernel-based Virtual Machine (KVM), VMware, Hyper-V and container virtualization. Major OpenStack updates are released twice a year, with each update adding new components each of which corresponds to a specific function in the cloud environment. The main components, included in the scope of the thesis are shown in Figure 5:
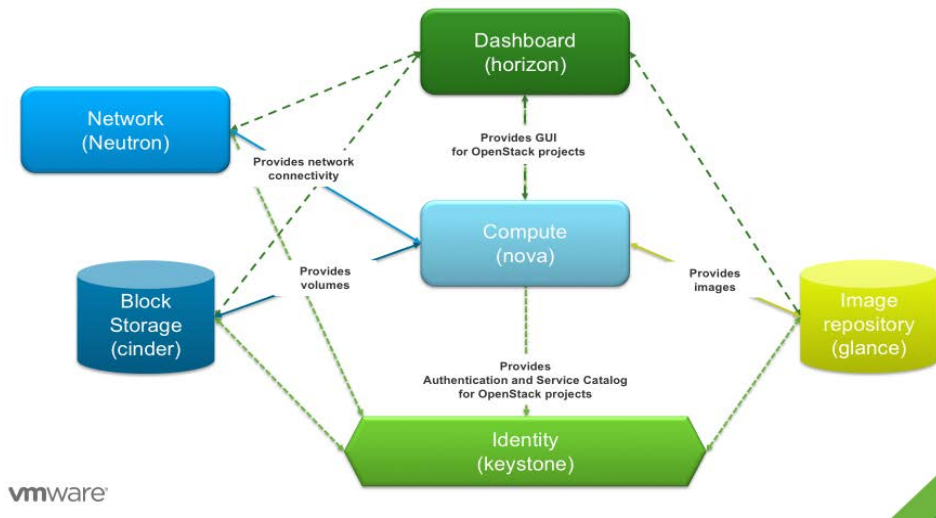
Figure 5: High-level VIO architecture. Reprinted from Trevor Robert Jr, VMware (2015) [14]
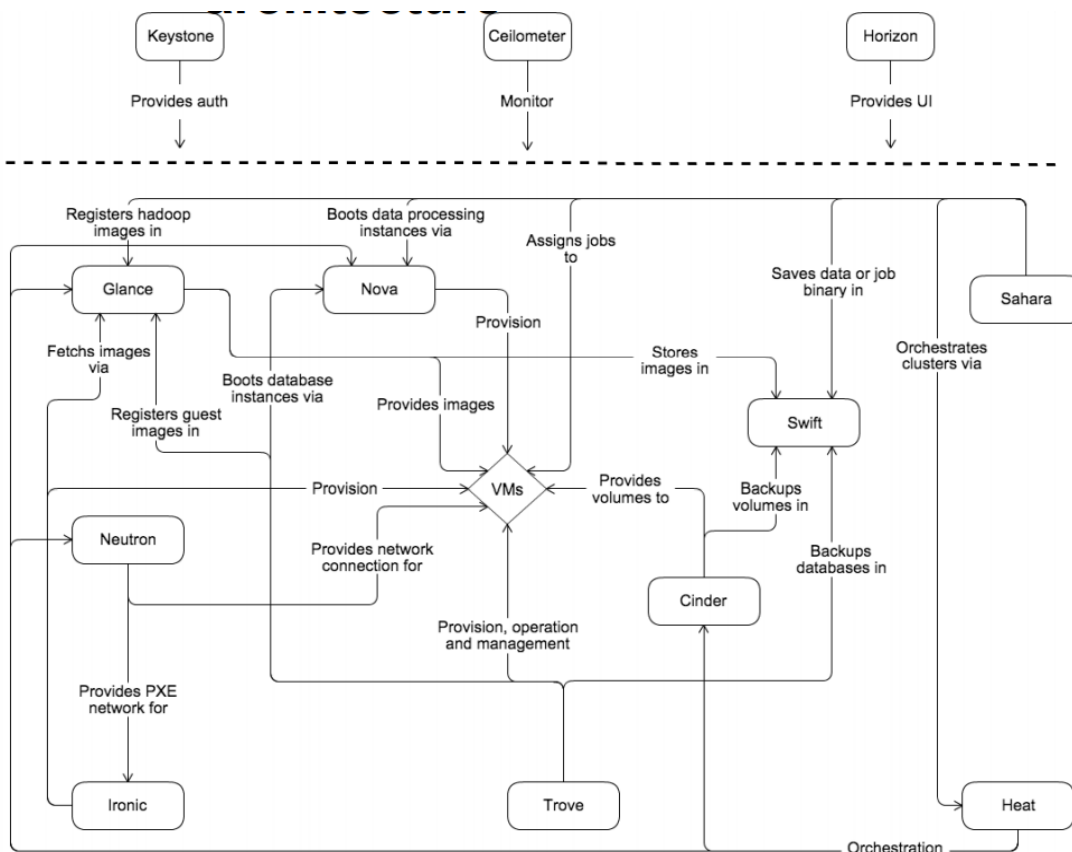

Figure 6: Extended Illustration of interfaces between the high-level OpenStack elements. Reprinted from Nabil Abdennadher, HES-SO (2016)[15]

Figure 6 illustrates the complexity of interfaces between primary and secondary OpenStack components. A list of essential OpenStack elements is available in Appendix A.

2.7 OpenStack versions

OpenStack versions are named in alphabetic order, with the latest OpenStack version called Liberty and the following one called Mitaka. Due to market competition and synergy, companies are motivated to update their added-value products to the latest OpenStack release within a few months. The important objective also is to separate the updates to the OpenStack components from other software components of an infrastructure and allow the possibility of roll-back. This way the production environment does not get ruined by a potential change in the OpenStack architecture. Liberty increases performance of the virtual networking component, image signing and better hybrid cloud management. [16] Mitaka will bring update from both corporate and user sides, enhancing object storage encryption while lowering storage access latency. [17] However for some large enterprises the benefits of an existing OpenStack version are sufficient to just stick to an older version, which is why CERN is still using Kilo in the production. [18]

2.8 User cases with OpenStack

An important advantage of the OpenStack hype is the synergy between the system integrators. People are willing to share their experience of deploying OpenStack with other companies, allowing them to envision potential constraints and challenges.

Amadeus is a global company which provides airplane ticket reservations. They are actively evangelising OpenStack with VMware Integrated OpenStack, claiming it is the perfect solution for rapid deployment of productional OpenStack. Amadeus processed about 1.6 billion data requests per day and processed 95% of the world's scheduled airline seat requests. Amadeus operations are hosted in Germany, and starting 2015 are focusing on the cloud based technologies. They are focusing on cloud automation, utilizing special tools in addition to typical Heat/Puppet/Docker automation: HashiCorp Terraform and JFrog Artifactory. HashiCorp provides well-known datacenter management products like Vagrant. Terraform provides an infrastructure deployment

solution and Artifactory provides a unified repository manager to deploy code from different platforms like Maven and Gradle. Also, Amadeus has solutions for migrating applications between different virtualization platforms (i.e, from KVM to VMware). [19]

AirCloud is a private cloud currently developed by Airbus. It will be used to run applications related to the company's employees, suppliers, customers and partners. AirCloud will be converged in several datacenters across Europe like Germany and France to serve the computing needs of various Airbus Departments.

CERN currently hosts a cluster of around 10 000 VMs primarily used for high-performance physics computing. [20] A few years ago they ran into the problem of exhausting capabilities of Geneva's power grid network, so they built the second extendable full-scale datacenter in Hungary connected with Geneva over a duplicated 100G network, proving the usability of OpenStack-enabled distributed computing on the datacenter level. Tim Bell, CERN's group leader of OS and infrastructure systems, was personally elected as a member of the OpenStack board of directors as recognition of the strategic vision of CERN's computing development.

Intel currently hosts one of the largest VMware-enabled OpenStack clouds, with 10 000 VMs in production as of the end of 2015. [21; 22] Based on the results of the deployment in the production, OpenStack was considered strategically important enough to justify 100M $ investment into Mirantis OpenStack. [23] Despite the history of successful OpenStack deployments, Intel still considers it missing some important enterprise features like native failover, version control, ease integration with existing infrastructure and feature-rich monitoring (although the latter is getting address in OpenStack Mitaka release). [24]

National Security Agency (NSA) is not disclosing the scale of its OpenStack deployment for security reasons. However the scale of their datacenter in Utah provides a glimpse on the potential scale: $2 billion cost of hardware and software. This exceeds the limits of most virtualization systems; however their presence on the OpenStack Summit clearly demonstrates the interest. (OpenStack Summit is a five-day conference organized by the community to bring together OpenStack administrators and developers and discuss the future of cloud computing) [25; 26]

3 Hardware configuration

3.1 Memory constraints for the server

The minimum recommended Random-access memory (RAM) capacity for OpenStack testing is around 64 GB. For that, I had to specifically use a processor and a motherboard which support such RAM capacity. In addition, due to the working conditions (necessity to travel), the server was built on the smaller sized micro Advanced Technology eXtended (mATX)-format motherboard. For the storage, server is using a 500 GB Solid State Drive (SSD) and an additional 2 TB Hard Drive for alternative system topologies.

3.2 Intel Haswell and its virtualization features

Virtualization imposes high requirements on the computational elements of the infrastructure; therefore 6-core Intel Haswell processor is used. With Intel Hyper-Threading technology, up to 12 virtual cores can be used in the cluster, allowing more VMs to run on a single piece of hardware.

3.3 Hardware prerequisites

The computation complexity of the project imposes several assumptions on the hardware in use. Due to virtualization being resource-consuming even on the medium scale, the project will run on a dedicated high-end consumer-level server with a laptop being used for monitoring, testing and deploying additional topologies. The focus, due to the parallelizable nature of cluster virtualization, is to utilize more RAM and processor cores in comparison with average consumer hardware.

3.4 Enterprise prerequisites

The main consideration factors for selection of OpenStack distribution are security, flexibility and availability of enterprise 24/7 service-level agreement (SLA) support. The price of delays in case of junctions in production pipeline is very high, and therefore

use of high-quality SLA license is justified despite the corresponding price. The project has to be able to plug an existing physical infrastructure, including virtual Cisco Nexus 1000V switch. For the licensing cost-reduction, Nexus 1000V Essential edition (with the needed services like Quality of Service (QoS), layer 2 switching and layers 4-7 optimization) can be used for free and then extended to the Advanced edition, adding more security features like IP (Internet Protocol) Guards, Dynamic Address Resolution Protocol Inspection and Dynamic Security Gateway.

3.5 Governmental constraints

One of the governmental restrictions concerns the usage of SSDs. SSDs have to be properly sanitized using tools approved by the government. Until recently, such tools did not exist. However, my setup still uses an unsanitized SSD for the performance and necessitated ubiquity reasons. [27; 28]

4 Software configuration

4.1 OpenNebula as an alternative to OpenStack

OpenNebula is another value-added open-source cloud computing solution. It has some political leverage for deployment in European governmental and research facilities, much like Boeing/Airbus bipolar competition, because OpenNebula (despite being open-source), is mainly developed by European OpenNebula company. Initially it was used in CERN; however CERN moved to OpenStack later on. The main reason was that American companies were financially committed to evaluation of OpenStack possibilities. [29] Another reason was that academia was not willing to be the largest consumer of OpenNebula technologies in order to avoid being the pioneer in running into scalability constraints. For testing purposes, it is possible to deploy a testing OpenNebula environment using Virtualbox.

4.2 OpenStack Flavor selection

The extendability evaluated includes support for the main mainstream virtualization platforms, including KVM, Hyper-V and VMware vSphere, [30] since most companies rely on multi-hypervisor solutions for the cloud deployment. In the scope of the project,

however, the selection of cloud solutions is limited to the private infrastructure solutions.

The full list of third-party vendors providing VMware integration with OpenStack is as follows:

- HP Helion OpenStack
- IBM Cloud Manager with OpenStack
- Mirantis OpenStack Private Cloud Software
- Platform9 Managed OpenStack
- Red Hat Enterprise Linux® OpenStack Platform
- SUSE OpenStack Cloud
- Ubuntu OpenStack
- VMware Integrated OpenStack.

RHEL and CentOS have to be supported as the node OSs due to Red Hat being prevalent in the secure Linux OS market. Support for CentOS nodes has been deprecated, so for this particular use case, Red Hat Distributed OpenStack (RDO) platform has to be used. Red Hat does not provide the certification for other OpenStack platforms besides their own, so for governmental use, RDO is preferable.

Another point of consideration is the availability of various configuration management databases (CMDBs) for storage options. Traditionally, Oracle Database is considered for the enterprise; however with open source solutions reaching good-enough state and database not having a central role in the project, other database options are taken into consideration (i.e, MongoDB). Additionally, selected OpenStack solution has to support a wide-range of cross-platform backend products, since the final choice of the backend is by the customer (a.i, the customer supplies hardware), so the main products lines of Dell, HP, Cisco and Juniper has to be supported.

4.3 Hypervisor selection

Container-based virtualization capabilities were not considered due to inherent problems of the state of container security (that actually refers to nested containerization, since OpenStack Fuel itself is deployed using containers). The problems with container security are unavoidable by design, since containers share the

same OS kernel and many require root (administrator) access level to operate [31] Also, container-virtualization requires extensive expenses on the maintenance personnel once the solution is returned to the customer and deployed at scale. (Airbus Defence and Space mainly focus on the infrastructure development with the maintenance performed by the customer).

The important criteria was the reusability of the present IT training of the support personnel and ease of transition to the newer environment. Therefore, the hypervisor hides the complexity of the OpenStack design behind the known features of the traditional cloud infrastructure. For the scalability and due to the fact that initial OpenStack hosting and management solution imposes some load on the hardware by itself (without the deployed infrastructure), VMware ESXi enterprise bare-metal hypervisor was selected. Additionally, VMware stack is confirmed to integrate with the Nexus 1000V switch by the manufacturer. [32]

4.4 Mirantis OpenStack

Mirantis is a software company which provides business-to-business OpenStack distribution. It has a proven record of being used in an enterprise, being used i.e by the largest Middle East telecom company, Saudi Telecom. [33] It specifically targets OpenStack and specifically its controller component as a point of development, making the company able to better understand the issues and possess deeper knowledge about the product, unlike some broad-product-spectrum companies offering OpenStack like Red Hat.

Due to the moderate size of the company, there is an opportunity to negotiate a discount with them, since all the other enterprise OpenStack solutions are provided by large corporations like Microsoft and Dell, which have less financial flexibility for negotiations. Also, being a relatively new company, Mirantis has an incentive to keep up the support quality in order to attract and keep the new customers.

Due to the quality of Mirantis software, Mirantis Fuel (a deployment and management solution), [34] was moved to an OpenStack upstream, meaning it is commercially supported and recognized by the whole community, ensuring long-term support of the Mirantis-based OpenStack solutions. This was possible because Mirantis employees

are members of both the technical committee and the board of directors of the OpenStack project, giving the company organizational leverage. Mirantis Fuel has an added layer of virtualization, encapsulating the components of OpenStack itself into the Docker, another open-source project which provides systems abstraction by running applications as separate Linux containers. This allows rapid convergence and re-deployment of the Fuel environment.

4.5 Fuel architecture

As shown in Figure 7, Fuel architecture is built using standardized solutions in software architecture (as shown in Figure 7), including: REST API (Representational State Transfer Application Programming Interface) is the architectural style of World Wide Web (WWW) applications.
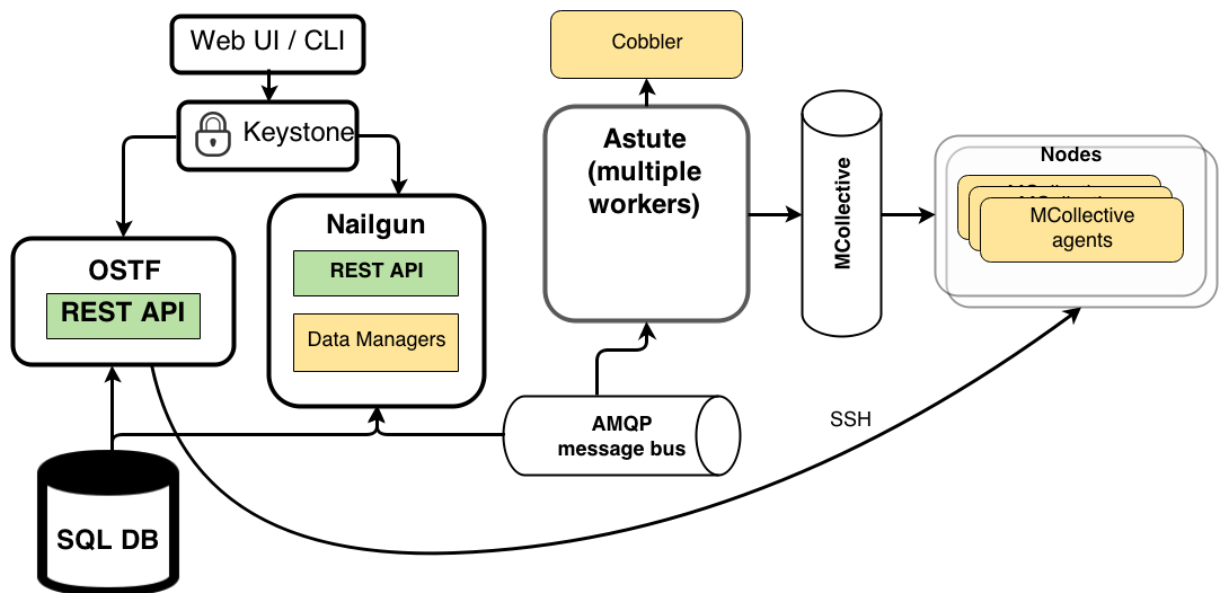

Figure 7: Fuel architecture. Reprinted from Fuel, Mirantis (2013) [35]

REST focuses on inducing the following properties on WWW components: Performance, Scalability, Simplicity, Modifiability, Visibility, Portability and Reliability.

Figure 8 illustrates Simplicity and Visibility aspects of REST architecture as implemented in HTTP GET queries.

Source	Destination	Protocol	Length	Info
10.100.21.132	216.58.209.110	HTTP	1258	GET / HTTP/1.1
216.58.209.110	10.100.21.132	HTTP	537	HTTP/1.1 302 Found (text/html)
10.100.21.132	216.58.213.3	HTTP	1382	GET /?gfe_rd=cr&ei=ihvsVrrNMKSr8wfWyrzQDA HTTP/1.1
216.58.213.3	10.100.21.132	HTTP	640	HTTP/1.1 302 Found (text/html)

Figure 8: analysis of HTTP network queries upon entering google.com in the browser

AMQP (Advanced Message Queuing Protocol) as a messaging protocol. It implements unifies messaging systems, ensuring message security, routing and reliability. SSH (secure shell), provided by the Helsinki-based SSH Communications, is an encrypted network protocol for secure remote login and network connection over insecure network. SSH and REST are providing, correspondingly, secure- and standardization features to the HTTP protocol, which is an application protocol and basically the foundation of the World Wide Web. [36][1]

5 PoC Implementation of OpenStack-based solution

PoC impelementation is focusing on implementing the basic goals of the project:
1) Building scalable OpenStack deployment using a budget-conscious hardware solution as mentioned in chapter 4.
2) Implementing necessary business-related deployment, management and monitoring functions on top OpenStack solution.

5.1 Installing vCenter Server

ESXi is installed on the server, with the VMware vSphere client being installed on a laptop for the monitoring and configuration purposes and VMware vCenter Server installed on the ESXi. A Windows guest machine is used to run vCenter Server instead of Linux-based VCSA (VMware vCenter Server Virtual Appliance) even despite higher overhead, because the same Windows guest is planned to be reused to host Active Directory service which has to be integrated with OpenStack infrastructure for authentication. Domain Name System (DNS) and Dynamic Host Configuration Protocol (DHCP) services are provided to the end nodes by the Mirantis Master node higher on the software stack.

[1] The rest of architecture is explained in section 5.4

VMware is configured to utilise Dynamic Resource Scheduler, which is an important feature for enterprise deployment since it allows to better maintain the dynamic workload on VMs, reducing downtime and performance of the system.

As of December 2015, there were issues with accessing web vSphere Web Client through the Chrome browser because Chrome browser deprecated support for the Netscape Plugin Application Programming Interface (NPAPI) which vSphere is using. Also Internet Explorer 11 could not be used in an air gapped environment because it required updating before installation. Therefore, Firefox with pre-installed Adobe Flash and vSphere Client integration plugin has to be used.
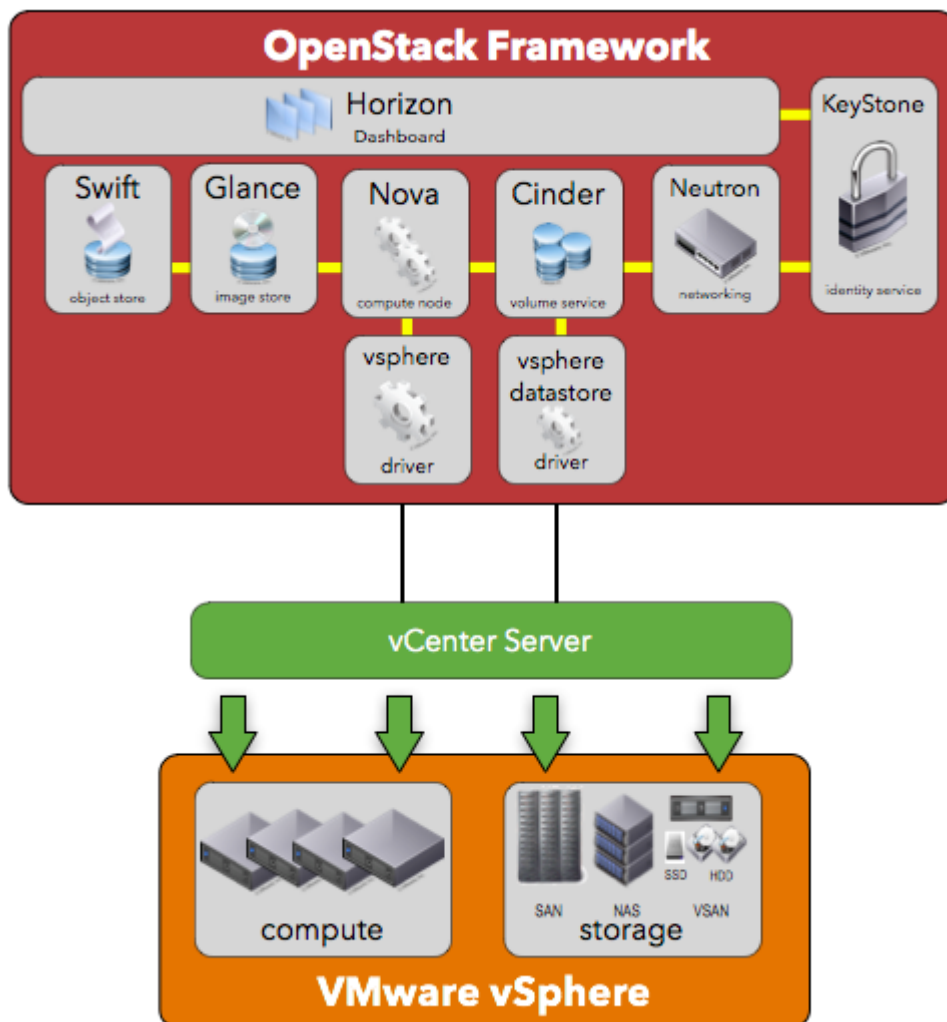
Figure 9: vSphere - OpenStack integration. Reprinted from Rawlinson Rivera, VMware (2014) [37]

Figure 9 illustrates the reasoning behind using vSphere as a hardware management backend: it abstracts the complexity of management from the OpenStack layer,

allowing PaaS as a Minimum Valuable Product (MVP) to be built using less resources and time.

5.2 Preparing private deployment

For the security reasons, solution has to run air gapped (meaning no internet access in any form). Since Mirantis uses public repositories to download Linux images to deploy on the nodes, local repository has to be set on a vSphere infrastructure. This is done using mirantis-createmirror tool on the Mirantis Master node. In Mirantis 8.0, there is an option to configure a proxy to maintain some balance between security and dynamic update rollouts.

5.3 Installing Mirantis Fuel

Initially, Fuel is deployed as a VMware Open Virtualization Format (OVF) template, which is a collection of virtual machines operated and monitored together. Once deployed, Fuel vApp converges into a set of four virtual machines (six in the case of Virtualbox-based minimal configuration, used for initial testing). Out of these machines, one is always pre-configured as a Master Node and the roles for others can be freely assigned from the Fuel GUI according to the topological requirements. Master Node hosts the syslog file which stores the real-time system logging information from the nodes and the web interface, so it is possible to see the history of all changes to the deployment. Figure 10 illustrates the timing and verbosity of syslog updates:
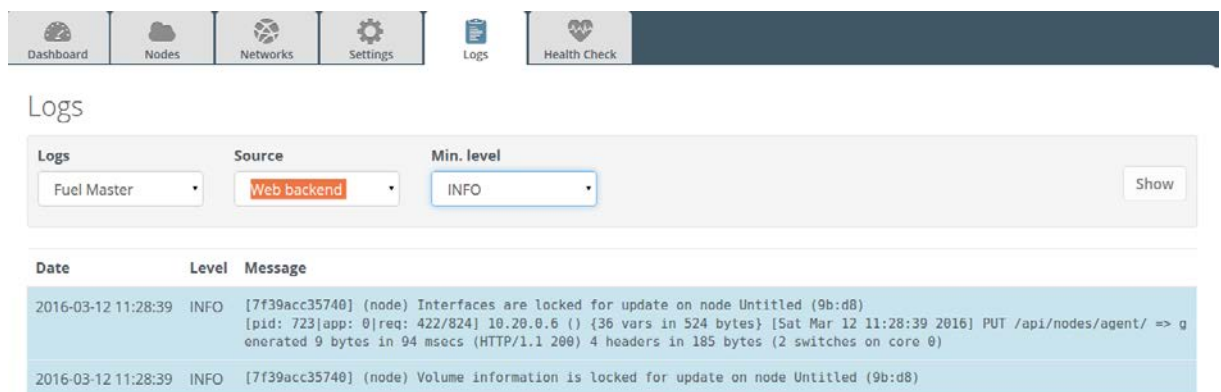
Figure 10: Screencap of Fuel logging interface

An eth1 Master node IP address is used to access the Fuel Graphical User Interface (GUI), upon logging in with default admin credentials following system elements has to be configured:

- Environment name,
- OpenStack version and guest VMs OS (configured on the Master node beforehand by creating the local mirror),
- Compute configuration:
  KVM, Qemu or vCenter,
- network configuration: Neutron or (outdated) Nova, (Neutron can be configured in multi-tenant topology, since the deployment is for private datacenter, single tenant configuration is used),
- Storage backend: default or Ceph (distributed storage cluster),
- Additional components: Sahara (Hadoop support),
- Murano (cloud app catalog, not used in air gapped solution),
- Ceilometer (potentially useful as an addition to Zabbix and vCenter-included (vRealize Operations Management Suite)) for system monitoring.

5.4 Fuel node discovery and modification

Once a physical (or virtually hosted) machine with the pre-enabled Pre-Boot Execution Environment (PXE) is found by the Master Node (as shown in Figure 11), the Master Nodes pushes a specific bootstrap image with a specific Python-based application called Nailgun Agent.
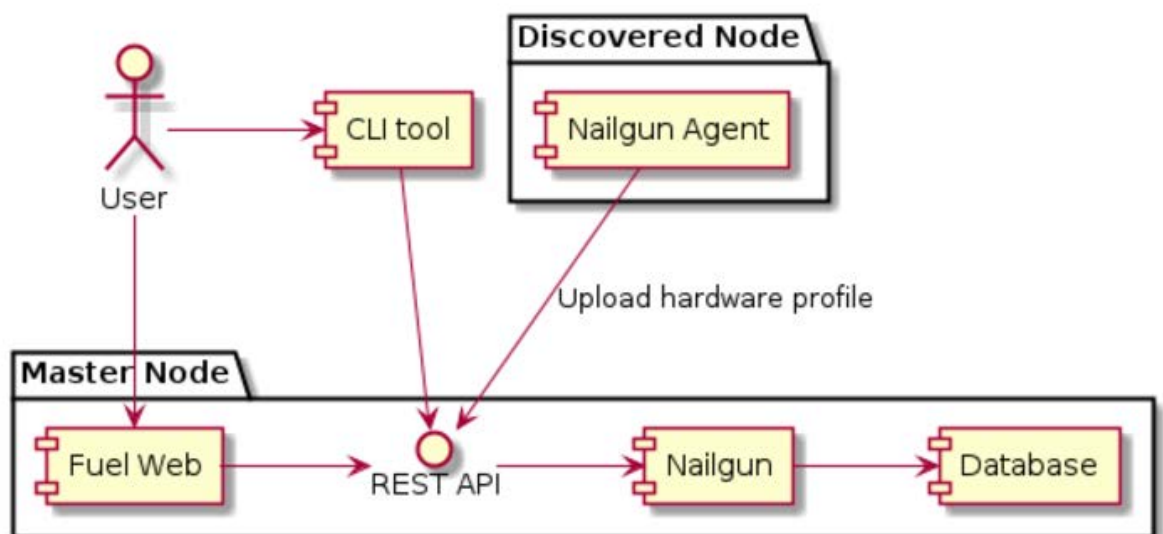
Figure 11: Fuel architecture. Reprinted from Mirantis (2014) [38]

Nailgun duplicates the role of an SNMP agent in the OpenStack context, allowing the Master node to communicate and collect the data from the discovered node through the CLI or the web interface.
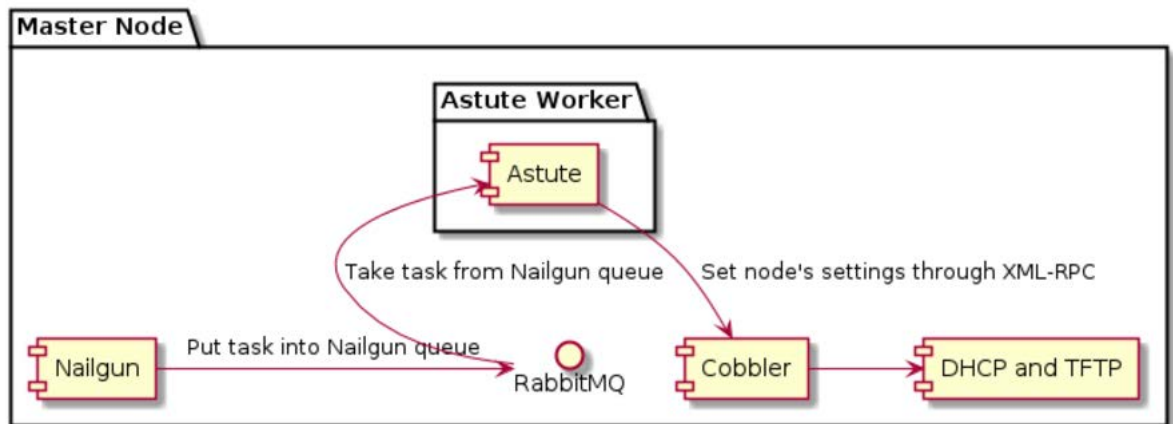
Figure 12: Fuel architecture. Reprinted from Mirantis (2014) [38]

Figure 12 provides an insight on components of the Master Node: Astute Worker is a set of environment deployment processes mainly involved in the installation stage, however it also handles some tasks after the initial deployment, like updating /etc/hosts on the existing nodes then the new nodes are discovered. Cobbler is a bare-metal provisioning systems which does the task of initial installation of Linux on OpenStack nodes. It can be directly accessed from the Fuel GUI interface. It allows, for example, to set specific kernel parameters to an OpenStack Linux nodes. [39]
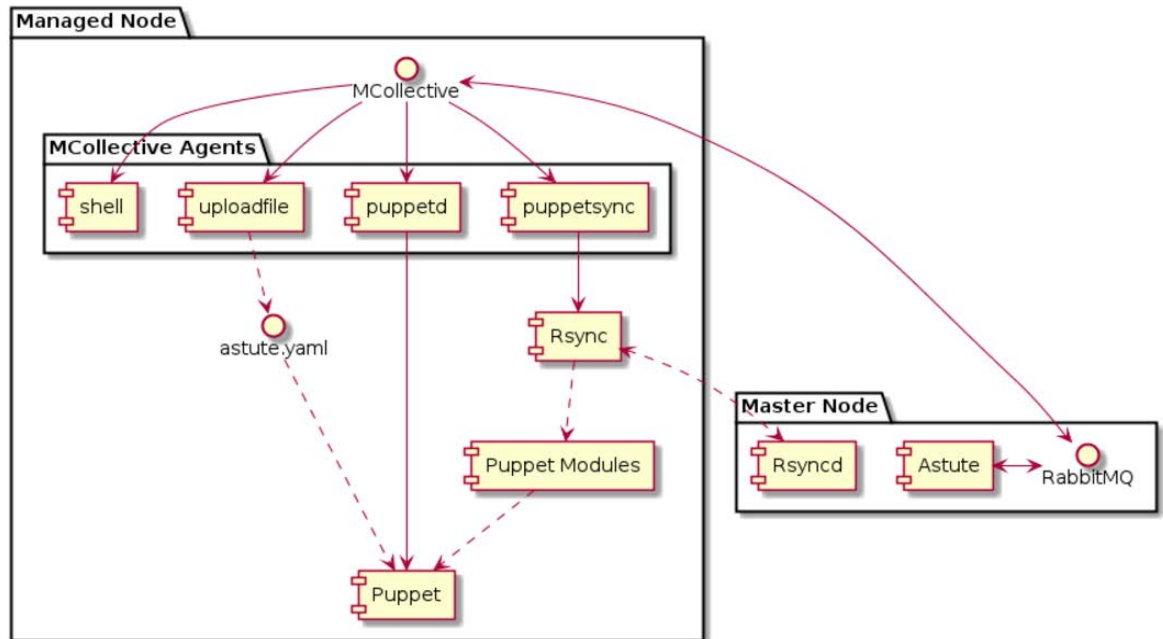
Figure 13: Fuel architecture. Reprinted from Mirantis (2014) [38]

As Figure 13 illustrates, Master Nodes host an rsyncd server which enables node management with Puppet.

5.5 Fuel internal networking setup

Just to deploy the initial OpenStack infrastructure, Fuel requires five networks to be configured on the VMware:

Admin PXE: Allows PXE booting of the VMs

Storage: used for storage traffic

Management: used for internal OpenStack communication

Private: used for private virtual local area network (VLAN) allocation

Public: enables virtual machine to access the network outside OpenStack cloud.

5.6 Fuel node configuration

For the reasons of productional stability, Fuel from the scratch is configured in highly-available configuration (with 3 virtual machines deployed as controller nodes). All the other nodes can be assigned a role of controller, compute or storage (as shown in Figure 14):

Assign Roles

Controller
The Controller initiates orchestration activities and provides an external API. Other components like Glance (image storage), Keystone (identity management), Horizon (OpenStack dashboard) and Nova-Scheduler are installed on the controller as well.

Compute
A Compute node creates, manages, and terminates virtual machine instances.

Storage - Cinder
Cinder provides scheduling of block storage resources, typically delivered over iSCSI and other compatible backend storage systems. Block storage can be used for database storage, expandable file systems, or to provide a server with access to raw block level devices.

Figure 14: Screencap of Fuel node configuration interface

Additionally, each Fuel node can be flexibly configured with storage and networking resources:

1) The amount of network interfaces and the binding of the VLANs to these interfaces.

2) Allocated storage and the amount of the hard drives.

Individual node monitoring from the pre-deployment GUI is available for Original Equipment Manufacturer (OEM) type, CPU type, RAM, storage and network allocation.

5.7 Adding plugins

Plugins are installed by adding rpm packages to Fuel Master node. Since the node is installed as a guest on the Windows host system, third-party software (WinSCP) is used to connect to the Fuel node over Secure Copy (SCP) protocol.

```
# scp zabbix_monitorin
g-2.0-2.0.0-1.noarch.rpm root@:/tmp
# cd /tmp # fuel plugins --install zabbix_monitoring-2.0-2.0.0-1.noarch.rpm
# fuel plugins id | name | version | package_version
---|--------------------------|---------|---------------
1 | zabbix_monitoring | 2.0.0 | 3.0.0
```

(Example of commands required to install Zabbix monitoring plugin).
With update of Mirantis Fuel to version 8 in March 2016, Fuel gained the ability to push new enterprise plugins to the end nodes without the need to redeploy the whole infrastructure. [40]

5.8 Configuring OpenStack Dashboard

Once the system nodes are configured, the management browser-based GUI dashboard called Horizon can be launched from the Fuel GUI. Horizon is the main tool for the system administrator to interact with the OpenStack cloud. It is hosted on the Fuel Master node. OpenStack Dashboard is Django-powered, meaning it runs on the Master node as a Python-based webserver, elimination the need in Apache. With Django, the whole Dashboard can be easily modified to the given project needs using Python. [38] Figure 15 illustrates the system elements of OpenStack Dashboard, all of which can be modified using Python:
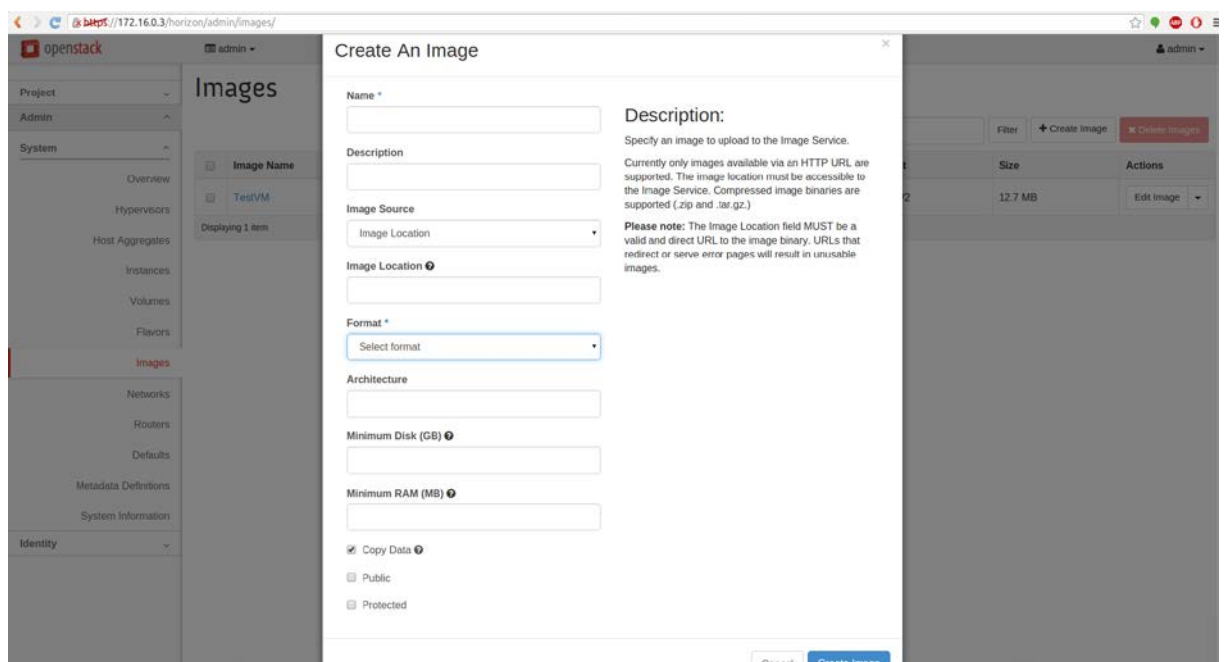
Figure 15: Creation of the new VM template in OpenStack Dashboard

OpenStack Dashboard allows to directly launch new VMware cluster machines from the Horizon Hypervisor tab. The newly created machines are also visible in the vSphere web client.

5.9 OpenStack in a multi-hypervisor cloud

A typical enterprise company uses multiple hypervisors within its infrastructure. One of the most important needs is to support legacy applications, because normally they are the ones generating the largest share of revenue.

CERN, for example, was primarily using a mix of KVM and Hyper-V hypervisors before considering the migration to open-source solutions.
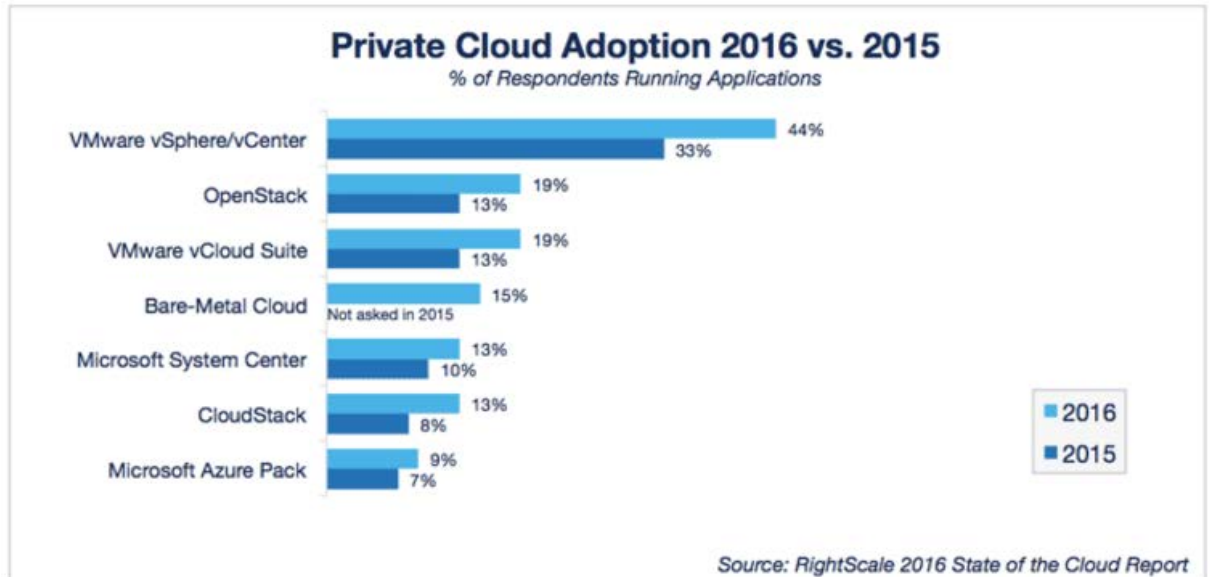
Figure 16: Cloud Computing Trends. Reprinted from Kim Weins, Rightscale (2016) [41]

Figure 16 confirms the industrial prevalence of vSphere and OpenStack as the leading private cloud platform. Additionally, it should be noticed that while Microsoft Azure Pack has the lowest market share, it will be replaced by the Azure Stack in 2016-2017. The difference is that Azure Pack provides application cloud hosting tied with System Center backend and Azure front end, while Azure Stack delivers the full set of data center features, including SDN, data center services and infrastructure and enhanced management capabilities. The positive business driver is that Azure Pack is free for customers paying for System Center license. I can not specify how much it costs, due to the NDA from Microsoft as of March 2016. [42; 43]

Figure 17: Microsoft Azure Stack Architecture. Reprinted from Dishan M.Francis [44]

Figure 17 illustrates what Azure Stack covers hardware as a service (HaaS) to software as a service (SaaS) service layers (as represented by the Cloud-inspired infrastructure and the Azure Resource Manager boxes in the figure, correspondingly). Note the overall design similarity with an OpenStack-on-VMware solution proposed in this paper (Figure 9).

5.10 CLI node configuration

Besides creation of the new node via Dashboard to vCenter approach, the following commands are used to create a new node via Nova CLI on the Fuel Master node:

- nova boot (create a new VM in OpenStack stack from the pre-configured template)
- nova list (list names of created OpenStack instances)
- nova list | grep -w instance_name | awk ' { print $XX } ' | cut -d = -f 2 (Where server_name is the name of the instance). (Lists IP addresses of an active OpenStack nodes)
- nc IP 22 (check if the node is reachable via ssh protocol). [45]

5.11 Deployment of distributed applications using Murano OpenStack

OpenStack supports three ways of reutilizing pre-packaged applications as shown in Figure 18:

Murano Packages

In Murano Packages you will find complete applications, in both simple and clustered configurations, ready to deploy on your cloud. To use them:

1. Verify that you have Murano installed
2. Browse the list and find the app package you want
3. Highlight and copy the name of the app package
4. In Horizon, navigate to Murano > Manage > Package Definitions and click Import Package
5. Paste the app package name into the labeled text field, and click Next. This will download and install the package components.
6. Now deploy the app on your cloud by navigating to Application Catalog > Environments, then creating and deploying that environment.

Heat Templates

In Heat Templates you will find templates for creating complete stacks in your cloud. To use them:

1. Browse the list and find the one you want
2. Download the template yaml (.yml) file to your local machine
3. Use Horizon to add the template to Heat (by uploading it via file selector, or copy/pasting it into the editable field)
4. Use the Heat client to create a stack

Glance Images

In Glance Images you will find a library of preconfigured images ready to launch virtual machines on your cloud. To use them:

1. Browse the list and find the one you want
2. Copy the URL for the image file
3. Use the Glance client to add it to your cloud with the --copy-from option, or add the image from Horizon by creating a new image, and specifying the URL as the image location.
4. You can use Nova to launch a VM from the new image; or, you can choose an image to launch from the Glance images list shown in Horizon. Of course, if a service is preconfigured to launch VMs by itself directly from specific guest images, you're good to go.
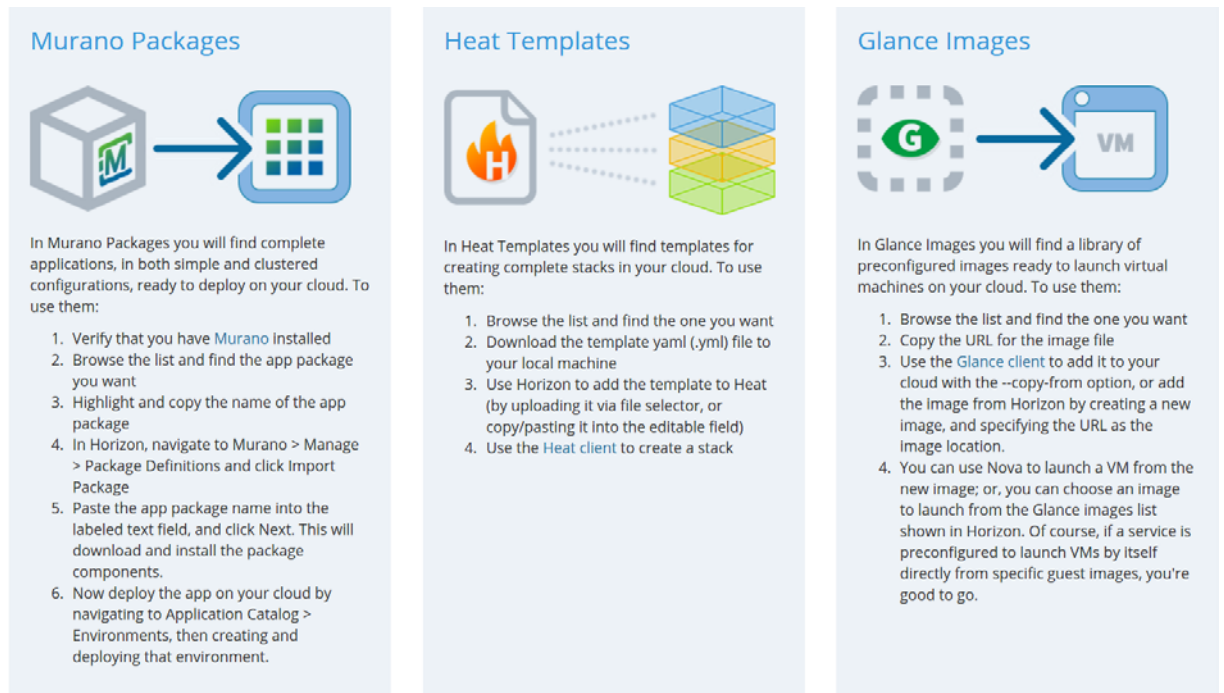
Figure 18: OpenStack Application Catalog. Reprinted from OpenStack Foundation [46]

OpenStack App Catalog allows replication of community assets (applications) from the public repository to sustain air gapped deployment requirement. [47]

The main application installation method for Mirantis OpenStack is Murano. Murano is an native OpenStack component which consists of the following elements: Murano dashboard in the management GUI, Murano API with an access to the database of application packages, Murano Agents deployed on the end nodes (similarly to Nailgun Agents), Murano client CLI and Murano Engine which binds all the elements together. Murano API and Engine are interfaced together via RabbitMQ (RabbitMQ is an implementation of AMQP (See section 4.6 Fuel architecture)). [48] Murano provides an easy way to redistribute such pre-packages application on the VMs as Apache Tomcat, Docker-powered NginxTomcat/Jenkins/MongoDB/MySQL, Zabbix and WordPress. It also provides application auto-scaling and usage statistics.

5.12 Deployment of distributed applications using Openshift

The following section comes from my correspondence with Amadeus engineers, providing curious insight on the business drives behind Openshift integration:

"The drive to build the first OpenStack evaluation environment came from a new project that tries to evolve a traditional application into becoming more cloud-ready. These are inhouse, C++, enterprise service bus (ESB)-based applications, and the path to making them cloud-ready is through containerization (docker). So one part of the project is making the application run on containers, the other part is deploying container runtimes (Openshift v3/Kubernetes)*[2] on top of public/private clouds. That's where OpenStack comes in.

We went with VIO (VMware Integrated OpenStack) for production due to our long relationship with VMware at the Ops site. We also went with Red Hat OpenStack Platform (OSP) at the Research and Development (R&D) site due to the good relationship with them as well. For the application, the choice of OpenStack platform does not make a big difference: we deploy it mostly in the same way on the two platforms.

For the applications that we do not develop ourselves (mostly in the persistence and monitoring/data collection layers), we just automated their deployment on top of the public/private clouds. We did not look at OpenStack Marketplace. Long term, I think we will be using containerization more and more in preference to just virtualization through the IaaS layer. But to migrate everything to that model, I think IaaS (like OpenStack) will be the transition technology." (Roberto Jung Drebes, Amadeus, March 2016).[49]

5.13 Evaluating SDN with OpenStack

Mirantis OpenStack has a native plugins to support network virtualization (NSX) and Juniper OpenContrail software-defined network (SDN) solutions. However, the final

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[2] Openshift is a Red Hat-supported Docker-based platform for the streamlined application delivery. Openshift is a Red Hat-supported Docker-based platform for the streamlined application delivery.

implementation of these plugins is left beyond the scope of this thesis. The Figure 18 presents potential interfaces for SDN integration.

Figure 18: Installing Contrail with VMware vCenter. Reprinted from VMware [50][51]

5.14 Windows integration

Windows integration is an important agenda due to the necessity of backward support for the presently deployed application. [52] Even though Windows is declared as integrated in the OpenStack infrastructure, in practice it need to be modified to be seen as OpenStack element. This is done by installing VirtIO drivers on each Windows templated used for the node deployment. [53] Unfortunately, there are no Windows 10 drivers as of January 2016. However, for now there are proven solutions for integration Windows Nano Server into an OpenStack infrastructure. [54] Windows Nano is a new feature in Windows Server which will be released in autumn 2016. Windows Nano Server is like a CoreOS for Windows (CoreOS is a minimized kernel-based Linux distribution for massive server deployments). Nano also reduces an attack surface and

the number of updates and increases overall stability by cutting out GUI and x32 features from Windows Server image.

From the security point of view, Windows integration is important because it enables Active Directory Domain Services authentication, which is one of the dominant solutions for authentication in an enterprise.

Possible configuration steps needed to prepare a Windows template for an OpenStack deployment include the following:

A. Contacting third-party like Cloudbased Solutions for the outsourcing
B. Manual installation:
1) Create VM in vsphere
2) Connect two ISOs to the VM: Windows image and VirtIO drivers.

In fact, Cloudbased Solutions are an official Mirantis partner, providing Hyper-V driver.

6 Comparison with System Center / Azure Stack

For the project to be considered successful, it has to demonstrate benefits over (potentially) existent infrastructure solutions. Therefore, the deployed OpenStack infrastructure is compared against presently prevalent data center management solutions: Microsoft System Center. System Center is a set of tools for hosting, controlling and monitoring IT services in a heterogenous Windows/Unix environment.

6.1 Advantages of OpenStack over System Center

OpenStack by itself (without third-party provider software like Mirantis) if free, and even with a full-set of such software still considerable cheaper than the corresponding System Center Operations Manager / System center Configuration Manager (SCOM/SCCM) license for large-scale deployment. Another advantage is that a big share of the SCOM/SCCM license cost comes from the Microsoft Azure (Microsoft Public Cloud Solution) management functionality which is not needed in a private datacenter. With the tighter competition between VMware and Microsoft on the hypervisor market, Microsoft is cutting corners [55] on the support of VMware and XenServer as a hosting backend, making a multi-hypervisor environment less desirable. Fortunately, the latter is not an issue in OpenStack. Also, with the public

cloud hype, Microsoft seems to be pouring significant amount of effort into Azure development instead of adding new features to the System Center.

6.2 Disadvantages and limitations of OpenStack over System Center

Naturally, OpenStack enables a much lesser degree of Windows integration for the infrastructure. System Center is basically maintained by a single company promoting its own interests, while OpenStack distributions tend to compete between each other and lock other vendors from reaching additional functionality (like in the case of Red Hat denying certifications to promote its own OpenStack RDO distribution).

7 Discussion

It requires a significant amount of reconfiguration to migrate an existing pre-configured environment from the traditional private cloud architecture to OpenStack. The level of Microsoft integration is definitely lower in comparison with System Center; however semi-heterogenous or pure Linux-based infrastructures are good enough. The next-generation networking components like SDN are much better integrated in the Linux-on-OpenStack scenario. The system has to define the necessity of the deployment of distributed applications as a business goal of next-generation distributed applications. Otherwise, the benefits of deploying OpenStack are overshadowed by configuration complexity. Quoting Forrester Research report ordered by OpenStack project itself, "Legacy workloads are rarely suitable for simple migration to a cloud environment, and retrofitting can be costly and time-intensive." [56] Retrospectively, it would have been easier to use RDO as an OpenStack flavor due to the Red Hat licensing from the former.

8 Conclusion

The testing infrastructure was built according to the stated goals and guidelines, the management and monitoring components of the system were evaluated, but the full scope of the system was not achieved due to the lack of available solutions for the distributed OpenStack computing. OpenStack is presently in the state there it can be effectively used in production under a range of assumptions, including running in a

predominantly Linux environment with a strong focus on networking. Added value applications are benefiting from an OpenStack deployment unless the legacy monolithic solutions are deployed. During the thesis implementation phase, Azure Stack surfaced as an exciting target for service delivery analysis, and even though the initially stated project goals and the project timeline prevented thorough analysis, Azure Stack does take an architectural inspiration in OpenStack, simplifying further investigation of the topic (section 5.9). It could also be very beneficial to further evaluate commercial SDN solutions with OpenStack.

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Appendix A

Component Name	Description
OpenStack Compute (Nova)	OpenStack compute (codename: Nova) is the component which allows the user to create and manage virtual servers using the machine images. It is the brain of the Cloud. OpenStack compute provisions and manages large networks of virtual machines.
Block Storage (Cinder)	This component provides persistent block storage to running instances. The flexible architecture makes creating and managing block storage devices very easy.
Object Storage (Swift)	This component stores and retrieves unstructured data objects through the HTTP based APIs. Further, it is also fault tolerant due to its data replication and scale out architecture.
OpenStack Networking (Neutron)	It is a pluggable, scalable and API-driven system for managing networks. OpenStack networking is useful for VLAN management, management of IP addresses to different VMs and management of firewalls using these components.
Identity Service (Keystone)	This provides a central directory of users mapped to the OpenStack services. It is used to provide an authentication and authorization service for other OpenStack services.
OpenStack Image Service (Glance)	This provides the discovery, registration and delivery services for the disk and server images. It stores and retrieves the virtual machine disk image.
OpenStack Telemetry Service (Ceilometer)	It monitors the usage of the Cloud services and decides the billing accordingly. This component is also used to decide the scalability and obtain the statistics regarding the usage.
Dashboard (Horizon)	This component provides a web-based portal to interact with all the underlying OpenStack services, such as NOVA, Neutron, etc.

| Orchestration (Heat) | Orchestration engine to launch multiple composite cloud applications based on templates in the form of text files that can be treated like code. |