Criteria for Evaluation of Open Source Cloud Computing Solutions

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Abstract. *Cloud computing promises on-demand scalability and flexibility for the enterprise environment and open source products have a large presence in this area. We have devised an elaborate set of criteria for evaluation and comparison of open source IaaS cloud computing solutions which can be used for ranking and choosing between the available products. We explain each criteria group, and give both the rationale and the estimated impact of the criteria. We also briefly introduce a number of most common open source cloud computing IaaS solutions to be evaluated using the explained criteria.*

Keywords. Cloud Computing, Open Source Cloud, Infrastructure as a Service, Enterprise, Evaluation

1. Introduction

Cloud computing is a recent combination of resource management and provisioning technologies build on the concepts of elasticity, ease of use and mass deployment. Cloud computing implementations are centered around three service models [3]: *Software-as-a-Service* (SaaS), offering its users a ready-made application with little or no control or customizability of its innards or underlying infrastructure; *Platform-as-a-Service* (PaaS), offering developers a development and deployment platform with a rich set of APIs, programming languages and tools used to create customized applications for end-users, with limited control over the entire environment; and *Infrastructure-as-a-Service* (IaaS), offering full control of virtualized low-level infrastructure used to build customized applications or higher-level products.

2. Motivation

Most important goals for enterprise IT departments are agility and cost control. Cloud computing fulfills these requirements and allows IT departments to elastically deploy resources from a centrally managed pool. Open source solutions, with lower initial investments, are a viable alternative to commercial vendors, especially as business conditions deteriorate and the economy constrains.

3. Criteria

Evaluation of complex products requires an elaborate and complete set of evaluation criteria as a baseline for comparison. Even though the primary focus of our evaluation is on open source IaaS products, we found the opportunity to objectively compare such products to those from closed/commercial domain to be very valuable. Furthermore, some of the criteria can be directly applied to or easily extended to apply to other cloud computing models (SaaS and PaaS). This is especially true for high-level criteria such as management, security and service levels.

We have devised a set of about 100 criteria grouped into six main categories: storage, virtualization, network, management, security and vendor support. These categories, targeting features interesting for enterprise deployment, can further be divided into basic IaaS properties commonly described in literature (storage, virtualization, network and management) [3,4], and additional generic features (security, vendor support). Assigning weights to areas of special interest enables high-level decisions.

3.1. Storage criteria

Virtual machine storage management is vital for cloud computing architectures as it must be powerful and flexible enough to allow the implementation of core cloud goals: flexibility, scaling and ease of use. Storage criteria cover the main technology groups in which the storage may be implemented: direct-attached storage (DAS), storage area networks (SAN) and network-attached storage (NAS). Backup technologies are covered as a related feature.

These main technology groups include a list of criteria which detailed support for specific technologies, e.g. the NAS group considers the support for NFS and CIFS network file systems, and the DAS group the supported file system and block-based replication. Similarly, the backup group contains criteria for backup over local (tape and DAS) and remote (NAS) storage.

Organizations can thus choose products depending on their internal storage strategies (e.g. if they invested in SAN storage) or even plan future strategies based on selected products.

3.2. Virtualization criteria

Virtualization technologies are at the core of cloud computing idea of flexible and scalable computing resources. Open source products are ahead of the commercial/closed products in the number of supported virtualization technologies, often supporting several different open source, and to some extent even commercial hypervisors.

Virtualization criteria are grouped as follows: VM Type, VM Technology, Quotas, Prioritization, Migration, Cloning, Hot configuration and Provisioning. These groups address the virtualization type (full, paravirtualized or containers), specific virtualization technology (Xen, KVM, OpenVZ etc.), quotas and prioritizing of CPU, network, memory and disk, live and offline migration and cloning, hot reconfiguration and provisioning, respectively.

As the support for certain feature-sets differs among supported virtualization types, we decided that the evaluation process should consider the feature superset, with additional commentary describing which features are available in which virtualization products.

3.3. Network criteria

Network is important both as means of using the services deployed inside the virtual machines and for managing the entire cloud environment. We divided low-level network support into four groups: VLAN, Firewall, Performance and Integration.

The VLAN group describes the support for VLAN packet tagging (IEEE 802.1Q) for network management and isolation, the Firewall group describes the level of support for network filtering in the form of stateful packet inspection, the Performance group covers Ethernet QoS (IEEE 802.1p), and the Integration group describes the support for IPv6 and virtual private networks (VPNs) for access and management.

3.4. Management criteria

Management category describes features directly related to the way evaluated products manage their clouds. The criteria within this category are grouped into Integration, Accounting, Reporting and Recovery.

The Integration group focuses on software integration between the host and the guest operating systems, support for specific and mass management of both, and available options for integration with third party software via exposed and consumed APIs. The Accounting group deals with data collecting and billing resource usage to cloud users. Along with billing, we included criteria for reporting on current system status and historical logs in the Reporting category, while the Recovery category contains criteria describing the product's automatic recovery abilities, high availability features and administrative alerting about exceptional operational conditions.

Easy and comprehensive management is crucial for successfully implementing clouds, and we believe that the proposed criteria can be used to asses and compare these features across varied products.

3.5. Security criteria

Security features are important for all computer system deployments and clouds are no exception. Security criteria groups are Integration, Permissions, Reporting, Support, Encryption, Certification and Auditing.

The Integration group describes the product's ability to integrate with Active Directory and generic LDAP servers for user authentication, while the Permission group deals with authorization levels for specific resource (e.g. VM server or storage servers) or virtual machine access. Reporting covers the security report types available to cloud administrators, and Auditing covers the types of events which can be audited. Certification details third-party product evaluations for compliance with security standards. Finally, Encryption contains the criteria describing support for encrypted virtual disk storage and secure management access.

Security criteria are more important in public and hybrid clouds than in private clouds, but a comprehensive list of criteria allows comparison and evaluation to be used in making decision about overall security architecture.

3.6. Vendor support criteria

Large open source projects are often supported or even created by commercial entities. Support for such projects is often divided between a community, which is almost exclusively oriented toward open source development, and a vendor in a strict sense, which may offer commercial support or even commercial versions of the products. Our criteria cover both potential sides of a project and contain the following groups: Community, Certification, Documentation, Vendor, Support and Overall.

The Community group deals with support channels freely available to everyone via the open source community gathered around the project (e.g. mailing lists, forums), as well as the quality of these channels. Certification covers the possibility of third-party auditing for compliance with laws, regulations and business rules. The documentation is evaluated for its completeness.

The Vendor group concerns itself with direct vendor support for the products (if any) and includes the possibility of signing a SLA contract with the vendor. The Support group covers general methods of customer relations and includes criteria for public issue tracking (public disclosure of bugs and security vulnerabilities), proactive updates and CRM-like approaches to customer relations. Finally, the Overall group contains criteria describing the completeness of open source product versions and estimates about the project's openness, past track record and future viability.

Vendor and community support are of critical importance in enterprise deployments and our goal in criteria design was to cover important aspects of these support types.

4. Usage and grading with the criteria

Our method for grading products based on the presented criteria includes a numeric aspect and a descriptive aspect. The numeric grade is in the range of 0 to 5 where 0 designates absolutely no support for the criteria within the product and the other grades have meaning similar to the classical grades 1-5 used in education systems. Alongside these grades, each criteria in the evaluation sheet can contain a note with detailed information about the relation of specific criteria to the product, if required.

5. Open source cloud computing solutions

This chapter presents (alphabetically) a selected set of open source cloud computing solutions.

5.1. Abiquo Community Edition

Abiquo[1] presents cloud management solutions in the form of commercial Abiquo Enterprise Edition and as open source Abiquo Community Edition, differing mostly in resource limits and management features. It provides network, storage and workload management, multiple-image public, shared and private libraries, and multi-tenancy hierarchical user management. Open source version supports Appliances repository storage for virtual images in NFS shared folders, while commercial version additionally supports virtual block devices. This solution consists of several components: Abiquo Core, which contains the business logic and resides on Abiquo server, BPM that executes complex asynchronous tasks, and Appliance Manager for image library management. Remote services provide virtual and physical resources management with overall system monitoring, and integration through standardized REST API.

Support for Amazon EC2 enables combining public and private services on various servers types e.g. Java EE, database, cloud node, storage etc. It can be deployed on numerous OSs including most of Linux distributions (Ubuntu, Debian, CentOS, RHEL, OpenSUSE, and Fedora), Windows, OpenSolaris, and OS X. Furthermore, it supports various virtualization standards including Xen, KVM, ESX and ESXi, Hyper-V, XenServer, and VirtualBox. Besides these benefits, it implements a powerful web management with powerful features such as drag-and-drop service deployment.

5.2. Eucalyptus Community Cloud (ECC)

One of the most adopted cloud computing architectures is the scalable IaaS framework Eucalyptus with academic roots at the University

[1] Abiquo, http://www.abiquo.com

of California, Santa Barbara. Besides commercial Eucalyptus Enterprise Edition, there is an open source Eucalyptus Community Cloud (ECC)[2] [1], with hierarchical architecture of flexible and highly modular system components with well-defined interfaces. Components are exposed in the form of stand-alone, standardized and easily replaceable Web services.

Additionally, ECC utilizes standardized language-independent communication and virtual network overlay that isolates user network traffic and utilizes cluster transparency. Interoperability concerns are addressed through implementation of AWS API and emulation of SOAP and REST interfaces, allowing seamless integration with existing Amazon EC2 and S3 public cloud services, thus enabling hybrid clouds. Operations and data structures of services are described in the form of WSDL documents, and optionally secured using WS-Security policies. Cloud Controller component provides main user interface, which interacts with a set of resource, data and interface services used for managing resources. Storage Controller (Walrus) is a stream and storage service, which accesses and stores user data and virtual machine images. Cluster Controller collects information from host nodes, schedules run requests, and manages virtual network overlay. Node Controller queries virtualization and OS on the host node, thus controlling resources availability, authorization, and execution. ECC currently supports Xen and KVM virtualizations and can be deployed on all major Linux distributions (Ubuntu, CentOS, Debian, RHEL, openSUSE, SLES etc.), but the preferred installation is Ubuntu.

5.3. mOSAIC

Consortium of several European academic and industry partners recently created the mOSAIC project[3], a joint initiative for creation of open source portable platform for cloud services based on platform- and language-independent API for resources and usage patterns. This promising platform is intended for developing multi-cloud oriented applications, which interfaces extend the existing platform-dependent APIs with composite features based on usage patterns. For representation of various user's resources and functionalities an adaptable generic agent skeleton should be extended. Main features include support for cloud ontology, user-centric service level agreements, and dynamic negotiation of resources. The work on the project is ongoing on usage patterns, cloud ontology, and description of API, but currently software deliverables are not available.

5.4. Nimbus

Nimbus[4], "*cloud computing for science*", represents a set of open source software cloud computing components with emphasis on the needs of scientific community. Nimbus consists of several components. Standalone virtual machine and cloud management Workspace service supports WSRF frontend and Amazon EC2 via SOAP and REST interfaces. Cumulus is an open source implementation of S3 REST API which presents scalable quota-based storage for multiple cloud configurations. Context Broker service enables coordination of large-scale virtual clusters and management of common cloud configuration in secure context across resources provisioned from potentially multiple clouds or distributed providers with hybrid clouds. It supports Xen and KVM virtualization, and virtual machine schedulers OGE and PBS. Besides, it can be combined with OpenNebula virtual machine manager. Currently Nimbus is mostly used for scientific purposes, but there is a possible pathway for business utilization.

5.5. OpenNebula

Open source software toolkit for cloud computing OpenNebula[5] is used for management of private and public clouds. It orchestrates existing systems and services, but does not contain virtualization, network, storage or security technologies. Some of the main design principles of OpenNebula are fully opened architecture with standardized interfaces, integration, interoperability, portability, and scalability. It can be used for virtual infrastructure management of private clouds in data centers or clusters, or hybrid scalable cloud environments. Cloud-bursting is supported with Amazon EC2, providing simultaneous access to multiple clouds and cloud federation. Some of the features include secure user management of virtual images, virtual machines, virtual

[2] Eucalyptus Community Edition, http://open.eucalyptus.com
[3] mOSAIC, http:// www.mosaic-cloud.eu
[4] Nimbus, http://www.nimbusproject.org
[5] OpenNebula, http:// www.opennebula.org

networks, and storage, using secure authentication, multi-tenancy and quota management. Abstraction from an infrastructure and modular approach supports standardization and interoperability with most common virtualization standards (Xen, VMware, and KVM), interfaces (Amazon AWS, VMware vCloud, and OGF OCCI), and APIs (Java, Ruby and XMLRPC). A welcome addition to the toolkit is a set of tools, extensions and plug-ins named OpenNebula EcoSystem, which enhances integration with existing virtualization and clouds products, services and management tools. OpenNebula is currently highly adopted in scientific institutions (e.g. CERN), telecom and hosting providers.

5.6. openQRM

openQRM[6] is advertised as a data-center management platform. It follows the modular design and has no functionality itself, but instead focuses on abstracting storage and resources (computing resources, running virtual machines, VM images and other objects), moving features to plugins which use the exposed services. This aims to make the whole system more stable and easier to manage. openQRM can be installed on a variety of Linux operating systems: Debian, Ubuntu, SuSE, CentOS, and Fedora. To achieve its goal of managed virtualized data-center, openQRM provides server and storage management, high-availability, real-time monitoring and virtual machine deployment and provisioning services, among others.

openQRM plugins provide a wide range of services, from integrated storage management (supporting direct-attached storage, and various SAN and NAS variants), abstraction of virtualization (Xen, KVM, Linux-VServer, VMware Server and ESX VMs), migration from physical to virtual machines (P2V, V2P and V2V of different VM type), high-availability (with failover from physical to virtual machines, and virtual to virtual failover between machines of same, or different type), and VM image templates or appliances.

5.7. OpenStack

One of the upcoming and promising open source players is collaborative software project OpenStack[7], with a mission to produce the ubiquitous cloud computing platform for public and private clouds, massively scalable regardless of size, and simple to implement. There are interrelated projects named Compute and Storage, which deliver three products. First product, OpenStack Compute is used for deployment, management and provisioning on large-scale virtual private servers. This IaaS platform orchestrator is used as a cloud fabric controller for management of various resources, networking, and security options. It does not contain any virtualization, but interacts with underlying virtualization mechanisms on hosts over web-based API. It extends standard cloud features (e.g. of Amazon EC2) with group settings under virtual "projects", thus supporting multiple users, keys, volumes, instances, images, and VLANs.

OpenStack Compute supports KVM, Xen UML, MS Hyper-V and QEMU virtualizations. OpenStack Compute can be deployed and runs on Ubuntu, but tests are performed on CentOS and RHEL. Second product named OpenStack Object Storage is used as a redundant and scalable storage system on clusters of commodity servers, providing data replication, failover and cluster integrity. Third component is named OpenStack Imaging Service and enables retrieval of virtual machine images. OpenStack relies on some external tools e.g. Eucalyptus's euca2ools for image management and OpenStack Dashboard, a reference implementation of a web-based management console for Compute. Images can be stored in local file system, OpenStack Object Storage or Amazon S3. OpenStack's open design process already delivered afore-mentioned products in a Bexar release which will be soon replaced with next release called Cactus.

5.8. Red Hat Cloud Foundations

Red Hat Cloud Foundations (RHCF) is primarily presented as a set of products for cloud computing, virtualization, scheduling and application management, but it also includes other Red Hat's[8] products e.g. Red Hat Enterprise Linux (RHEL) OS, middleware, and reference architectures, combined with documentation, training and consulting services.

RHCF suite of open source software provides infrastructure for public and private cloud

[6] openQRM, http://www.openqrm.com

[7] OpenStack, http:// www.openstack.org

[8] Red Hat, http://www.redhat.com

solutions, and in current Edition One consists of Red Hat Enterprise Virtualization (RHEV) used for end-to-end virtualizations, system management product Red Hat Network (RHN) Satellite, clustering solution Red Hat Cluster Suite (RHCS), and Red Hat Enterprise MRG which is a distributed computing platform providing messaging, real-time and grid functionalities. RHEV consists of server virtualization system RHEV Manager (RHEV-M) with storage management, high availability, live migration, scheduler etc., and RHEV Hypervisor (RHEV-H), based on KVM hypervisor and deployed standalone or on top of RHEL. RHN Satellite enables configuration management, updates, provisioning and monitoring, while RHCS supports load balancing, service failover and high availability.

RHCF supports multiple hosts of RHEV-H hypervisors and/or KVM hypervisors on RHEL with Windows and RHEL tenant VMs, and various MRG, RHEL, and JBoss applications. RHCF is intended for private clouds [2], but also supports hybrid clouds where application instances could be deployed in Amazon EC2, with dynamic balancing and scheduling using MRG Grid. Besides, Red Hat is intensely participating and investing in various open source projects related to cloud computing, which serve as add-on features on its products.

5.9. Ubuntu Enterprise Cloud (UEC)

Canonical's cloud computing services present two open source cloud IaaS solutions: Ubuntu Server Edition (USE) with support for Amazon EC2 public cloud services, and Ubuntu Enterprise Cloud (UEC)[9], which comprises of USE with ECC architecture integrated with KVM hypervisor. UEC [5] infrastructure is compatible with AWS API and can be used in creation of private clouds. Additionally, UEC delivers images runnable on Xen hypervisor or UEC/ECC/KVM. UEC exposes the same high-level components with the same functionalities as ECC: Cloud Controller, Walrus Storage Controller (WS3), Cluster Controller, and Node Controller, with an addition of Elastic Block Storage Controller (EBS). CLC comprises three interfaces: standard SOAP-base API compatible with Amazons EC2, REST interface which uses euca2ools and Elastic Fox, and Web interface. EBS in conjunction with CLC provides usage of persistent block devices and point-in-time volume snapshots. Furthermore, UEC provides security layers for authentication and authorization, network isolation in system, static, managed and managed-noVLAN modes, and machine instance isolation on hypervisor based machine, networking, and OS levels. It is obvious that UEC uses all of the advantages of underlying ECC, and ECC is at current time mostly adopted in the form of UEC system.

[9] Ubuntu Enterprise Cloud, http://www.ubuntu.cloud/private

5.10. Other

Enomaly ECP Community Edition[10] and its fork OpenECP[11] was to be included in this evaluation, but was omitted due to discontinuous work and legal issues.

6. Conclusion and future work

We believe the proposed set of criteria to be very applicable to capturing the most important features offered by open source products, and also that it can be easily adapted or directly used for evaluation of closed/commercial products. Having a common evaluation framework for a wide range of products creates a necessary comparison baseline and allows IT professionals and management to make educated decisions.

7. References

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