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Evaluating Open-Source Cloud Computing Solutions

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Abstract - Cloud computing is becoming a mainstream technology in enterprise environment, promising more efficient use of hardware resources through virtualization, elastic computing facilities and secure management of user applications. Various cloud computing architectures are emerging and several commercial and open source products on the market advertise a rich feature-set. While commercial vendors try to give potential users the (not necessarily unbiased) tools to reason on the comparative advantages of their product, the open source community trusts users to make a well-informed selection on their own.

In this paper we take a look at the open source cloud solutions and discuss the criteria that can be used to evaluate the stability, performance and features of open source clouds, and compare some available solutions. The evaluation criteria focus on three main components of a cloud solution – the storage layer, the virtualization layer, and the management layer. In addition, we explain the motivation for application of open source cloud solutions from an enterprise perspective, and discuss the potential benefits of these solutions for private cloud computing environments.

I. Introduction

Cloud computing is a relatively recent concept which combines technologies for resource management and provisioning with the ideas of mass deployment, elasticity and ease of use. To enterprises it is an interesting concept on several levels – from internal applications to the possibility of sharing resources with other organization or providing their own resources as a service to others.

Predictions by IDC Adriatics suggests that 2011 will be a year of transition for the global cloud computing services as it is expected that the related technologies will graduate from the early adoption to the new mainstream phase [5]. Cloud computing has found significant support in the business world, with expected rises in the revenue coming from cloud-related services as high as 30%, public clouds valued at USD 29 billion, and private clouds valued at USD 13 billion. Predictions for more distant future are even more optimistic, with some predictions of its growth by 2014 being notably higher (as much as up to five times) than the average global IT spending, with a compound annual growth rate of 27%.

Enterprises have a number of reasons to adopt cloud computing technologies among which are [4][10]: easier management of their resources, introduction of dynamic infrastructure, per-consumption billing, support for varied platforms and operating systems and the possibility to start and stop the provisioned resources as needed.

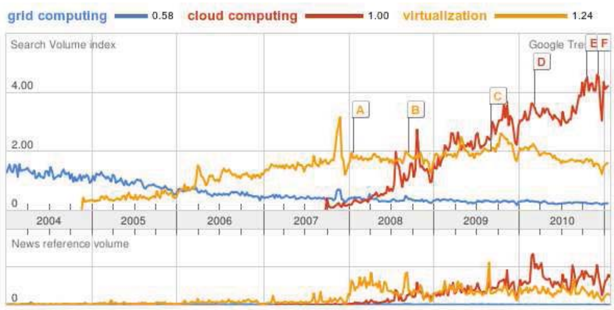

Figure 1. Google Trends' view of popularity of terms “grid computing”, “cloud computing” and “virtualization”

Although the technologies underlying cloud computing have been popular for a longer time period, the concept itself has only been popular since 2008 (as demonstrated by Figure 1) but has already surpassed its components or predecessors in popularity.

This paper is organized as follows: in chapter II we examine the motivations for this concept from the enterprise point of view. Chapter III provides the definition of cloud computing, and description of service and deployment models. Most prominent open source cloud computing products are overviewed in chapter IV. We propose and discuss a list of criteria applicable to evaluating these products in chapter V and conclude in chapter VI.

II. Motivation

Two of the most important goals set before today's IT departments in order to react promptly to the ever-changing business and market demands are cost control and agility. Cloud computing fulfils both requirements allowing IT to elastically deploy services from a centrally managed pool of shared resources. Virtualization is a key enabler of this model. Predictions for the next five year period suggest that the highest growth in the public cloud services (IT spending on business applications, application development and deployment, systems infrastructure software, server and storage capacity provided via the public cloud services) will be focused towards application (Software as a Service) services, but this sector will at the same time experience a decrease of its overall share. Infrastructure-related services such as infrastructure software, server and storage capacity are projected to experience a steady rise and will account for a combined 50% of the total increase. When we additionally include application development and deployment with the increase of 19%, we could conclude that the infrastructure-supporting services will be the focus of investors in the years to come. This is a logical consequence of the flexibility and the least investment required to enter the Infrastructure as a Service market. It is difficult to make such predictions with respect to the private clouds, as the data is not widely available. We expect a similar trend, as this cloud variety is mostly used to support internal company services and development, for migration of existing applications, or for virtualization of existing data centres.

Open source solutions are gaining momentum and present a viable option for enterprises, especially in the time with deteriorating business conditions and constraining economy, due its lower initial investment costs.

III. Cloud Computing Defined

The term *cloud computing* is still more of an industry buzzword for a promising technology than a stable concept with a strict formal definition. The closest to a succinct definition, still a very broad and generic one, is given by [1] and adopted by a number of other works [2][3]. It begins with the essential description: "*Clouds are large pools of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services)*." Another popular definition by the United States' National Institute of Standards and Technology (NIST) [7] states it is a "*a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*". Both definitions touch on the basic properties of cloud computing – sharing of resources and ease of use. They directly lead to introduction of the three common service models in which cloud computing is implemented [3]:

- *Software as a Service (SaaS)*, where the product is an application (usually a Web application) offered to users with little to no customizations. The users may have high-level administrative access to the application but have no control or influence on the application's implementation, inner workings or underlying infrastructure. This is an extension of the already popular hosted application model.
- *Platform as a Service (PaaS)*, where the product is a development and deployment platform, a set of APIs, libraries, programming languages and associated tools used for application creation. Users of PaaS are developers and companies which create customized applications for end-users, and as such they are allowed to have control over some aspects of the application's environment but without direct access to the operating system and the hardware.
- *Infrastructure as a Service (IaaS)*, where the product is the low-level infrastructure used to create customized application environments or even higher level products (which might be PaaS or SaaS). Users of IaaS are given complete control of their infrastructure resources (most notably, virtual machines) and can configure and use them as they see fit. IaaS is the lowest-level type of cloud service and it does not usually carry the obligation to use any prescribed technologies (though the hosted environments may be preconfigured).

These models progress from a high-level service model directly accessible to end-users to more low-level services in which their immediate users have control over the application or the basic infrastructure.

A. Cloud computing examples and target users

Each of the models has its primary audience, its strengths and weaknesses. SaaS is already popular among end-users in the form of publicly available, widely used hosted applications like web-mail applications (e.g. Google Mail[1], HotMail[2], Yahoo Mail[3]), picture sharing applications (e.g. Picasa[4], Flickr[5]), video clip sharing applications (e.g. YouTube[6], Vimeo[7]), and some forms of office applications (e.g. Google Apps[8], Microsoft Exchange Hosted Services[9], Microsoft Office Live[10]). Such services are provided without giving users access to any advanced application, infrastructure or hardware-level configuration or management features. This benefits users who do not want to concern themselves with the technical aspects of the service, while allowing providers to reduce costs through mass deployments without significant reconfiguration and integration [6].

The PaaS model is oriented towards application developers and integrators, offering a common development and deployment platform for new applications or the customization of existing ones. It is

[1] Google Mail, http://mail.google.com
[2] HotMail, http://www.hotmail.com
[3] Yahoo Mail, http://mail.yahoo.com
[4] Picasa, http://picasa.google.com
[5] Flickr, http://www.flickr.com
[6] YouTube, http://www.youtube.com
[7] Vimeo, http://www.vimeo.com
[8] Google Apps, http://apps.google.com
[9] Microsoft Exchange Hosted Services, http://www.microsoft.com/online/exchange-hosted-services.aspx
[10] Microsoft Office Live, http://www.officelive.com

successfully offered by Google (Google App Engine[11]), Microsoft (Windows Azure[12]) and Salesforce.com (Force.com[13]), among others. The model strongly focuses on developing applications that make use of the elasticity features offered by the platform, leaving lower-level tasks to the provider.

As with the SaaS and the PaaS model, IaaS offers services to users, while removing a certain level of responsibility. The users are given a larger degree of control over assigned resources, including storage, CPU and network resources, usually by allowing direct control of virtual machines. The properties of easy access, on-demand self-service and elasticity separate IaaS in cloud computing context from server hosting (and collocation) offered by a large number of companies. IaaS is implemented globally by providers such as Amazon (Amazon EC2[14]), Rackspace (Rackspace Cloud[15]), FlexiAnt (FlexiScale[16]) and others.

The IaaS model allows the greatest flexibility for users that can make use of it. It is the least complicated for providers, which need only concern themselves with the general infrastructure and running of the virtual machines, leaving users to manage the virtual machines' contents. Open source IaaS solutions suitable for enterprise use are the primary focus of this paper.

B. Deployment models

The deployment models are orthogonal to the service models and describe the availability of the cloud deployments [3]. The three basic deployment models are:

- *Private clouds*, used exclusively by one organization, usually operated internally by the organization.
- *Public clouds*, used by generally interested parties (usually for a fee) in various ways. They can be an extension of the "hosting provider" business model.
- *Community clouds*, used by parties interested in specific requirements, such as organizations working on the same projects or on the same problem.

In addition to these three models, literature describes a fourth model: a *hybrid cloud model* which combines two or more of the basic models. It is the most flexible model as it allows migrations of groups of resources between the categories.

In this work we focus on the *private cloud model* which can be used by enterprises to realize the benefits of cloud computing while still retaining control over the infrastructure they use [8][9].

[11] Google App Engine, http://appengine.google.com
[12] Windows Azure, http://www.microsoft.com/windowsazure
[13] Force.com, http://www.salesforce.com/platform
[14] Amazon Elastic Compute Cloud (EC2), http://aws.amazon.com/ec2
[15] Rackspace Cloud, http://www.rackspacecloud.com
[16] FlexiScale, http://www.flexiant.com/products/flexiscale

IV. Open Source Cloud Computing Products

We have selected a number of open source products which we consider to have a viable future for applications in enterprise environments. We intended to include the Enomaly ECP Community Edition[17] but due to discontinuous work, we decided to omit it.

A. OpenNebula

OpenNebula[18] is an open source software toolkit for cloud computing, which can be used to build and manage private, public and hybrid clouds. Since it does not contain virtualization, network, storage or security technologies, its primary use is as an orchestration tool for virtual infrastructure management in data-centers or clusters in private clouds and as merger of local and public cloud infrastructure supporting hybrid scalable cloud environments.

Some of the main principles which guided the design of OpenNebula are full openness of architecture and interfaces, adaptability to various hardware and software combinations, interoperability, portability, integration, stability, scalability and standardization. Its main features include data-center or cluster management with Xen, KVM or VMware virtualization. It leverages the most common cloud interfaces Amazon AWS, OGF OCCI and VMware vCloud, and provides user management with authentication, multiple user rolling, secure multi-tenancy and quota management. In the scope of cloud management a rich set of storage, virtual image, virtual machine and virtual network management features is provided. It supports cloud-bursting with Amazon EC2, simultaneous access to multiple clouds, and cloud federation. Standardization and interoperability are supported through abstraction from infrastructure and modular approach. Standard APIs includes Ruby, Java and XMLRPC. Security concerns are addressed with internal and external SSL communication and LDAP integration.

OpenNebula EcoSystem adds a set of tools, extensions and plugins to OpenNebula Cloud Toolkit components enabling integration with existing products, services and management tools for virtualization, clouds and data centers. Telecom and hosting market, and respectable scientific organizations like CERN adopted OpenNebula.

B. Eucalyptus

Open source cloud computing architecture Eucalyptus [12] provides a scalable IaaS framework for implementation of private and hybrid clouds. It was initially developed to support high performance computing (HPC) research at the University of California, Santa Barbara, and engineered to ensure compatibility with existing Linux-based data centers. It is component-based, flexible and highly modular with well-defined interfaces. Main design goals were simple installation, non-intrusion and standardized language-

[17] Enomaly ECP Community Edition, http://src.enomaly.com
[18] OpenNebula, http:// www.opennebula.org

independent communication. Eucalyptus also provides a virtual network overlay that isolates user network traffic and allows multiple clusters to appear as in the same LAN.

Eucalyptus implements the Amazon Web Service (AWS) API allowing interoperability with existing services, enabling the possibility to combine resources from internal private clouds and from external public clouds to create hybrid clouds. This capability presents seamless integration with Amazon EC2 and S3 public cloud services. Eucalyptus currently supports Xen and KVM virtualizations, with plans to support others.

Four high level components are implemented as Web services. Cloud Controller (CLC) is a set of resource, data and interface services used for managing resources via node manager's queries, scheduling and cluster controller requests, visible as the main user interface. Storage Controller (Walrus) is a data storage service compatible with Amazon's S3 interface and Web services REST and SOAP interfaces. It accesses and stores virtual machine images and user data. Node Controller (NC) controls the execution, resources availability, and authorization on the host node. Cluster Controller (CC) collects information about a set of NCs, schedules run requests to NCs, and controls the instance virtual network overlay.

Eucalyptus can be deployed on all major Linux OS distributions, including Ubuntu, Red Hat Enterprise Linux, CentOS, openSUSE, and Debian. Eucalyptus software core is included in Ubuntu distributions as a key component of the Ubuntu Enterprise Cloud.

C. Ubuntu Enterprise Cloud

Canonical's Ubuntu Linux distribution presents itself as a cloud OS with several cloud strategies, two of which are IaaS. Ubuntu Server Edition enables the use of Amazons EC2 but only as a public cloud. Ubuntu Enterprise Cloud (UEC)[19] integrates Ubuntu Server Edition with Eucalyptus over KVM hypervisor. The infrastructure of UEC is similar to Amazon's, but with simpler creation of private clouds.

UEC [13] exposes five high-level components in a form of Web services: Cloud Controller (CLC), Walrus Storage Controller (WS3), Cluster Controller (CC), Node Controller (NC), and Elastic Block Storage Controller (EBS). The first four have the same functionalities as described in Eucalyptus overview, EBS runs besides CLC and provides persistent block devices and point-in-time volume snapshots stored on WS3. UEC defines security layers for authentication and authorization, network isolation, and machine instance isolation. Network isolation can be performed in four networking modes: system, static, managed and managed-noVLAN. Machine instance isolation is provided on three levels: networking, OS, and hypervisor-based machine.

D. OpenQRM

OpenQRM[20] advertises itself as a data-center management platform. The core of openQRM follows the modern 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). OpenQRM features are provided via plugins which use the services exposed by the openQRM base. This architecture aims to make the whole system more stable and easier to manage as the base changes less often and provides a solid platform. OpenQRM can be installed on a variety of officially supported 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: iSCSI, LVM2, ATA-over-Ethernet and NFS), abstraction of virtualization (Xen, KVM, Linux-VServer, VMware Server and ESX VMs), migration from physical to virtual machines in three combinations (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.

E. Abiquo

Abiquo[21] is a cloud management solution for virtualized environments in open source and commercial versions, mainly differing in resource limits, management and support options. Open source Abiquo Community Edition is licensed under LGPL Version 3. Main features include multi-tenancy, hierarchical user management and role based permissions with delegated control, resource limits, network, storage and workload management, multiple public, shared and private image libraries. It supports many Linux distributions (Red Hat, OpenSUSE, Ubuntu, Debian, CentOS, and Fedora), Oracle OpenSolaris, Microsoft Windows, and Mac OS X.

Abiquo uses two storage systems: Appliances repository for virtual images in the form of NFS shared folder, and Virtual storage for virtual block devices available only in Enterprise edition. It distinguishes several types of server-side services: Java EE compatible application servers, database servers, cloud node servers, Appliance repository servers, and ISC DHCP servers. REST API can be used for integration with other systems. Abiquo server node incorporates Abiquo Core which contains the business logic, Appliance Manager for image library management and BPM that executes complex asynchronous tasks. Remote services deployed in the

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

[20] OpenQRM, http:// www.openqrm.com

[21] Abiquo, http://www.abiquo.com, http://www.abicloud.org

cloud expose system monitoring and management of virtual resources, physical machines, and storage.

Abiquo supports various virtualization technologies including VMware ESX and ESXi, Hyper-V, VirtualBox, Xen, Citrix XenServer and KVM. Users of this solution benefit from powerful web management with functionalities such as drag-and-drop service deployment. It can be used for private clouds but also provides support for Amazon EC2.

F. Red Hat Cloud Foundations, Edition One

Red Hat[22] offers a suite of open source software which provides infrastructure for public and private cloud solutions [11]. Red Hat Cloud Foundations, Edition One (RHCF) comprises of a set of products for virtualization, cloud, and application management and scheduling, but also operating systems, middleware, cookbooks, reference architectures with deployment instructions, consulting services, and training. RHCF Products are often tightly coupled with other Red Hat products. The suite comprises of Red Hat Enterprise Virtualization (RHEV), Red Hat Enterprise Linux (RHEL), Red Hat Network (RHN) Satellite, Red Hat Cluster Suite (RHCS), and Red Hat Enterprise MRG. RHEV for Servers is a product for end-to-end virtualization consisting of two components: RHEV Manager (RHEV-M) as a server virtualization system that provides advanced features (high availability, live migration, storage management, scheduler, etc.), and RHEV Hypervisor (RHEV-H), based on KVM hypervisor and deployed standalone or as RHEL hypervisor. RHN Satellite is a system management product providing software updates, configuration management, provisioning and monitoring across physical and virtual RHEL servers. RHCS is a clustering solution for RHEL supporting application/service failover and IP load balancing. Red Hat Enterprise MRG is a high-performance distributed computing platform providing messaging (MRG Messaging), real-time (MRG Realtime) and grid (MRG Grid) functionalities, and support for distributed tasks.

Red Hat is investing and strongly participating in several cloud computing-related open source projects: Deltacloud, BoxGrinder, Cobbler, Condor, CoolingTower, Hail, Infinispan, Libvirt, Spice, and Thincrust. Red Hat also delivers JBoss Enterprise Middleware as a PaaS solution.

G. OpenStack

Collaborative software project OpenStack[23], intends to produce an ubiquitous open source cloud computing platform that will meet the needs of public and private clouds regardless of size, at the same time be simple to implement and massively scalable.

Three interrelated components are currently under development: OpenStack Object Storage used for creation of redundant and scalable storage using clusters of commodity servers, OpenStack Imaging Service for retrieval of virtual machine images, and OpenStack Compute for provisioning and management of large groups of virtual private servers. OpenStack Compute represents cloud computing fabric controller and orchestrator for IaaS platform which can be used for management of various resources, networking, security, and access options. It defines drivers that interact with underlying virtualization mechanisms running on host and exposes functionality over a web-based API, but does not include any virtualization software. It is comparable to Amazon EC2 with additional support for projects that include volumes, instances, images, VLANs, keys and users. Images management relies on euca2ools (provided by Eucalyptus) and images are served through OpenStack Imaging Service or OpenStack Compute Service, supporting Amazon S3, OpenStack Object Storage or local storage. It also supports several virtualization standards including KVM, UML, XEN, Hyper-V and QEMU. OpenStack Compute can be deployed on Ubuntu, with tests on CentOS and RHEL under way.

H. Nimbus

Nimbus[24] is a set of open source software cloud computing components written in Java and Python targeting the needs of the scientific community, but also supporting other business use-cases. The main component is the Workspace service which represents a standalone site VM manager with different remote protocol frontends, currently supporting Nimbus WSRF frontend and partially Amazon EC2 with SOAP and REST interface. While Workspace service represents a compute cloud, there is also a quota-based storage cloud solution Cumulus, designed to address scalability and multiple storage cloud configurations. There are two types of clients: cloud clients for quick instance launch from various sites, and reference clients acting as full command-line WSRF frontend clients. Context Broker service allows clients to coordinate large virtual cluster launches using Context Agent, a lightweight agent on each VM. Context Broker manages a common cloud configuration in secure context across resources provisioned from potentially multiple clouds, with a possibility to scale hybrid clouds across multiple distributed providers.

Nimbus supports the Xen or KVM hypervisors, and virtual machine schedulers Portable Batch System and Oracle Grid Engine The main advantage of Nimbus compared to OpenNebula is that it exposes EC2 and WSRF remote interfaces with attention to security issues, and can be combined with OpenNebula VM manager.

I. mOSAIC

The mOSAIC project[25] is a relatively young joint initiative from several European academic and industry partners which intends to promote an open source cloud application programming interface (API) and a platform

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[22] Red Hat, http://www.redhat.com
[23] OpenStack, http:// www.openstack.org
[24] Nimbus, http://www.nimbusproject.org
[25] mOSAIC, http:// www.mosaic-cloud.eu

targeted for developing multi-cloud oriented applications. The project is motivated by weaknesses of the current research and practice in cloud computing which include lack of common programming model and standard interfaces, platform dependability and non-portability, lack of tools for deployment of scalable applications and multiple based services, and lack of adequate service level agreements with dynamic negotiation.

The main goal of the mOSAIC project [14] is the design of open source language- and platform-independent API for resources and usage patterns that could be used in multiple cloud environments and construction of open source portable platform for cloud services. At the current time there are no software deliverables, but the work is ongoing in cloud ontology, API description, testing environment, and usage patterns.

V. Evaluation Criteria

Evaluating open source cloud computing products requires an elaborate set of evaluation criteria in order to provide a common baseline for IaaS cloud comparison. We have devised a set of 95 criteria which target features interesting for enterprise deployment. The criteria are grouped into six main categories: storage, virtualization, management, network, security and support.

Storage-related criteria focus on supported approaches to storage: direct-attached storage, storage area network, and network-attached storage, as well as support for backup technologies and storage types.

Virtualization criteria include virtualization types, support for actual virtualization technologies, and various monitoring and reconfiguration features, as well as support for migration and provisioning.

Management features are essential for cloud implementers. The related criteria group captures features such as hardware and software integration, accounting, mass maintenance, reporting, and recovery.

Network features are highly dependent on the actual implementation, and the criteria focus on VLAN, firewall, performance, and integration support.

Security criteria deal with permission granularity, integration with various directories, auditing, reporting of security events. Additional important features include storage encryption and secure management access.

OEM support is vital for enterprise deployment, and related criteria include an estimate of community vitality, vendor track record, possible support channels and SLAs, future viability of the product ecosystem, and completeness of provided free releases of the product.

The criteria were devised with open source IaaS products in mind, but can be easily expanded to include commercial/closed technologies.

VI. Conclusion and Future Work

Cloud computing is an attractive concept for enterprises as it brings benefits on many levels. Open source products play an increasingly important role on this market, as several open source solutions became available during the past few years, with feature sets which are comparable to commercial/closed products.

We have reviewed some of the most popular open source cloud computing products and devised a set of evaluation criteria, which can be used to select the most appropriate product based on the specific needs of an organization. We intend to continue with an evaluation of presented IaaS solutions based on proposed evaluation criteria.

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