Energy-Efficient Datacenter

A reinforcement learning based approach

# SLA Negotiation

# **Introduction**

## Motivation

Reducing energy consumption and using biodegradable materials has become the main purpose in all the existent industry fields. In the last few decades, researchers have been focusing on improving performance in all possible fields, neglecting overall efficiency considering energy consumption. With the growth of impact of industry and pollution on the environment, the direction of evolution has changed from a performance directed one to an efficiency based approach.

Green computing is a new trend in computer science, encouraging the development of environmentally sustainable computing. Basically, it regards the study and practice of using computing resources efficiently. Studies have been focused on designing computing resources which maximize the energy efficiency during product’s lifetime, are biodegradable and don’t use hazardous materials. Extensive research is being undertaken in design of algorithms and systems for environmentally-friendly computer technologies and efficient use of computers.

On 2007, the report to congress on server and data energy efficiency [1] gave a definite warning in what regards the energy consumption of servers and data centers. From 2000 to 2006 the energy consumption of datacenters has doubled in United States, rising to about 61 billion kilowatt-hours (kWh) and being similar to the amount of electricity consumed by approximately 5.8 million average U.S. households. This is why a great part of the effort of painting the computing industry in green has to be directed towards decreasing datacenters’ and servers’ overall energy consumption, including the cooling infrastructure that supports IT equipment in datacenters.

Reducing the energy consumption in datacenters can be approached by improving the efficiency of computer resources or by software solutions of intelligently using those resources. Several solutions have been approached for decreasing datacenters’ overall energy consumption. These can be categorized in two main directions: hardware solutions and software solutions. The hardware solutions intend to decrease energy consumption by designing low power components thereby reducing the entire’s machine energy consumption. The software solutions are at their beginnings but there have been researches focused on decreasing power consumption depending on the existing load or on distributing efficiently tasks in the datacenter in order to have optimal power consumption.

## Objectives and contributions

The objectives of this thesis project are the following:

* A **description of the datacenter context** composed from servers which have certain resources as CPU, Storage, Memory and this **context’s mapping on the <R,A,P>**(Resources, Actors, Policies) model presented in [2].

The datacenter is composed of a number of servers with different characteristics for different resources like memory, storage and CPU. These are being mapped on a context model composed of Resources, Actors and Policies. The role of Resource is being played by any server in the datacenter and the task plays the Actor role. Considering the previously mentioned elements, policies are being defined using SWRL describing the situations in which the GPI ( Green Performance Indicators) for the datacenter, and the KPI (Key Performance Indicators) for the task are being respected.

* **Developing a self-\* algorithm** with the purpose of optimally distributing the workload, while using as less energy as possible.

Using the above context, a self-adapting algorithm is being designed, for the getting the described model to the lowest possible energy consumption. This algorithm involves a reinforcement learning approach by adapting the self-healing algorithm presented in [3], and adding few improvements. The self-healing algorithm is also being used for controlling the temperature and humidity in the datacenter room.

* **Negotiating the Service Level Agreement** of the task for the case in which the task doesn’t fit in any server on the datacenter, to modify existing policies for the datacenter and make it possible for the tasks to be properly distributed.

Because the user is giving us a requested range for the resources of a server, there might be a situation in which there is no place for that task due to GPI Policies. In this case, a negotiation should be made in order to have a higher maximum accepted value and the task to fit. There is also the case where the task could get more than the minimum requested value, case in which a redistribution of available resources among existing tasks on that server will be made.

## Overview of the report

In the next parts of this report, I will present a theoretical background needed in order to present this project, with available software and technologies needed for implementing it on a real datacenter. The next chapter, chapter 3 gives a view on the existing work in the domain. The fourth chapter describes the algorithms and models and from here on the architecture, the design and implementation is presented ending with testing and conclusion.

# Theoretical Background

## Context-Aware Computing

Awareness is one of the main problems arising in nowadays computing systems. Building systems which are aware about what happens and about their awareness becomes crucial in hospitals, modern buildings and even personal houses. To handle contexts in all of these environments the system must have sensors for each monitored element and a way to control that element, through different actuators. In order for the system to know when the context is not in the state desired by the user, policies are being described for all elements composing the context. For example, in a smart laboratory, we need to know that if no one is inside the light should be off. Generally the system takes the sensor information and enforces actions on actuators through web services, this way having a low coupled architecture.

## Energy-Aware Computing

Energy-awareness is a subset of context awareness, improving the systems towards green use of the computing infrastructure. The green use of a datacenter implies reducing the energy consumption of computers and other information systems as well as using them in an environmentally sound manner. For the real servers and datacenters to have this behavior there are several options like programmatically assign loads to resources or programmatically assigning loads to servers. The load assignment for datacenters is easily accomplished through virtualization. By this, a system administrator could combine several physical systems into virtual machines on one single, powerful system, thereby unplugging the original hardware and reducing power and cooling consumption.

### Virtualization

According to Wikipedia, the term "virtualization" was coined in the 1960s, to refer to a virtual machine (sometimes called pseudo machine), a term which itself dates from the experimental IBM M44/44X system [4].Virtualization is a new technique reproducing computer hardware through software. In a typical server environment there exist different servers each hosting only one task, for example a web server and a file server. By using server virtualization, both the previously mentioned servers will be running on the same machine, one independently of the other, therefore reducing the costs and energy consumption of a second machine. The center of the entire virtualization process is the virtual machine, it being defined as a software implementation of a machine that executes programs like a physical machine. There are two types of virtual machines: system virtual machines and process virtual machines. From the process virtual machines, the JVM (Java Virtual Machine) and the .NET Framework, which runs on a VM called the Common Language Runtime, are the most known one. Process virtual machines run as a single application inside the operating system, and support one single process. They are created when that process is started, and destroyed when it exits. We are interested with the system virtual machines which allow the sharing of the underlying physical machine resources between different virtual machines, each running its own operating system [4]. There are several advantages coming with the use of system virtual machines, like the fact that multiple operating system environments can run on the same computer, in strong isolation from each other or that the virtual machine can provide an instruction set architecture different from that of the real virtual machine. The software layer providing virtualization for system virtual machines is called a virtual machine monitor or hypervisor. Due to the fact that it is an important part of datacenter administration having virtual machines in the role of tasks, hypervisor description will be detailed in the followings.

#### Hypervisors

The hypervisor, also called Virtual Machine Monitor (VMM) provides the guest operating system a virtual platform and monitors their execution. Despite the fact that the virtual machines can commonly used resources, the failure of one virtual machine won’t produce the failure of all the other virtual servers running on that machine. The isolation ensured by the hypervisor is one of the main features of virtualization, which brings it to the top of technologies to be used in modern datacenters. The hypervisors are split into two categories: software and bare-metal. Software hypervisors need a host operating system to run on and have lower I/O performance due to the overhead resulting from the hypervisor-host OS communication. Bare-metal hypervisors received their name from the fact that they run on “bare metal”, needing no host operating system. Actually the server must be formatted before this hypervisors are installed. This close connection to the underlying hardware brings better I/O performance and is also faster due to the removal of the layer introduced by the operating system.

Microsoft Hyper-V is the hypervisor which is the most present one in the data centers all over the world. It can be run on an x64 version of Windows Server 2008, the R2 version having the live migration feature enabled. In order for Hyper-V role to be enabled for a windows server, the processor needs to have hardware assisted virtualization. This is available for processors that include a virtualization option (Intel VT or AMD Virtualization). Live migration is supported with the use of cluster shared volumes (CSV). This feature is extremely important for enabling the movement of a virtual machine from a server to another, from efficiency reasons. Live migration of virtual machines from a server to another is done automatically for situations in which the node (the Hyper-V server) fails. In this situation, each virtual machine running on the failed node may migrate to other live nodes independently of other virtual machines. Due to the fact that this diploma project is undertaken within a larger group with different missions, we have chosen Hyper-V as a hypervisor, it providing both a high-level and a low level API. In there are presented on short two other hypervisors, one which offers full virtualization and one offering paravirtualization, together with a description of paravirtualization and comparison to full virtualization.

VMWare ESXi is a “bare metal” hypervisor, meaning that it doesn’t need to run on top of other operating systems. This implies a lower overhead and a better control and granularity for allocating resources (CPU time, disk bandwidth, etc.) and a considerable increase of security. VMWare ESX and VMWare ESXi offers advanced resource management capabilities to improve performance and increases consolidation ratios.

Both Hyper-V and VMWare ESXi offer a full virtualization approach which allows datacenters to run an unmodified guest operating system, thus maintaining the existing investments in operating systems and applications and providing a nondisruptive migration to virtualized environments. On the other hand, the paravirtualization approach modifies the guest operating system to eliminate the need for binary translation. Therefore it offers potential performance advantages for certain workloads but requires using specially modified operating system kernels [5].

The Xen open source project was designed initially to support paravirtualized operating systems. While it is possible to modify open source operating systems, such as Linux and OpenBSD, it is not possible to modify “closed” source operating systems such as Microsoft Windows. It is also not practical to modify older versions of open source operating systems that are already in use. As it turns out, Microsoft Windows is the most widely deployed operating system in enterprise datacenters. For such unmodified guest operating systems, a virtualization hypervisor must either adopt the full virtualization approach or rely on hardware virtualization in the processor architecture [6].

#### Virtual appliances

A software appliance is a full application stack containing the operating system, the application software and any required dependencies, and the configuration and data files required to operate. Everything is preinstalled, preintegrated and ready to run. Software appliances come in the form of a file which can be a virtual machine image, an ISO, a USB key image, or an Amazon EC2 AMI. They run a JeOS(Just Enough Operating System) is a customized operating system that precisely fits the needs of a particular application (Ubuntu JeOS, OEL JeOS, SUSE JeOS, OpenSolaris JeOS, OpenSolaris JeOS, Orange JeOS, and Windows Server Core).The virtual appliances, a sub-class of software appliances, add to the advantages of software appliances the benefits of virtualization.

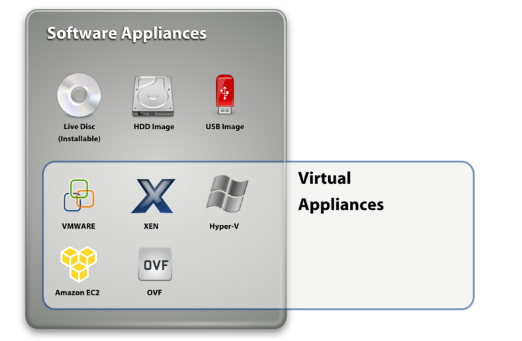


Figure 2.1: Software Appliances Taxonomy- © Novell Inc

The biggest advantage of virtual appliances is that there is a considerable energy economy because we don’t have any more tasks waiting one for another and redirection of conflicting tasks, being an alternative to massive changes and increased complexity on the software stack. Virtual appliances allow for rapid movement of virtual appliances between physical execution environments, provide an improved isolation between several appliances sunning on the same server and improve fault tolerance .For tasks that need to be sent to a data center and run on a server, a virtual appliance can be created with all the needed applications and only the needed part of the operating system and sent to be run secure and isolated from other tasks.

In terms of solutions to energy efficient datacenters, software appliances are a feasible alternative to virtual machines, considering that by having all the needed software and no more than that on top of a lightweight JeOS the time for programmatically creating virtual machines with different characteristics is reduced to 0 and the dimension of the virtual machine is reduced. Not all the hypervisors are able yet to host virtual appliances, therefore this is a subject for implementation after virtual appliances leave the research state and people get acquainted with them.

### Hyper-V WMI Provider

For monitoring virtual machines in a network of servers running Hyper-V, the Hyper-V WMI Provider is being used. It is a high level API, giving information about virtual machines and their status. It enables developers and scripters to build custom tools, utilities and enhancements for the virtualization platform, managing all aspects of the Hyper-V Services [7]. Most functions in this API are available in Basic, PowerShell, C# and C++, therefore the limitations from the programming language point are not too high.

## Autonomic Features

In a manifesto in 2001, IBM invites the world, their customers, competitors and colleagues to accept the Grand Challenge of building and deploying computing systems that regulate themselves and remove complexity from the lives of administrators and users. On short, they consider that the new Grand Challenge in computing industry is the overgrowing software complexity both in terms of management and in terms of maintenance. They believe that the growing complexity of the I/T infrastructure threatens to undetermine the very benefits that information technology aims to provide. Human intervention and administration to manage software complexity is starting to be overwhelmed. It is estimated that at current rates of expansion, there will not be enough skilled IT people to keep the world’s computing systems running.

Considering the fact that “in the evolution of humans and human society, automation has always been the foundation for progress” [8], IBM states that it’s time to design and build computing systems capable of running themselves, adjusting to varying circumstances and preparing their resources to handle most efficiently the workloads we put upon them. These autonomic systems must anticipate the needs and allow users to concentrate on what they want to accomplish rather than figuring how to rig the computer systems to get them there [9].

They give four directions of approach in terms of self-management, described bellow: self-configuration, self-healing, self-optimization and self-protection. Systems having all these capabilities are also called CHOP systems or self-\* systems. This thesis presents a self-healing approach for the datacenter room, and a self-optimizing approach for having a datacenter which consumes the optimum amount of energy.

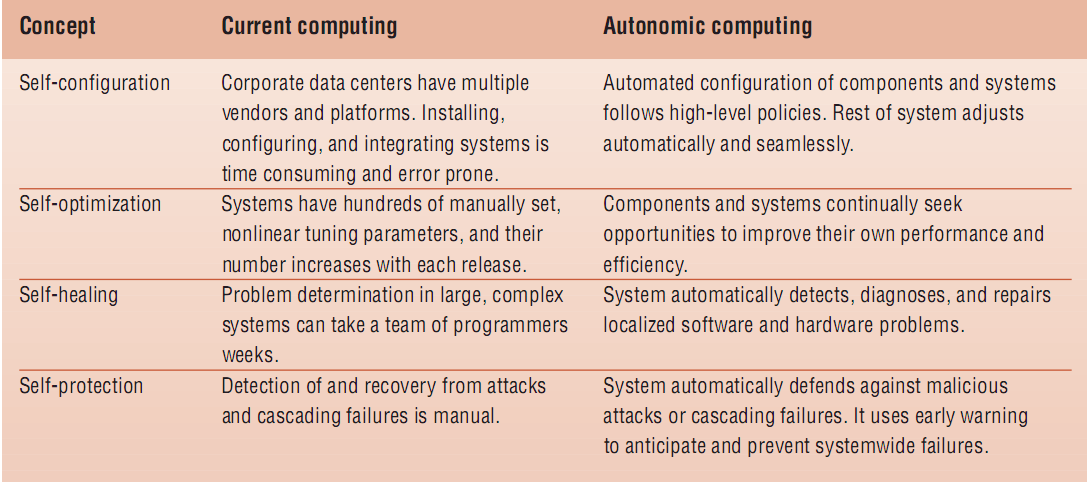


Figure 2.2: Four aspects of self-management © IBM

## Ontologies

The ancient Greek philosopher Parmenides of Elea was among the first to propose an ontological characterization of the fundamental nature of reality. An ontology together with a set of individual instances of classes constitutes a knowledge base. In reality, there is a fine line where the ontology ends and the knowledge base begins.

Considering that the thesis describes an approach of realizing an energy efficient datacenter a description of the energy-aware context needs to be made. The best way of describing context-aware models is with the help of an ontology, resources are added to the ontology with their corresponding individuals. After adding SWRL (Semantic Web Rule Language) rules to the ontology, through a reasoning process the system can find out whether the rules are broken or not.

# Related Work

## Context Aware Systems

## Energy Aware Systems

## Policies

## 3.4 SLA Negotiation

# References

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