

# Energy Efficient Data Centres within Smart Cities: IaaS and PaaS optimizations

Corentin Dupont, Mehdi Sheikhalishahi, and Federico M. Facca<sup>1</sup>

Create-Net, Trento, Italy {dupont, msheikhalishahi, ffacca}@create-net.org

**Summary.** Data centres are power-hungry facilities that host ICT services and consumes up to 3% of the global electricity production. Consequently, in the last years, research trends in the field focused on mechanisms able to reduce the overall consumption of a data centre so as to reduce its energy footprint. Following such research outcomes, several data centre management frameworks started to implement energy efficiency policies. Those energy management techniques - with the help of other factors, such as the introduction of less power hungry CPUs - had a positive impact: a recent study showed that the energy consumption of data centres is actually less than the one previously predicted. However, from a research perspective, techniques for reducing energy consumption of virtualized infrastructures - such as server consolidation - are now well-known and not great breakthroughs are expected. The introduction of new solutions, such as containers and platform as a service (PaaS) in cloud data-centres opens new challenges and opportunities. Moreover, new interests toward aspects such as green footprint demands for more than just reducing energy consumption. Aiming at reducing energy consumption in data centres becomes part of a larger equation: being able to consume energy in a better way, prioritizing the consumption of green energies. In this paper we present the concept of Service Flexibility Agreement (SFA), an extension of the traditional SLA able to qualify the flexibility of applications deployed in a cloud environment. In particular, we detail preliminary models able to exploit this flexibility in order to increase the ratio of renewable energy consumed. Finally, we describe how the combination of PaaS and IaaS cloud layers provide the needed flexibility to support the SFA.

**Key words:** Platform as a Service, Energy Management, Flexibility, Scalability

## 1 Introduction

A recent study [?] showed that, while still growing, the current energy consumption of data centres is less than previously expected. Electricity used in US data centres in 2010 was significantly lower than predicted by the EPAs 2007 report to Congress on data centres. There is a combination of factors explaining this slow down, among which the application of new energy policies in data centres. For example, consolidation techniques to reduce the power of servers in a data

centre are nowadays adopted in several cloud management solutions. However, the problem of how to improve Virtual Machines (VMs) consolidation is already well studied and it is probably not going to bring big breakthroughs any more. Nevertheless, societal challenges are evolving. It is not only *how much* energy you consume which is important, but also *which* energy you consume. As important energy consumers, it is important that the energy management and policies of data centres prioritize the consumption of renewable energies over brown energies. However, the main problem with the utilization of renewable energies is that they are very variable in time. To adapt to such energies, we need to adapt and shift the workload of applications. This means reducing the workload when there is less renewable energies available, for example.

Beyond that, the technological landscape is changing. Data centres can now host more than simple virtual machines. New "virtualization" techniques such as containers are appearing on the scene, and Platform-as-a-Service solutions are more and more used on top of Infrastructure-as-a-Service solutions. PaaS management frameworks models the architecture of applications and provide management functions to scale up and down multi-tier applications. Some frameworks allow to automatize this process: Cloudify<sup>1</sup>, for example, provides a language for auto-scaling. This language defines Key Performance Indicators (KPIs) and thresholds that will trigger the scaling operations. For example, in the case of a 3-tier Web server application, it is possible to describe that if the latency in serving the pages goes over a certain threshold, a new front-end VM should be launched. As such, the "intelligence" of PaaS management frameworks can be easily employed to apply energy management policies taking into account application SLAs and their architecture. Following this reasoning, we believe that the combined management of PaaS and IaaS may bring new opportunities in energy policies management a bit overstating.

However, when it comes to the adaptation of applications workload to dynamic power budgets, we think that a piece is missing. Indeed, currently PaaS frameworks have no way to lower or postpone workload in a reasonable way when there is no renewable energy or energy is too expensive, for instance. PaaS models can be enhanced to better describe the flexibility of applications and allow to perform optimizations at data centre level, such as increasing the renewable energy usage.

Thus, in this paper we propose the concept of Service Flexibility Agreement (SFA). The SFA is an extended Service Level Agreement (SLA): it includes a description of the flexibility of an application. While the SLA usually defines only minimum levels of resources that an application should be guaranteed to have, in the context of flexible applications, this is not enough: for example some applications can accept to have a temporarily reduced performance or shifted activities. Similarly, some applications would benefit from a temporary increase of allocation of resources when renewable energies are available. The SFA defines a simple interface to describe this flexibility in term of resource allocated over time, with possible deviations. Thanks to the SFA, an energy-

<sup>1</sup> <http://www.gigaspaces.com/cloudify-cloud-orchestration/overview>

aware PaaS framework is able to dynamically reconfigure applications or single layers (e.g. scale-up and down) to comply with a given energy budget (e.g. the amount of green energy available at a given moment in time). Finally, changes occurring at the level of the PaaS framework can be exploited by an underlying IaaS framework: the information sharing between the two improves the energy usage. smartcity We need to put an additional section on Smart Cities... Why do they need to have data centres inside the city (and not in Finland), what does that imply in term of management, energy consumption, renewables, data security/privacy and governance...

Also a loose connection can be made with 5G/communications: 5G technologies are enabling yet more use of internet/videos/social media. This data is more and more processed in the Cloud. So DC located in the City near the base station = more responsiveness/less losses.

Perhaps we could also talk about the concept of "cloud edge" or mini-cloud located near a base station or a sensor network (in a smart city where a sensor network is deployed) or about a CDN (content delivery network) and where energy efficiency is needed.

## 2 Service Flexibility Agreement

In current PaaS architectures, the framework grants a certain flexibility to applications. For example, an application can ask the PaaS framework to spawn more or less VMs or Linux containers<sup>2</sup> according to its needs. However, the flexibility is entirely controlled by the application and/or the application owner. The intuition behind SFA is to delegate some of the flexibility control to the PaaS framework while still guaranteeing the end user satisfaction. With respect to a traditional SLA, the SFA adds a few new dimensions: the possibility for the required resources to vary in time, plus the possibility to qualify violations of the required performance.

[h] [frame=single]yaml SFA: - Time: 00:00 to 05:59 RecoBP: 100 Hz PosDev: 20 Hz/H NegDev: 80 Hz/H - Time: 06:00 to 11:59 RecoBP: 200 Hz PosDev: 100 Hz/H NegDev: 25 Hz/H

WorkingModes: - WMName: WM1 actuator: 'cf scale myApp -i 3' defaultPower: '300 W' maxBusinessPerf: '100 Hz' - WMName: WM2 actuator: 'cf scale myApp -i 5' defaultPower: '500 W' maxBusinessPerf: '150 Hz'

As shown in listing 2 and also represented graphically in figure 1, for each time frame of a day the SFA defines a recommended business performance (RecoBP, in red in the figure). The business performance is one of the KPIs of the application. For example, for a Web server it is the number of pages served per minutes, for a video transcoding service it will be how many videos can be transcoded per minutes.

We then define a concept called "Happy points", noted "H". This is an abstraction of the end-user satisfaction. An application having zero Happy points

<sup>2</sup> <http://docs.cloudfoundry.org/concepts/architecture/warden.html>

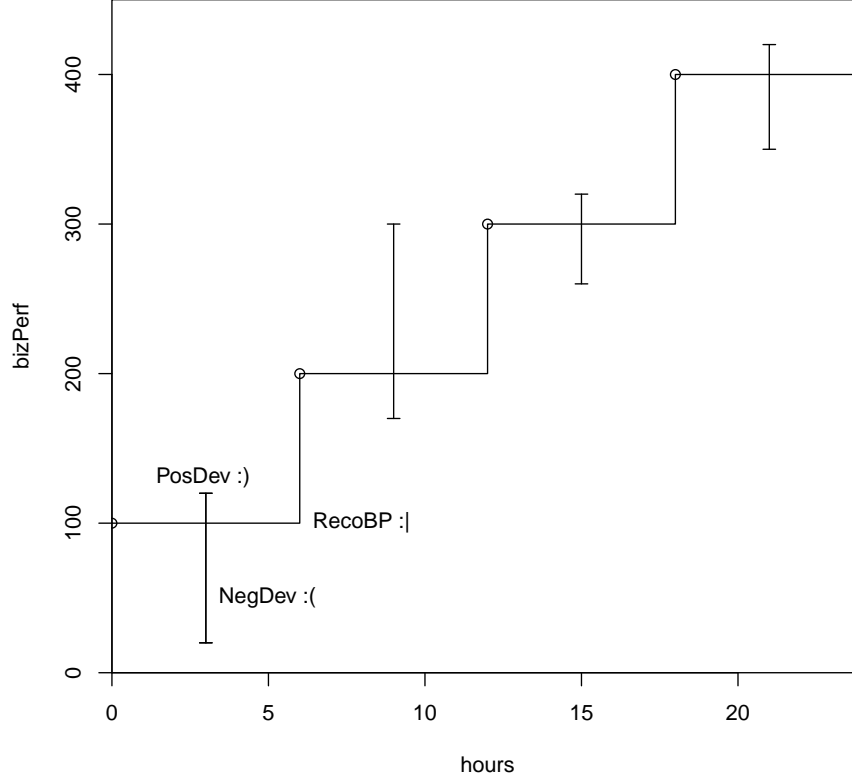


Fig. 1: Service Flexibility Agreement representation

means that the end user is reasonably satisfied. An application being allocated exactly the number of resources corresponding to the RecoBP collects 0 Happy points. This situation corresponds to the traditional SLA threshold. The positive and negative deviations (PosDev and NegDev) declared in the SFA are then the way that each application "reacts" to being given more or less resources than the RecoBP. Indeed, some applications such as video transcoding can benefit from receiving temporarily more resources because they can process more videos and thus make their end user happier. This kind of application reacts linearly to the amount of resources it is allocated. On the other hand, an application such as a web server typically have a "turning point" in their relation between performance and resources. Indeed, giving them less than a certain level of resources (such as the number of front-end VMs) will start to augment the latency in delivering web pages, thus making the end-user unhappy. On the contrary, giving

them more than that level of resources will not have any perceptible impact on the end user, as the latency is already small. This is represented by the vertical deviation bars in figure 1: the length of the bar represents the amount of Happy points that the application will win/lose when given more/less performance than the recoBP, respectively. In this example, at 10 O'clock, if the PaaS framework allocates the resource corresponding to the recommended business performance of 200Hz, the application will collect 0 Happy points. If the application gets 300Hz, it will get 1H, and one more Happy point for each 100Hz above that. Conversely, if it gets less than the recommended 200Hz, it will lose Happy point at the rate of one happy point per 25Hz.

We further define the various Working Modes (WM) of an application. A WM corresponds to a set of resources allocated by the PaaS to an application. We associate to each WM its typical power consumption and the maximum business performance it can offer. In practice, a WM corresponds to a number of VMs or Linux Containers, each running instances of the application. Using the SFA, it is now possible to compute the number of Happy points provided by each WM for each time slot.

### 3 Interaction among IaaS and PaaS layers

In novel PaaS frameworks, application scaling is performed by launching more containers. Each container is an instance, or worker, of the application. Containers run in a VM, controlled by an underlying IaaS framework. To save energy, those VMs are traditionally consolidated on a part of the servers of the data centre, which permits to switch off unused servers and thus save energy. Using the SFA, it is now possible to predict the amount of resource that an application will need, together with the possible deviations. This will allow to optimize VMs by consolidating containers in them and at a second level optimize servers by consolidating the VMs. VMs and containers movements should be minimized to preserve the energy efficiency. However to achieve this we need to enhance the interaction between the IaaS and PaaS. There are essentially two types of information that need to be exchanged:

- VMs grouping
- VMs life-time

The PaaS layer has a certain degree of knowledge about the architecture of deployed applications. If an application is composed of several containers forming the different layers, it is beneficial to keep them together on the same VMs as much as possible, because they will probably have the same life cycle. Those containers will probably exchange a lot of information among them. Furthermore, they will be switched off together when the application is terminated. This justifies to keep them together on the same VM or group of VMs as much as possible.

Knowing the VM life-time (an estimated duration that the VM will be kept running before being switched off) is important for the IaaS layer when optimiz-

ing the energy consumption of a data centre through VM consolidation. Indeed, migrating a VM to consolidate it is an investment, and if the VM is about to be terminated soon, this investment is lost. In PaaS environments, the VM life-time is determined by the life-time of the underlying containers. This life-time should be calculated by the PaaS framework and transmitted to the IaaS framework. Of course, the IaaS layer shouldn't be aware of the applications running in the data centre, as it is not its role and would furthermore break the separation of concerns between the IaaS and the PaaS. The sharing of VMs grouping and VMs life-time does not break the separation of concerns between IaaS and PaaS, because they are expressed in terms of the IaaS VMs only.

## 4 Design & Optimization

The SFA is used in the communication between an application and the underlying PaaS framework (while the SLA, on the contrary, is used for the communication between the data centre and its clients), as shown in figure 2.



Fig. 2: SFA block diagram

In practice, we add a component in the Cloud Foundry stack called the "Optimizer". This component accepts commands from the application load balancer. Instead of just scale-up/scale-down commands as it is the case currently, we include a recommended scaling level, together with a positive deviation and a negative deviation, as described in Section 2. This will let the Optimizer to optimize the full PaaS layer according to multiple criteria: 1) the energy consumption

in the data centre, 2) the global happiness of the applications (as the sum of all happy points granted to applications) and finally 3) the usage of renewable energies. Using the SFA, the Optimizer is able to find the correct trade-offs that will allow it to comply with energy budgets while maximizing the overall end-user happiness in the data centre.

## 5 Related Works

in a paper of 4 pages, related works should be very short: I'd say half a page.

VM consolidation approaches to reduce energy consumption at IaaS layer have been explored in many recent papers [?] [?] [?] [?] [?].

In addition, there are energy efficient solutions based on scaling operations (scale up/down application) based on applications performance metrics. Although these proposals reduce the energy footprint of applications and cloud infrastructures, they do not model the applications performance trend to finely define a trade-off between applications Quality of Service and energy footprint.

Autonomic Computing has been exploited in the design of cloud computing architectures in order to devise autonomic loops aiming at providing coordinated actions among cloud layers for efficiency measures, turning each layer of the cloud stack more autonomous, adaptable and aware of the runtime environment [?] [?].

In order to reach a global and efficient state due to conflicting objectives, autonomic loops need to be synchronized. In [?], authors proposed a generic model to synchronize and coordinate autonomic loops in cloud computing stack. The feasibility and scalability of their approach is evaluated via simulation-based experiments on the interaction of several self-adaptive applications with a common self-adaptive infrastructure.

In addition to elasticity, scalability is another major advantage introduced by the cloud paradigm. In [?], automated application scalability in cloud environments are presented. Authors highlight challenges that will likely be addressed in new research efforts and present an ideal scalable cloud system.

[?] proposes a co-design of IaaS and PaaS layers for energy optimization in the cloud. The paper outlines the design of interfaces to enable cross-layer cooperation in clouds. This position paper claims that significant energy gains could be obtained by creating a cooperation API between the IaaS layer and the PaaS layer. Authors discuss two complementary approaches for establishing such cooperation: cross-layer information sharing, and cross-layer coordination.

## 6 Conclusion and Future Work

change the conclusion

The PaaS Cloud paradigm and the corresponding frameworks are currently developing at high-speed. As shown in this paper, they provide new opportunities for energy optimization. We presented the SFA, a concept able to describe

the flexibility of applications. This format includes the trade-off between the amount of resources allocated to a PaaS scalable application, the resulting performance and the corresponding user experience, in a simple way. This allows the PaaS framework to perform multi-criteria optimizations such as lowering the global energy consumption of the data centre, using more renewable energies and increasing the application user satisfaction. As future work, we will design the proposed API and components within the Cloud Foundry framework.

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## References