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# Autonomic cloud computing platform for scaling users' application

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# Framework dla autoskalowalnego środowiska wykonawczego dla aplikacji użytkowników w konfiguracji hybrydowej chmury obliczeniowej

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I would love to express my best wishes

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# Abstract

Cloud computing has become an attractive model for provisioning on demand computing resources as services to end-users. It is based on the assumption that almost anything can be viewed as a service, starting from applications delivered over Internet, through hardware in the data centers and ending on computing power. That model appears to be so attractive as from the user point of view the offered resources are infinite, transparent, robust and ready to consume at any time.

Most of the times end-users do not know in advance what the demand for the service is. This creates a requirement in which their systems are auto-scalable, i.e. they support sudden spikes in demand followed by underutilization at other times. An architecture of a cloud computing system, that meets these requirements, has a characteristic of a multi-hierarchical autonomic system, where different layers corresponds to different levels where cloud operates: starting from an application layer, through the application platform, infrastructure to end on a cloud instance.

Problem complexity raises challenges in a variety of aspects, especially in terms of providing cooperation and mutual sharing of resources that may belong to different kind of cloud providers. Therefore, an architecture that enables seamless cooperation among cloud providers and takes into account various QoS requirements of end-users be developed is absolutely vital. The InterCloud architecture is one of the first attempts that had been made in this direction. Having characteristic of an application platform in mind, we propose a variation of that architecture that supports cooperation among these application platform and fulfils needs of a decentralized environment.

The main contributions of this thesis are as follows: a) proposition of an architecture that enables aforementioned scenarios, b) implementation of that architecture c) simulation and laboratory tests.

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# 1. Introduction

## 1.1. Motivation

One of the keys factors that has driven transformation of computing industry in the last years is the perception of computing utilities as an ordinary property[23], which can be easily accessed and adjusted to a specific needs. That point of view resulted in profusion of different services, often collectively referred as a cloud computing [33]. Similarly to services common to traditional markets, customers expect them to be accessible on demand and in easy manner, while paying only for the consumed goods. Furthermore, customers are interested in a given service provider only when it is eligible to guarantee appropriate quality of service.

The particular service providers that are addressed by this paper are the ones that supply users with an application execution platform, what is widely known as providing Platform-as-a-Service. In that case, a customer is an entity that has developed application and is eager to deploy it on an application platform that is able to fulfil his specific requirements, both in terms of quality and cost.

Having customer requirements in mind, it is crucial that service provider is able to adapt itself to meet them. For example, such adaptation can be triggered by a sudden spike in resource demand and may result in provisioning additional application platforms. However, due to the complexity of a system under consideration, there are different levels where adaptation is possible:

- user application
- application platform
- infrastructure

What is more, the fact that single service provider is constrained by his finite amount of resources poses a risk that it may not be able to serve customer all the time. Consequently, it is expected that adaptation at a service provider level is also possible, i.e. provider can offload some traffic to a different provider, as long as it satisfies a customer.

While autonomic computing has a long history [34], it has not been directly applied to a multi-layered problem that exists in a cloud computing environment. Especially, the research area at the last layer, which sizes across different service providers, is new. Although, architecture known as InterCloud [20] investigates problem of co-operation and negotiation at cloud level, it neither has been implemented nor presented in context of autonomic system.

### 1.1.1. Business potential

The rapid growth of interest in cloud computing in recent years resulted in huge sums of money being invested in the field. Figure 1.1 shows the size of the public cloud services market in 2012 and the forecast of its nearly two times growth in 2016. This data suggests that the subject is attractive for IT industry from the economic point of view. However, higher amounts of money spent on cloud services involve higher expectations of theirs quality



from customers. Although the most significant players in cloud computing have been in the field for quite a long time, it is still possible to outline some deficiencies their products have. Additionally, lack of common standards hinder cooperation among different cloud providers. For example it is nearly impossible to create an autoscaling cloud federation with Amazon Web Services (current leader in providing cloud services[30]) and another provider. What is more, Amazon AWS users cannot use more lightweight virtualization methods, such as linux containers. Nevertheless, when compared to other companies especially in terms of autoscaling capabilities, Amazon really shines. OpenShift, RedHat PaaS solution, ensures application scaling but with very limited possibilities of customisation of the process – the user can only choose if their application should scale and the whole algorithm is solely based on the number of concurrent requests to the application. Users of Heroku, another PaaS solution, have no automation tool that would control the number of instances (*dynos* in Heroku nomenclature) their application is running on – they can change it manually.

The proposed solution in this dissertation tries to deal with the aforementioned providers problems by outlining an example architecture that enables seamless cooperation among cloud providers and provides auto-scaling capabilities.

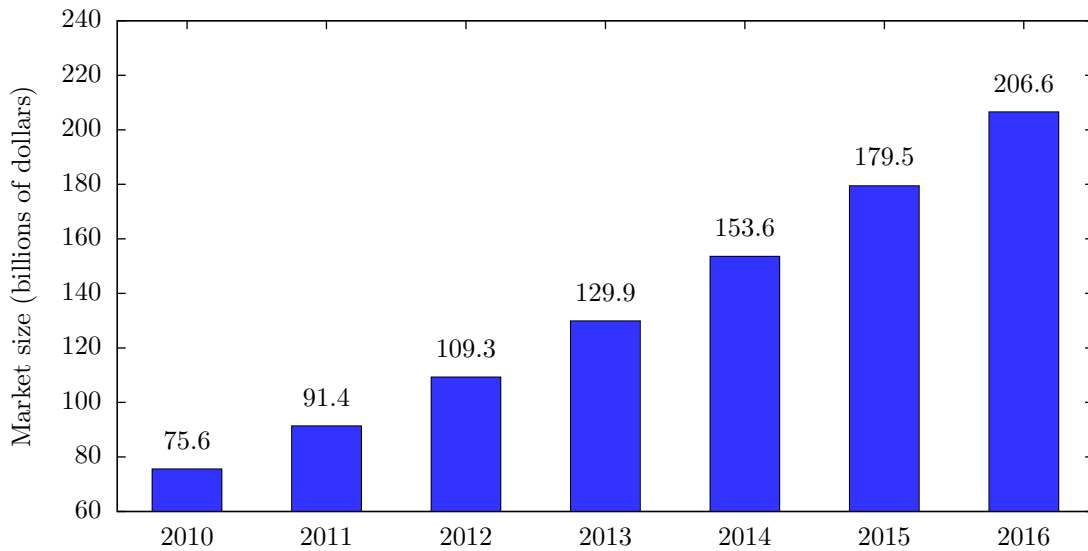


Figure 1.1: Public Cloud Services Market Size, 2010-2016 (forecast). Source: *Gartner*, 08/2012

## 1.2. Contributions

The main contributions of this dissertation are as follows:

- A proposal of an architecture of federated cloud computing environment, which is based on and can be viewed as a simplified version of *InterCloud*
- The notion of considering each service model as an autonomic system
- The implementation of the proposed architecture using OpenNebula technology stack

## 1.3. Impact

We hope that the concept of representing each level of an autoscaling subsystem as an autonomic one can be thought-provoking for cloud computing scientists. What is more, we believe that our successful attempt to implement a simplified variant of an InterCloud architecture will cause its gain in interest and popularity. Finally, we consider the ideas contained in this work be beneficial to the OpenNebula ecosystem as they provide insights into the ways Quality of Service can be ensured:

- implementing autoscaling capabilities
- designing *cloud infrastructure* in accordance with InterCloud architecture

## 1.4. Thesis structure

## 2. Scaling applications

*This chapter is devoted to the concept of scaling users' application from the perspective of a cloud platform provider. To achieve that, it presents attainments of research groups working in that area as well as it considers mechanisms used in products currently available on the market.*

### 2.1. Introduction

The reason why scaling application lies in our area of interest is the fact that it is widely accepted measure for improving application performance, consequently increasing offered Quality-of-Service. Enriching system with capability to scale entails avoiding additional costs that are related to coping with excessive traffic. In some cases, these costs may be caused by not handling extra traffic at all and may involve aspects such as: increased response time, processing overhead, space, memory, or money [17].

While scalability is a widely used term, it still lacks a clear and concise definition. Over the time, there were a few attempts to define it, yet not all of them were claimed as successful [27] [25]. Hence, it is necessary to clarify this term before going into further discussion. Instinctively, scalability is perceived as ability of a system to accommodate an increasing number of elements or objects to process. In particular, we can point out different types of scalability that are affected by increased number of requests: [17]:

- *load scalability* - ability to work without delays and unproductive resource consumption at light, moderate, or heavy loads while making good use of available resources. Factors that may hinder load scalability include: scheduling shared resource, self-expansion, inadequate exploitation of parallelism
- *space scalability* - memory requirements do not grow to intolerable levels as the number of items system supports increases
- *space-time scalability* - system continues to function gracefully as the number of objects it encompasses increases by orders of magnitude
- *structural scalability* - implementation or standards do not impede the growth of the number of objects system encompasses

Although, all of the aforementioned aspects are vital for any application, our work focuses solely on the first type of scalability. The reasoning behind this statement is that, while all of these scalability types lies in direct responsibility of an application developer, the load scalability can be additionally improved by adding additional resources to a system. This brings us to a question what kind of resources are used by an application or more appropriately in context of this dissertation: *what kind of resources can we add to improve application performance?* Required resources varies from an application to an application. However, among the most common ones we can distinguish:

- CPU

- memory
- storage
- network bandwidth

It is commonly agreed that there are two main possible ways the resource can be added:

- *horizontal scaling (scaling out)* - adding more nodes to a system, such as servers in a context of distributed application
- *vertical scaling (scaling up)* - increasing capacity of a single node in a system, i.e. adding additional memory, CPU, storage, etc.

What makes scaling application particularly interesting are the benefits offered by a cloud computing, especially the illusion of a virtually infinite computing infrastructure [37]. Making use of virtualization technologies, which often underpins cloud computing platform, allows for resource manipulation in a dynamic, on-demand manner. Although, cloud computing offers additional scaling capabilities, it increases solution complexity since they operate in different layers: server, platform, network as stated in [37]. However, since platform containers are often represented either as virtual machines or another isolated environment (e.g. OpenShift leverages SELinux and cgroups) they are similar in nature to server scaling and supports both scaling up and out. Therefore, the remaining of this chapter is focused solely on server scaling, omitting network scaling as it lays outside of scope of this dissertation.

Having that said, common sense dictates that adding resources is only a part of the success - it should be accompanied by tuning application platform configuration. For example, adding supplementary CPUs without increasing thread pool size that handle requests makes a little sense. Similarly, in context of a Java application, we have to increase heap size, to make a good use of extra memory. While importance of application tuning cannot be underestimated, its detailed analysis lies outside of the scope of this dissertation. Figure 2.1 presents different scalability layers and actions that can be taken at each level to improve application performance.

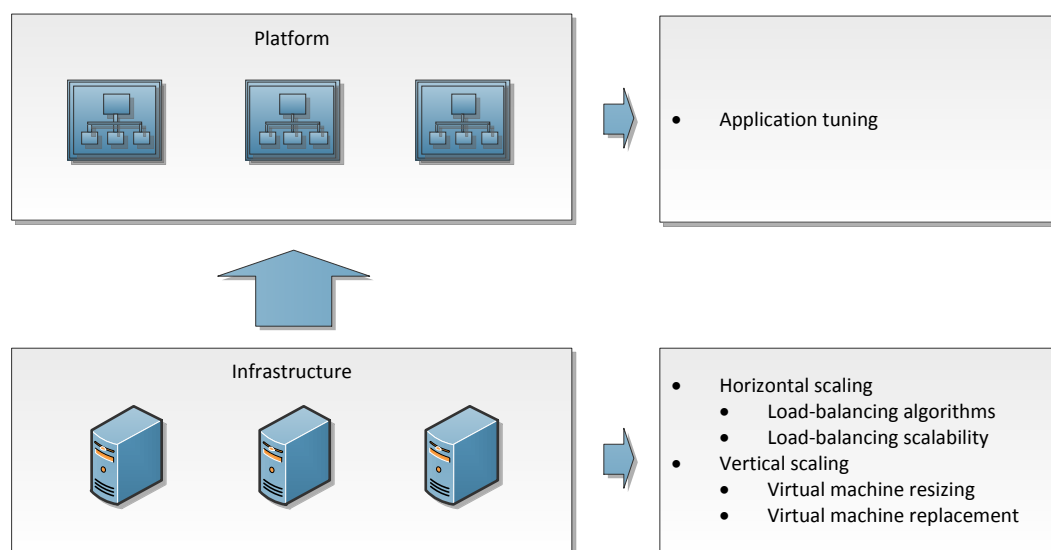


Figure 2.1: Scalability layers

With all that said, there is no silver bullet - not matter what underlying mechanism platform provider decides to use, the application developer is still responsible for creating an application with scaling in-mind. This statement has been already proven in 1967 by Amdahl law, which in short states that sequential component of a parallel algorithm impacts efficiency for a sufficiently large number processors [26] as shown in Figure 2.2. In other words, adding supplementary resources to a poorly written application (i.e. having a lot of sequential or synchronized components) can be beneficial only to a certain degree.

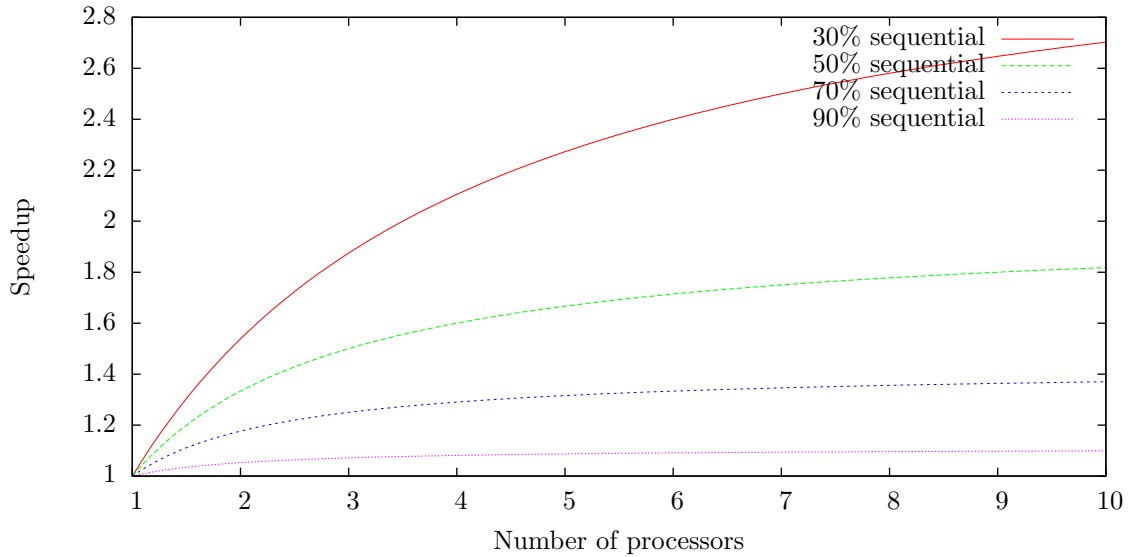


Figure 2.2: Amdahl's law

The rest of this chapter elaborates in detail about horizontal and vertical scaling taking into account mechanisms used in Platform-as-a-Service solutions that are available on the market.

## 2.2. Horizontal scaling

As outlined in previous section, horizontal scaling is about adding supplementary nodes to a system. As it is common to cloud computing, nodes are represented as virtual machines and this assumption is used in further discussion. Consequently, adding server comes down to cloning a new virtual machine from a template and possibly installing additional software and reconfiguring it later. While mechanism of creating new virtual machine from a template is offered literally in every IaaS platform currently available (OpenStack [14], OpenNebula [11], CloudStack [5] or Eucalyptus [6] to name a few) and is similar in manner, the underlying hardware and virtualization mechanism determines how fast provisioning is done.

Provisioning new server is only a first step in scaling an application, it is required to configure load balancing mechanism to make use of additional node. The two important aspects that have to be consider are: load-balancing algorithms and scalability.

### 2.2.1. Load-balancing algorithms

Generally, there are two types of load-balancers: hardware and software based. Due to the dynamic nature of system under consideration, we focus only on the latter as it offers a greater deal of flexibility. Among the most common algorithms we can distinguish [9]:

- *round-robin scheduling* - request are sent to successive nodes, according to their weights. This algorithm is fairest when the server's processing time remains equally distributed [9]
- *least connection* - the server with the lowest number of connections receives the connection
- *source routing* - source IP address is hashed, the same client IP address always reaches the same server
- *URI hashing* - URI that designates resource is hashed and divided by the total weight of the running servers. Such hash designates which server that receives the request. In practice, this algorithm is commonly used with proxy caches and anti-virus proxies in order to maximize the cache hit rate.
- *request counting algorithm* - load is distributed the requests among the various workers, ensuring that each gets their configured share of the number of requests
- *weighted traffic counting algorithm* - variation of above-mentioned algorithm with a difference that it is focused on bytes rather than number of request
- *pending request counting algorithm* - scheduler keeps track of how many requests each worker is assigned at present. A new request is automatically assigned to the worker with the lowest number of active requests

Situation gets further complicated when considering real-world web application that sends user information using cookies, what imposes requirement on load-balancer for session stickiness [36].

### 2.2.2. Load-balancing scalability

Although, it may seem that balancing workloads eliminates problem of a single point of failure (SPOF) among different servers, it is in fact shifted to load-balancing layer. In other words, load-balancer becomes a new SPOF. Therefore, in cases where high availability is required, multi-tiered load balancing architecture should be considered. This, however, seems not to be a case among IaaS or PaaS providers - none of them unequivocally specifies whether they provide redundancy at load-balancer level.

### 2.2.3. Load-balancer comparison

While there are many load-balancers available on the market, following are credited to be most popular:

- **HAProxy** [8] - load-balancer initially written by Willy Tarreau. Noticeably, it's used by OpenShift [12] to distribute load among gears [13]
- **BIG-IP Local Traffic Manager (LTM)** - solution offered by F5 [7]. Although LTM is a hardware solution, omitted in this section, it also has also its virtualized counterpart.
- **Apache HTTPD** [1] - popular HTTP server. When enhanced with additional modules, it can behave like a proxy or load-balancer. Over the time, there were several attempts to develop such modules: `mod_jk` [2], `mod_proxy_balancer` [3], to name a few. While the former is purely AJP13 oriented, the latter supports different protocols: HTTP, FTP and AJP13. As a consequence, only `mod_proxy_balancer` was taken into account during comparison.

Table 2.1 presents they key performance features and algorithm used to schedule requests.

	Performance features	Scheduling algorithms
HAProxy	<ul style="list-style-type: none"> <li>– a single-process, event-driven model reduces the cost of context switch and the memory usage</li> <li>– O(1) event checker</li> <li>– single-buffering without copying data between reads and writes</li> <li>– zero-copy forwarding</li> <li>– optimized HTTP header analysis: headers are parsed and interpreted on the fly</li> </ul>	<ul style="list-style-type: none"> <li>– round-robin scheduling</li> <li>– least connection</li> <li>– source routing</li> <li>– URI hashing</li> </ul>
BIG-IP Local Traffic Manager	<ul style="list-style-type: none"> <li>– managing at application services level rather than at individual devices and objects</li> <li>– scripting language that allows administrator to intercept, inspect, transform, and direct application traffic</li> <li>– built-in firewall protection, application security, and access control</li> <li>– real-time protocol and traffic management decisions</li> </ul>	
Apache HTTPD	<ul style="list-style-type: none"> <li>– support for session stickiness by using cookies and URL encoding. This approach [3] avoids unequal load distribution if clients are hidden behind proxies and stickiness errors when a client uses a dynamic IP address that changes during a session</li> </ul>	<ul style="list-style-type: none"> <li>– request counting algorithm</li> <li>– weighted traffic counting algorithm</li> <li>– pending request counting algorithm</li> </ul>

Table 2.1: Comparison of load balancers

## 2.3. Vertical scaling

Essentially, vertical scaling is concentrated upon increasing capacity of single node. Again, when considering technical advancements that comes with cloud computing and virtualization, we can differ two categories of scaling: virtual machine resizing and virtual machines replacement. This distinction is dictated by limitation hypervisors - not all of them are able to resize virtual machine without shutting it down.

### 2.3.1. Virtual machine resizing

	Memory	CPU	Disk
KVM 1.2.0		– dynamic pinning CPU to a specific virtual machine (depending on underlying hardware)	– adding a disk to a LVM group
Xen 4.3	– changing the amount of host physical memory assigned to virtual machine without rebooting it – start additional virtual machines on a host whose physical memory is currently full, by automatically reducing the memory allocations of existing virtual machines in order to make space	– dynamic pinning CPU to a specific virtual machine (depending on underlying hardware)	– dynamic block attaching, adding a disk to a LVM group
VMware ESX 5.1	– hot-plugging memory, ex. using VMware vSphere	– hot-plugging CPU, ex. using VMware vSphere	– adding additional disks to existing virtual machine
OpenVZ (kernel: 042)	– configurable via user beancounters	– configurable via user beancounters	– configurable via user beancounters

Table 2.2: Comparison of hypervisors resizing capabilities

### 2.3.2. Virtual machine replacement

As it was highlighted in previous section, reasoning behind virtual machine replacement is that, in case when dynamic resizing is not possible, a new virtual machine with a desired configuration can be provisioned and replace the old one. Since this is a basic operation, all above-mentioned hypervisors supports this scenario as long as required resources are available.



## 2.4. Providers comparison

Table 2.3 presents a summary of cloud providers auto-scaling capabilities. Interestingly, all of them are focused solely on horizontal scaling, ignoring advantages offered by a fine-grained approach to scaling that leverage scaling up and application tuning.

	Horizontal scaling	Vertical scaling	Application tuning
<b>Infrastructure provider</b>			
Carina	✓	×	×
OneFlow	✓	×	×
AWS EC2	✓	×	×
<b>Platform provider</b>			
CloudFoundry	×	×	×
OpenShift	✓	×	×
AppEngine	✓	×	×
Azure	✓	×	×
Heroku	×	×	×

Table 2.3: Comparison of cloud providers scaling capabilities

## 3. Platform adaptivity

*This chapter introduces concepts and mechanisms that enhance a platform with adaptivity capabilities, which are often achieved by fusion of rules, policies and scaling techniques.*

### 3.1. Introduction

In short, platform adaptivity adds a auto-scaling features to a solution offered by Platform-as-a-Service provider. Key concept is to have a Elasticity Controller which gathers probes from virtual machines and uses that knowledge to execute appropriate action on cloud instance, indirectly modifying consecutive probes [37]. This concept illustrates diagram 3.1.

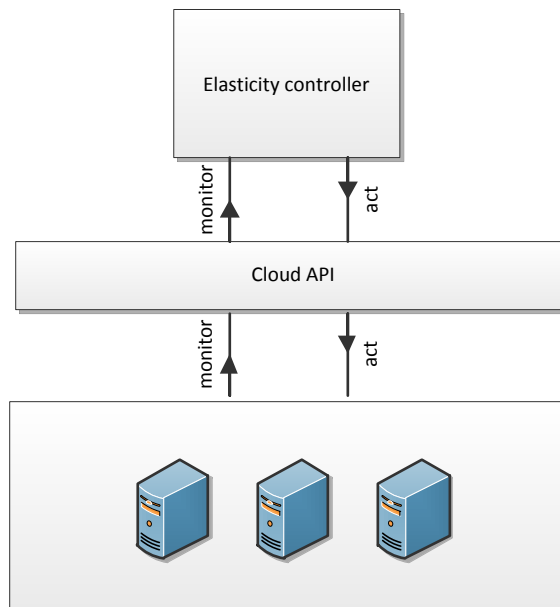


Figure 3.1: Elasticity controller

The remaining of this chapter describes crucial elements that compose elasticity controller: policies, data analysis, triggered actions and presents a comparison of cloud providers.

### 3.2. Policies

While auto-scaling is offered by a vast amount of cloud providers (e.g AWS, OpenShift, OpenNebula) it often lacks a sophisticated mechanisms allowing for specific scaling policies, being limited to only one predefined rule as it is in case of OpenShift for example.

Policy denotes a condition which, when satisfied, triggers an action that is supposed to harness cloud instance in a way that future evaluations of condition will be unsuccessful. Typically condition itself is accompanied by a minimal and maximal number of node instances, allowing for ensuring minimal QoS and controlling maximal costs. Currently, industry leaders supports two main kind of policies [4]:

- *expression based* - allows to define how you to scale application in response to changing conditions, which include factors such as memory, CPU usage, cost or some indirect, calculated metrics
- *scheduled* - allows to scale an application in response to predictable load changes. For example, traffic increases during the weekends and decreases on working days. Hence, that predictable traffic patterns is used to scale application based on current time.

Technically, policies are expressed in some human-readable format such as JSON, XML as it is in case of AWS EC2 or custom expression used for example by Carina. Appendix A.2 presents example configuration used by AWS E2 Auto-Scaling.

### 3.3. Data analysis

Having policies defined, their conditions are evaluated against data acquired from sensors. In a simplest case this evaluation can be based on a Threshold Model [31], which defines a valid range. In cases when given metric violates that condition (i.e. value is either smaller than minimal or bigger than maximal acceptable) corresponding resource is properly adjusted - figure 3.2 illustrates that idea.

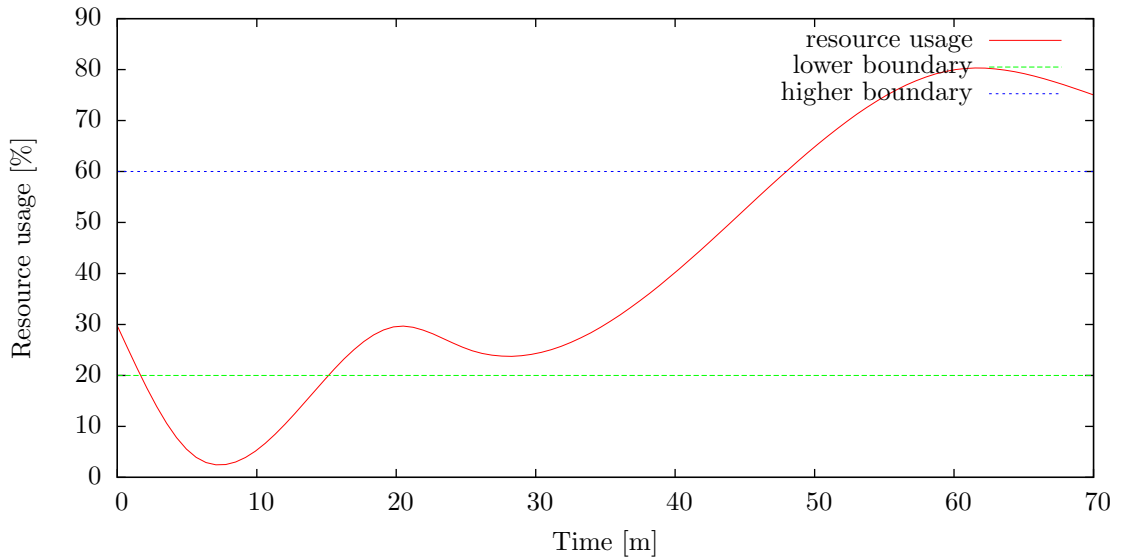


Figure 3.2: Threshold model

While trivial in its form, cases of AWS, OpenShift, Carina, OneCloud proves it is useful in a real-world scenarios. Having that said, more sophisticated algorithms also exists:

- *integer programming* - auto scaling is reduced to server integer programming problems, which aims to minimize the cost or maximize the computing power with either computing power constraints or budget constraints [32]
- *burst based padding* - employs a signal processing technique based on fast Fourier transform, burst pattern is extracted and used to calculate a padding value. Coefficients that represents the amplitude of each frequency component are used to calculate burst density. Depending of that value (i.e. is higher than 50%) appropriate percentile of the burst values are used [35]
- *remedial padding* - padding errors are being recorded and used in successive padding evaluations. In other words, let  $e_1, e_2, \dots, e_k$  denote the recent prediction errors, next the weighted moving average is calculated. Actual applied padding is either padding itself or weighted average, depending which one is greater [35]
- *linearised dynamic control* - linearised correction model is based on control equations [19]:

$$x(k+1) = Ax(k) + Bu(k) \quad (3.1)$$

$$y(k) = Cx(k) + Du(k) + Ez(k) \quad (3.2)$$

where  $x$  denotes the state variable vector and coefficient matrices:  $A B C D E$  are fitted to historical data as a regression model - [24]

- *markov decision process model* - computes optimal reaction to state changes by using observation on the system with assumptions about the rate of changes expected in the future [18]

### 3.4. Triggered actions

Actions that are being triggered by a elasticity controller are focused on application scaling. Previous chapter described that problem in detail.

### 3.5. Providers comparison

Table 3.1 summaries chapter with approaches to adaptivity taken by different cloud providers. Section 'triggered action' is omitted for brevity - it was described extensively in previous chapter.

	Policies	Data analysis
<b>Infrastructure provider</b>		
Carina	<ul style="list-style-type: none"> <li>– time frame based</li> <li>– expression based (only for CPU)</li> </ul>	– threshold model that takes into account minimal and maximal permitted instances of an application as well as application priority
OneFlow 4.2	<ul style="list-style-type: none"> <li>– time frame based with customizable padding</li> <li>– expression based build on custom language, where all vm's metrics are supported</li> <li>– customizable adjustment padding, cooldown time</li> </ul>	– threshold model
AWS EC2	<ul style="list-style-type: none"> <li>– time frame based</li> <li>– expression based, where expressions corresponds to a AutoScalingGroup</li> <li>– actions are triggered by a CloudWatch alarms</li> <li>– customizable adjustments paddings, types, cooldown time</li> </ul>	– threshold model, takes into account minimal and maximal permitted instances of an application as well as application priority
<b>Platform provider</b>		
CloudFoundry	×	×
OpenShift	– single built-in policy	– single built-in threshold model that scales an application when CPU load is greater than 50% for a given period
AppEngine	<ul style="list-style-type: none"> <li>– built-in policy based on request queue length</li> <li>– adjustable minimal, maximal number of application instances, pending latency</li> </ul>	– queue-based, new instance is provisioned if queue length got too long
Azure	<ul style="list-style-type: none"> <li>– time frame based</li> <li>– expression based, where expression can involve either CPU usage or Queue length</li> <li>– customizable adjustments paddings, types, cooldown time</li> </ul>	– threshold model, that takes into account minimal and maximal allowed instances
Heroku	×	×

Table 3.1: Comparison of cloud providers approach to adaptivity

## 4. Interoperability of clouds

*This chapter introduces the notion of a hybrid cloud and explains its role in IT industry. On top of this deployment model, the concept of InterCloud is presented and elaborated with the emphasis on its application in ensuring scalability of users' services.*

### 4.1. Introduction

From the perspective of a user of PaaS services it is vital that they are able to deploy seamlessly their applications using libraries, tools and services supported by the cloud provider[33]. Judging by such factors as the popularity of Heroku – currently one of the most popular PaaS providers which does not offer more advanced features which would enable management of the infrastructure underpinning the deployment platform, the fact that Microsoft added auto-scaling to its Azure platform as late as in June 2013, it is perfectly possible most PaaS users are satisfied with the current offers of their providers and do need another, more sophisticated functionalities. However, there are more complex applications and systems whose requirements regarding technology stack, availability and scalability are considerably more demanding. For such services there ought to be designed slightly specialized features that would require cooperation among different cloud providers.

### 4.2. Hybrid cloud

One can imagine scenarios in which customers of cloud services know their applications are vulnerable to sudden variations in demand and their responsiveness must be kept at the same level all the time. In such cases, they want them to scale dynamically according to current load or other predefined or manually specified metrics. What is more, in order to ensure high availability of their services, customers do not want to confine themselves to only one provider – in the best scenario they want their applications (or their logical parts, such as persistence layer) to be spanned across different providers and be able to cooperate with one another at the same time. Additionally, due to privacy concerns of the sensible data, companies are reluctant to put it in the public cloud storage. All these factors lead to the concept of a *hybrid cloud*[33] – the case in which the cloud is a composition of two or more distinct infrastructures which are unique entities, but there are technological means that make it possible to port data and applications among them.

#### 4.2.1. Deployment models

The informal introduction to the concept of a *hybrid cloud* in the previous section requires a strict definition, but it is virtually impossible without defining other deployment models:

- Private Cloud – The provisioned cloud infrastructure is used exclusively by a single organization (that may consist of many business units) and may be owned, managed and operated by the organization or a third party.
- Public Cloud – The provisioned cloud infrastructure is used by general public and may be owned, managed and operated by a business, academic or government organization or some combination of them. It exists on the premises of the cloud provider.
- Community Cloud – The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy , and compliance considerations). It may be owned, managed , and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.

Having defined those models, we can see that *hybrid cloud* can be placed among them and be defined as a model in which the provisioned infrastructure is a composition of two or more other infrastructures - *private,community* or *public*.

#### 4.2.2. Current usage and trends

##### Cloud – clients' view

Before digging into the details of current usage and popularity of the hybrid model, it is worth discussing the general attitude of clients towards cloud computing. As the recent survey [15] shows, the major factor that prevents companies from adopting cloud solutions is their concern over security – in 2012 as much as 52% responders considered it as a main concern with the regard to cloud in general. However, the tendency is that more and more enterprises do not find it a major issue as in 2012 the number declined to 46%. Complexity related to the management of cloud components, Vendor lock-in, interoperability and reliability were among the most frequent obstacles to adoption in 2013 for they constituted 46%, 35%, 27% and 22.3% of responders' votes respectively. Total results are shown in the figure 4.1.

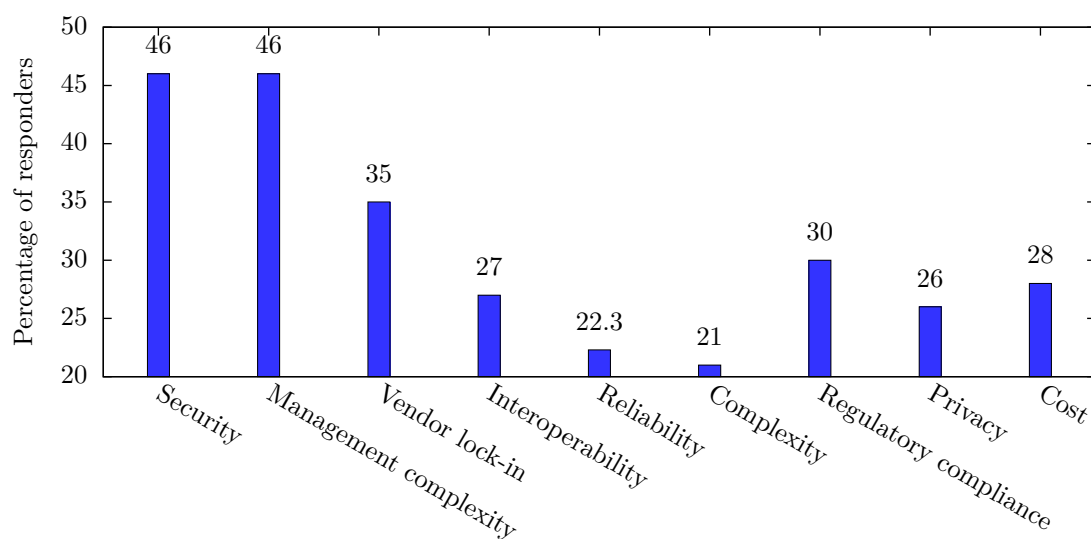


Figure 4.1: Major obstacles to cloud adoption in 2013 according to [15]

The same survey shows that the cloud adoption growth rate is high – 75 percent of responders stated usage of some sort of a cloud platform. This means 8 percent growth when compared to the results obtained in 2012. The expectations for the total worldwide addressable market for cloud computing are to reach \$158.8B by 2014 – an increase of 126.5 percent from 2011.

### View on hybrid cloud

When it comes to the application of a hybrid model in industry, in most cases the definition introduced in the previous chapter now becomes a 'public-private' composition. And this is how the term should be understood when discussing the results of the surveys which aimed to provide insights onto the view on a hybrid cloud from the customers' perspective. The study [15] forecasts 16 percentage growth in the hybrid cloud adoption in 5 years, from 27 to 43 percent. At the same time, the usage of a public model will decline from 39 to 32 percent. The other survey, conducted by Rackspace [16], provides more detailed data about current usage and popularity of a hybrid model. The first interesting finding is that as much as 60% responders, which included 1300 companies in the UK and US, have moved or are planning to move certain applications either partially (41%) or completely (19%) off the public cloud because of its limitations or the potential benefits of other models, e.g. the hybrid one. The second one is about the pros of adopting the hybrid cloud – potential users find more control (59%) and better security (54%) top benefits of using this deployment model. The other most responded benefits are shown in the figure 4.2.

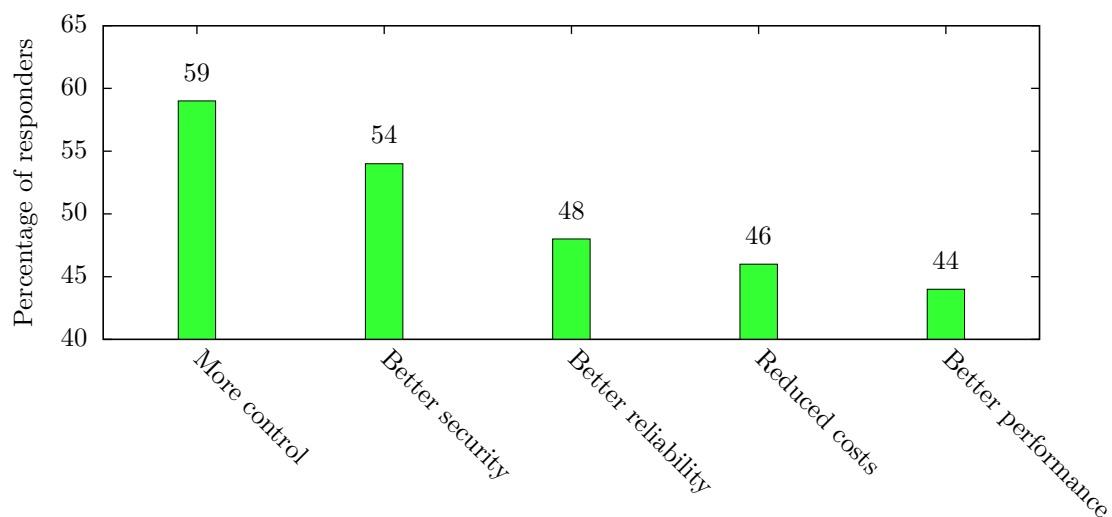


Figure 4.2: Top benefits of using the hybrid model according to [16]

## 4.3. Federation of clouds – InterCloud

As stated in the previous sections, one of the major obstacles that prevents consumers from adopting cloud solutions is reliability. It appears that these statements are not only imaginary worries of entrepreneurs, but real problems – there are cases, where some providers temporarily run short of capacity (e.g. because of provisioning too many virtual machines) in the face of high demand [29]. What is more, the more demanding clients require specific QoS to be satisfied by their providers as negotiated in Service Level Agreements. In order to meet these challenges there is a need of a completely new approach to the problem of effective management of resources. The new solution should take into account such factors as:



- users' requests priority
- users' QoS requirements (e.g. the deadline by which some jobs have to be executed)
- price that the clients pay for the usage of resources

Computer scientists in the field of cloud computing devised a model [22] in which resources are managed in a market-oriented fashion that enables dynamic regulation of the supply and demand of resources and promotes the mechanisms for their allocation that would take into account their priorities and levels of utilization. The extension of this model is a vision of creating the federated cloud computing environment, so called *InterCloud*, that “facilitates just-in-time, opportunistic, and scalable provisioning of application services, consistently achieving QoS targets under variable workload, resource and network conditions” [21]. The elements of the proposed architecture are as follows:

- Cloud Exchange – acts as a market maker for bringing together both producers and consumers of services. It allows Cloud Brokers and Cloud Coordinators to match consumers with the fitting offers from providers. Such a market is a step forward towards creating a dynamic infrastructure for trading based on Service Level Agreements.
- Cloud Coordinator – manages the instance of a cloud and its membership in the overall federation; provides an environment (programming, deployment) for applications
- Cloud Broker – acts on behalf of the client; communicates with the Cloud Exchange to find the best cloud instances for the application

#### **4.3.1. Usage in industry**

The depicted model has not yet been adopted in the industry, yet some simulations were carried out on a *CloudSim* platform and the obtained results showed that this concept has “immense potential” [21].

## 5. Design of Cloud-SAP

*This chapter introduces the high-level design of Cloud-SAP. Further elaboration on the layers of the proposed platform is presented and detailed discussion about the each layer is held.*

### 5.1. Requirements

One can notice that elements that yields a solution for a problem stated in the first chapter, which is ensuring that users' application provide appropriate Quality-of-Service for its customers in a most-cost effective manner, were gradually introduced in previous chapters:

- *scalability* - ability to improve application performance by enriching resources
- *adaptivity* - ability to adapt (i.e. scale) appropriately to a current usage pattern
- *inter-cloud awareness* - ability to compose an application deployment using different cloud providers; cooperation with different cloud provider to supply application with extra resources while performing application scaling

Next section states the general overview of the proposed solution, while the consecutive sections presents more detailed discussion of its elements and finally the last section summarises the design choices in a context of system requirements.

### 5.2. High-level design

#### 5.2.1. Overview

(Diagram komponentowy)

As diagram illustrates, we can distinguish two main components of proposed solution: auto-scaling module and inter-cloud broker. Together, they can be seen as an hierarchical autonomic system, where each layer corresponds to a different scalability perspective:

- application platform layer: application platform tuning
- container layer: vertical scaling
- stack layer: horizontal scaling
- inter-cloud layer: scaling out across different cloud providers

Figure 5.1 depicts that multi-layered structure.

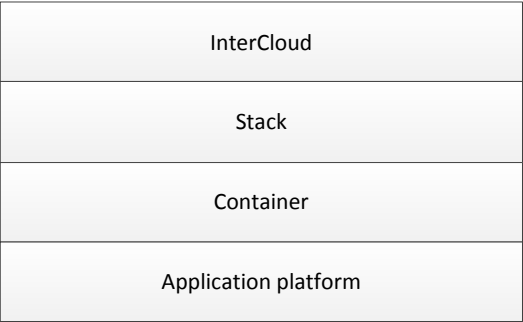


Figure 5.1: Layered structure of Cloud-SAP

5.2.2. Auto-scaling module

Autonomic components

Each layer of the Cloud-SAP (shown in figure 5.1) must be characterized by an ability to adapt to a given application usage. As the previous chapter stated, this can be achieved by adding an elasticity controller to each layer. This observation is a foundation of proposed architecture.

One of the first models that ensured system adaptivity is an autonomic component, concept based on a feed-back loop, initially proposed by IBM [28]. Figure 5.2 depicts that architecture.

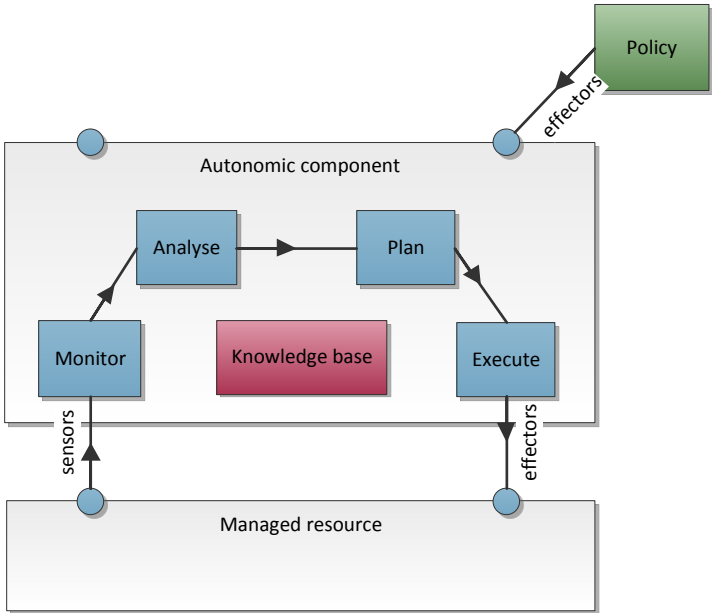


Figure 5.2: autonomic component

Since designed platform operates on multiple layers, we can extend that model by using concept of a multi-hierarchical autonomic system [31]. Figure ?? illustrates that hierarchy, were each level represents a different perspective on an application scaling. Using terminology characteristic to a autonomic system, first three hierarchy

levels (application tuning, container, stack) are centralized and controlled by a single elasticity controller at each level, while the last inter-cloud level is a decentralized one - each cloud instance is fully independent.

As [28] states, each autonomic component has modules that are responsible for:

- monitoring
- analysis
- planning
- action execution

While the managed component has:

- sensors
- effectors

Due to the hierarchy of our architecture, each level manages an underlying autonomic component, while being managed by an upper layer at the very same time.

**Monitoring**

**Analysis**

**Planning**

**Execution**

### **5.2.3. Cloud federation**

Opis najwyzej warstwy, ze ma brokery, wykorzystuje kilka chmur.

## **5.3. Auto-scaling module**

## **5.4. Cloud federation**

## **5.5. Solution discussion**

## 6. Implementation

*In this chapter we outline implementation details about each component of the proposed solution.*

### 6.1. Requirements

#### 6.1.1. Functional

One can notice that elements that yields a solution for a problem stated in the first chapter, which is ensuring that users' application provide appropriate Quality-of-Service for its customers, were introduced in previous chapters:

- scalability – ability to improve application performance by enriching
- adaptivity – ability to adapt (i.e. scale) appropriately to current usage pattern
- inter-cloud awareness – ability to cooperate with different cloud provider to supply application with extra resources

Having those in mind, we can make the list of functional requirements more formal:

1. The user of the platform is able to:
  - (a) deploy a service,
  - (b) cancel the service,
  - (c) check the status of the previously ordered-to-deploy service at any time. *Status* means a) whether or not the deployment succeeded, b) current uptime of the service, c) current cost
2. One of the elements of the platform is a client application that is used by the user of the platform to communicate with it,
3. During the deployment process, the platform takes as an input a description of the service (application) that consists of:
  - service name,
  - software stacks (e.g. *java*, *ruby*),
  - auto-scaling policies (per each stack) which define i) minimal and maximal number of VMs that are needed for the stack, ii) name of the policy (algorithm) which is used for scaling, iii) parameters of the policy
4. Deployment of a service is done in a way which minimizes the cost from the client's perspective with ensuring Quality-of-Service requirements at the same time,

5. It is assumed that the application which is going to be deployed is properly and fully tuned so that it is not possible to improve its performance by changing its or any of its components configuration(s),
6. The platform monitors the state of the deployed services and based on the results of this process takes appropriate steps in order to meet the auto-scaling requirements. These include a) altering VM's parameters and configuration, b) vertical scaling, c) horizontal scaling, d) scaling stacks among different cloud providers

TODO Alternative scenario – the client has a predefined budget that they cannot exceed – it can be mentioned in the overall discussion of the solution

### 6.1.2. Non-functional

- The platform uses *OpenVZ* as a hypervisor
- The platform uses *OpenNebula* and *AppFlow* as data-center management tools
- The platform does not confine itself to one provider, but to a *ecosystem of various cloud providers* that offers deployment capabilities which vary in terms of quality of service, cost, etc.
- All communication between the user and the platform and among platform components should be encrypted

## 7. Evaluation

*This chapter contains results and discussions on the evaluation of tests run on the proposed solution.*

### 7.1. Introduction

We carried out a number of tests which aim to prove the solution be better than currently available, especially in terms of:

1. deployment cost
2. cost of providing given Quality-of-Service
3. deployment time

### 7.2. Cost of service deployment

#### Description

The aim of this test case is to test the primary use case of the proposed solution – deployment of a service with the emphasis of client’s **cost**. It should show that the platform chooses the best mapping between the stacks and cloud providers so that the client’s pays the **lowest** possible price.

#### Preconditions

Service specification (A.2) forms an input to the application. Its elements are different software stacks that are parts of the whole service. Each cloud provider has its own price for a given software stack which is shown in table 7.1. Diagram ?? illustrates the overall configuration.

(JEB deployment diagram, podzial na wezly)

	CP-1	CP-2	CP-3
java	150	120	180
ruby	220	290	250
postgres	320	240	290
python	200	260	180
amqp	330	390	285

Table 7.1: Price for a stack in the given cloud provider

	CP-1	CP-2	CP-3
java		x	
ruby	x		
postgres		x	
python			x
amqp			x

Table 7.2: Chosen cloud providers for the given stack

## Results

Table 7.2 shows obtained mapping between stacks and cloud providers. Taking into account this result, figure 7.1 shows comparison of cost the client would have to pay with and without such a mapping.

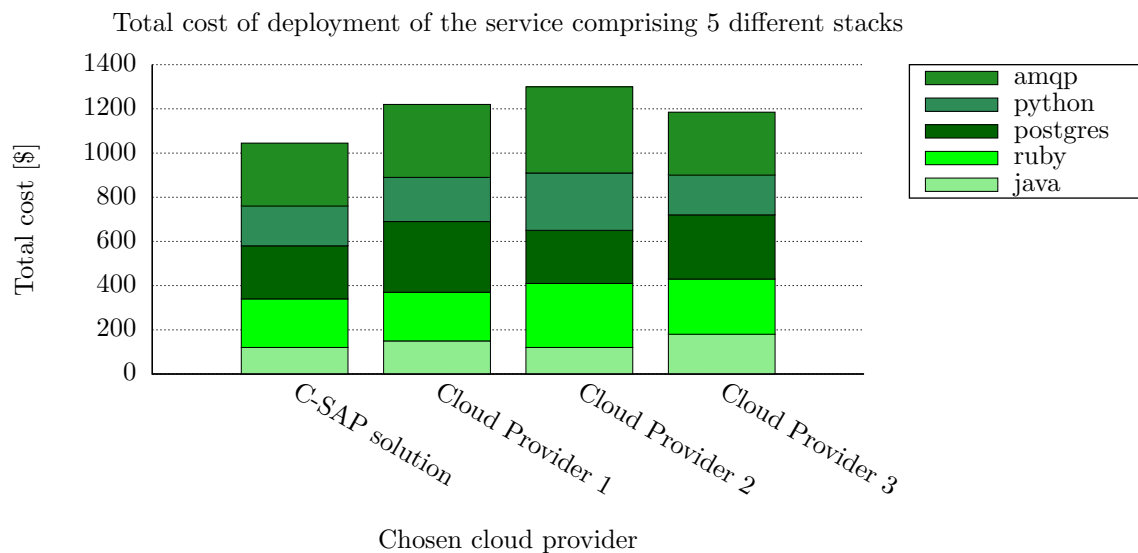


Figure 7.1: Comparison of the deployment cost when the service is deployed only on a selected cloud provider or a combination of cloud providers selected by Cloud-SAP



## Conclusion

### 7.3. Auto-scaling – single-provider based

#### Description

#### Preconditions

#### Results

#### Conclusion

### 7.4. Auto-scaling – multiple-provider based

#### Description

#### Preconditions

#### Results

#### Conclusion

### 7.5. Deployment time – solution comparison

#### Description

In this test we want to compare our solution to one of those available at the market which use *OpenNebula* as an underlying tool for managing resources of a data center and *OpenVZ* as a hypervisor in terms of **deployment time**, one of the most important factors of products whose main purpose is to scale applications. *Carina* [10] can be considered a perfect match of a solution for such a comparison and tests are ran against it.

This test involves the steps of i) instantiating one of the tested product, i.e. Cloud-SAP or Carina, ii) ordering the deployment of a service whose specification is shown in listing A.3, iii) measuring the time needed to set up the environment of the service.

#### Preconditions

Before performing any tests all virtual machines present at the deployment node are removed.

#### OpenNebula configuration

To ensure objectivity in tests, OpenNebula was configured in both products in the same way. One of the key factors that could influence the deployment time is the configuration of scheduler. Its parameters are shown in the listing 7.1.

Listing 7.1: OpenNebula scheduler configuration

```
SCHED_INTERVAL = 30
MAX_VM          = 300
MAX_DISPATCH    = 30
MAX_HOST        = 1
HYPERVISOR_MEM  = 0.1
```

Instance no	Solution	
	Cloud-SAP	Carina
2	198.0	158.7s
3	261.72	208.1s
4	294.38	230.6s

Table 7.3: Average deployment time for the service with the various number of VMs used for the whole environment

### Service description

The service comprises a simple java enterprise application, deployed in a master-slave configuration with one VM set as a load balancer and other nodes that serve as workers, which uses Tomcat as a web container.

The description of a service expressed in Carina format can be found in listing A.1.

- TODO dodać konfigurację każdej z maszyn wirtualnych

### Hardware configuration

All virtual machines were deployed on one node which had 3G RAM, AMD Athlon™64 X2 Dual Core Processor with each core of 2000 MHz frequency and a hard drive with a capacity of 160 GB. Diagram presents the physical configuration of nodes. - jeb physical diagram

### Environment configuration

Components that were used during tests are shown in figure . - jeb logical diagram

## Results

Obtained results are shown in table 7.3 and in figure 7.2.

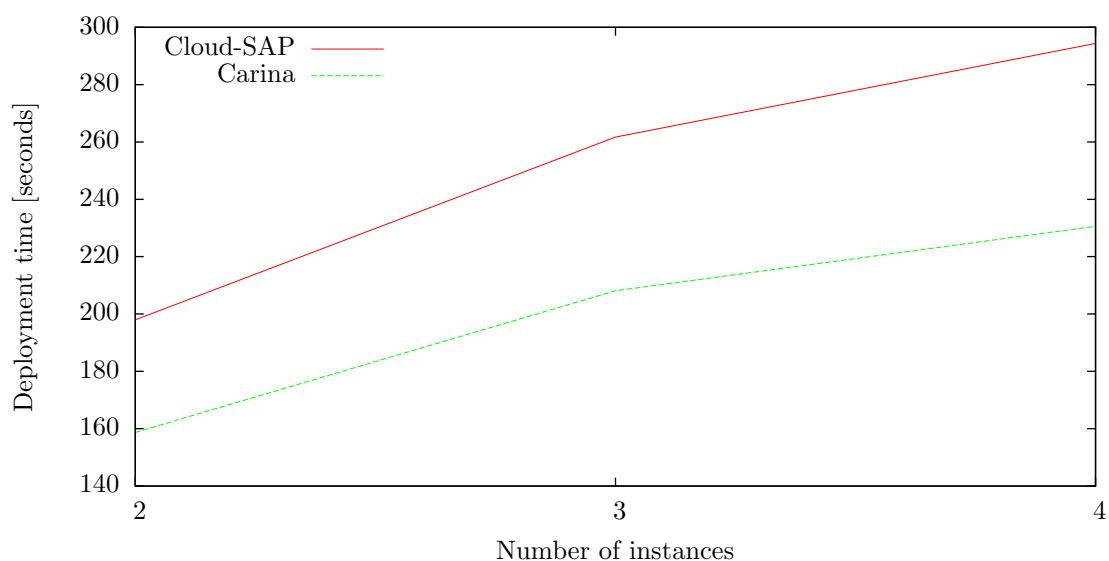


Figure 7.2: Average deployment time for two competing products when the variable is the number of instances of VMs

## **Conclusion**

## **7.6. Deployment time – hypervisor comparison**

### **Description**

### **Preconditions**

### **Results**

### **Conclusion**

## **8. Summary**

## A. Code listings

### A.1. Service specifications

Listing A.1: Carina Environment Specification which was used during tests of deployment time

```
ENDPOINT = {
  'mm01' => {
    :proxy    => 'http://192.168.0.35:2633/RPC2',
    :oneauth => "svc:xxxxx"
  }
}

TEMPLATE = {
  'tomcat' => {
    :file      => "~/vm/tomcat.vm",
    :cpu       => "0.3",
    :memory    => 512,
    :network_id => { 'mm01' => 7 },
    :image_id  => { 'mm01' => 10 }
  },
  'haproxy' => {
    :file      => "~/vm/haproxy.vm",
    :cpu       => "0.3",
    :memory    => 512,
    :network_id => { 'mm01' => 7 },
    :image_id  => { 'mm01' => 11 }
  }
}

ENVIRONMENT = {
  'testenv' => {
    :type                => "compute",
    :endpoint            => "mm01",
    :description         => "Example environment",
    :master_template     => "haproxy",
    :master_context_script => "sample-master-context-script.sh",
    :master_setup_time   => 30,
    :master_context_var  => "BALANCE_PORT=8080",
    :slave_template      => "tomcat",
    :slave_context_script => "sample-slave-context-script.sh",
    :slave_context_var   => "APP_PACKAGE=gwt-petstore.war",
    :placement_policy    => "pack",
    :num_slaves          => 3,
  }
}
```

```

        :slavedata           => "8080",
        :adminuser           => "root",
        :app_url              => "http://%MASTER%:8080/testapp"
    }
}

```

Listing A.2: Cloud-SAP Service Specification (without scaling policies)

```

{
  "name": "my new facebook",
  "stacks": [
    {
      "type": "java",
      "instances": 1
    },
    {
      "type": "amqp",
      "instances": 1
    },
    {
      "type": "python",
      "instances": 1
    },
    {
      "type": "ruby",
      "instances": 1
    },
    {
      "type": "postgres",
      "instances": 1
    }
  ]
}

```

Listing A.3: Cloud-SAP Service Specification used for testing deployment time

```

{
  "name": "Deployment time test service",
  "stacks": [
    {
      "type": "java",
      "instances": 2,
      "policy_set": {
        "min_vms": 0,
        "max_vms": 2,
        "policies": [
          {
            "name": "threshold_model",
            "parameters": {
              "min": "5",
              "max": "50"
            }
          }
        ]
      }
    }
  ]
}

```

```

    ]
}

```

## A.2. Scaling policies

Listings A.4 illustrates XML-based policy that is used by Auto Scaling of the Amazon Web Services EC2.

**Listing A.4: Scaling policy - AWS EC2**

```

<DescribeAutoScalingGroupsResponse xmlns="http://autoscaling.amazonaws.com/doc
/2011-01-01/">
  <DescribeAutoScalingGroupsResult>
    <AutoScalingGroups>
      <member>
        <Tags/>
        <SuspendedProcesses/>
        <AutoScalingGroupName>my-test-asg</AutoScalingGroupName>
        <HealthCheckType>EC2</HealthCheckType>
        <CreatedTime>2013-01-22T23:58:48.718Z</CreatedTime>
        <EnabledMetrics/>
        <LaunchConfigurationName>my-test-lc</LaunchConfigurationName>
        <Instances>
          <member>
            <HealthStatus>Healthy</HealthStatus>
            <AvailabilityZone>us-east-1e</AvailabilityZone>
            <InstanceId>i-98e204e8</InstanceId>
            <LaunchConfigurationName>my-test-lc</LaunchConfigurationName>
            <LifecycleState>InService</LifecycleState>
          </member>
        </Instances>
        <DesiredCapacity>1</DesiredCapacity>
        <AvailabilityZones>
          <member>us-east-1e</member>
        </AvailabilityZones>
        <LoadBalancerNames/>
        <MinSize>1</MinSize>
        <VPCZoneIdentifier/>
        <HealthCheckGracePeriod>0</HealthCheckGracePeriod>
        <DefaultCooldown>300</DefaultCooldown>
        <AutoScalingGroupARN>arn:aws:autoscaling:us-east-1:123456789012:autoScalingGroup:66
          be2dec-ee0f-4178-8a3a-e13d91c4eba9:autoScalingGroupName/my-test-asg<
      </AutoScalingGroupARN>
        <TerminationPolicies>
          <member>Default</member>
        </TerminationPolicies>
        <MaxSize>5</MaxSize>
      </member>
    </AutoScalingGroups>
  </DescribeAutoScalingGroupsResult>
  <ResponseMetadata>
    <RequestId>cb35382a-64ef-11e2-a7f1-9f203EXAMPLE</RequestId>
  </ResponseMetadata>
</DescribeAutoScalingGroupsResponse>

```

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