Outsourcing tasks in CometCloud-based federated systems

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***Abstract*—One of the key benefits of Cloud systems is their ability to provide elastic, on-demand (seemingly infinite) computing capability and performance for supporting service delivery. With the resource availability in single data centres proving to be limited, the option of obtaining extra-resources from a collection of Cloud providers has appeared as an efficacious solution. The ability to utilize resources from multiple Cloud providers is also often mentioned as a means to: (i) prevent vendor lock in, (ii) to enable in house capacity to be combined with an external Cloud provider; (iii) combine specialist capability from multiple Cloud vendors (especially when one vendor does not offer such capability or where such capability may come at a higher price). Such *federation* of Cloud systems can therefore overcome a limit in capacity and enable providers to dynamically increase the availability of resources to serve requests. We describe and evaluate the establishment of such a federation using a CometCloud based implementation by considering a a number of federation scenarios to determine the impact of outsourcing on the overall status of our system. CometCloud provides an overlay that enables multiple types of Cloud systems (both public and private) to be federated through the use of specialist gateways. We describe how two physical sites, in the UK and the US, can be federated in a seamless way using this system.**

Keywords*—*Cloud Computing, Cloud Federation, CometCloud, Tuple-Space, Task Outsourcing.

I. Introduction

With the emergence of federation in cloud systems it has become possible to connect local infrastructure providers to a global marketplace where participants can transact (buy and sell) capacity on demand. The mechanism of cloud federation can bring substantial benefits for service providers by offering facilities for accessing global services instead of increasing costs associated with building new infrastructure. More importantly, organisations with spare capacity in the data centre are now provided with a simple way to monetize that capacity by submitting it to the marketplace for other providers to buy, creating an additional source of revenue [1]. Federation in cloud systems has led to a real *democratisation* of cloud markets – enabling businesses to make use of a variety of different cloud providers in different geographic areas. The federated cloud can also provide to end users the ability to host applications with their cloud provider of choice. Similarly, users can choose a local host with the exact pricing, expertise and support packages while still receiving instant access to local or global IT resources.

In federated clouds, providers aspire to accept as many new requests as possible with the main objective of maximising profit; nevertheless, they must guarantee Quality of Service (QoS) based on the agreed Service Level Agreement (SLA) with customers. Establishing an SLA between two parties (client & service provider) implies that the service provider has agreed to provide a particular capability to the client subject to some QoS constraints. In return, the client must provide a monetary payment (most often) or credit to the provider once the service has been delivered (subject to a penalty, often also monetary, in case the quality of service terms have not been adhered to). In a federation context there are several parameters that need to be considered in order to determine the overall federation workflow. When two or more sites come together, it is important to identify not only the incoming workload of each site but also the cost of outsourcing additional resources, the revenue obtained from outsourcing tasks or the cost of maintaining a reasonable level of utilisation. Identifying a set of such parameters is a challenging task due to the variability in the parameters of a federated environment (such as number of resources allocated to local vs. remote jobs, how many jobs to outsource to another site, the time interval over which access to remote jobs should be allowed, etc) and the fluctuation of resource demand. Depending on their value, a site manager must decide whether to outsource resources, compute tasks locally or reject remote task requests [2].

However, when dealing with a federated system, there are several parameters that need to be optimised and associated policies to be applied in order to increase the utility of providers contributing resources in such a system. In this paper, we propose a CometCloud based federated system by having as an objective the reduction of delay in task processing and maximisation of profit within each site. We develop two different federation models (i) CometCloud Federation and (ii) aggregated CometCloud Federation enabling a process where tasks can be processed exclusively "in house" – using local capabilities or they can be outsourced to remote federated locations. Moreover, we include a third scenario that represents a market. In this case, we show how the profit is affected by the chosen benefit per task and the reputation of the involved site.

The reminder of this paper is organised as follows: Section I, section II and section IV present the problem of federated clouds, providing a key motivation of our research and analysing several related approaches in the area of cloud federation. Section V presents the model explaining the methodological details of the CometCloud and the *aggregated* CometCloud federation. The evaluation of our implemented

system is presented in section VII. We conclude and identify future work in sections VIII and IX respectively.

II. Related work

In the area of cloud federation several recent solutions have been proposed, such as [3], [4], [5]. Although these solutions enable participants to increase capacity and extend an existing market place, these efforts still leave undetermined when a participant should outsource a local request (compared to execute it locally) and the types of policies that may be used to govern such a federation model.

The Reservoir model [3] proposes an open service-based environment in which resources and services are transparently provisioned and managed across clouds. In the Reservoir model, the providers of the services and the infrastructure providers are two separated entities, where the service that a service providers commits to provide is actually outsourced to an infrastructure provider. Reservoir resides on the principle that federation and interoperability can enable infrastructure providers to take advantage of their aggregated capabilities to provide a seemingly infinite service computing utility. Therefore a provider federates with other providers (i.e., other Reservoir sites) based on its own local preferences within a fully autonomous environment and governed by business policies. For optimising the process of federation in Reservoir, a service may be moved to other sites based on economic, performance, or availability considerations.

Provider revenue in federated systems represents an important aspect especially in the context of outsourcing. Goiri et al. [6] explore federation from the perspective of a profit-driven policy for outsourcing by minimising the utilisation and the price of resources of providers. The approach makes use of a global Scheduler on each provider for deciding the placement and the allocated resources for that provider. This Scheduler is in charge of deciding where a service will be executed and managing its location during the execution (e.g. migrations, cancellations, etc.). Using a set of monitored parameters, such as the providers incoming workload, the cost of outsourcing additional resources, the ratio of outsourced resources, the ratio of unused resources to be sold, the system can make decisions about the placement of services on the nodes of the provider, and the number of resources that must be allocated to each node in order to guarantee that they meet an agreed performance and to maximise "utility".

More work on the topic of outsourcing policies has been undertaken by Toosi et al [2]. This work focuses on specifying reliable policies to enable providers to decide which incoming request to select and prioritise, thereby demonstrating that policies can provide a significant impact on the providers' performance. When optimising parameters such as the ratio of spot Virtual Machines (VMs) to the total workload, percentage of persistent spot VMs, number of providers in the federation and providers workload, providers are able to maximise profit and to reject less requests, while they keep utilisation at an acceptable level. It has also been identified that running on-demand requests locally is more profitable if the provider has high ratio of spot VMs. Conversely, outsourcing proves to be more profitable when spot VMs are scarce and termination of them may result in discontinuation of using such services by customers.

The possibility of creating federated markets has been extensively explored by researchers [7], [8]. Federation markets provide the mechanisms to mostly promote fairness and ensure mutual benefits for parties involved in the federation. Reliable resource sharing techniques can motivate both resource providers and resource consumers to join and stay in the market. Gomes et al. [7] explore the application of federation mechanisms based on the General Equilibrium Theory to coordinate the sharing of resources between providers in a federated cloud – with an objective of optimising costs and coping with variations in demand. By proposing a design and implementation of a federated cloud, the approach evaluates a series of trading strategies for individual providers to be applied and considered within the market. Experimental results show a significant gain in revenue and the improvement of resource usage.

Celesti et. al [15] propose a solution based on the Cross-Cloud Federation Manager allowing a cloud to establish the federation with other clouds according to a three-phase model: discovery, match-making and authentication. With a multi-phase federation mechanism the model aims to setup a new enhanced cloud environment in which operators can easily apply their business models. The federation model is based on a Cross-Cloud Federation Manager which represents the core element of the federation model. The manager is composed by three different subcomponent agents such as: discovery agent, match-making agent and authentication agent each responsible to accomplish the aforementioned three phases. Such federation system allow entities to can cooperate together accomplishing trust contexts and providing new business opportunities such as cost-effective assets optimization, power saving, and on-demand resources provisioning.

In this work we approach the problem of federation by implementing a real federation Cloud system based on CometCloud facilitating task processing by an "aggregated tuple-space mechanism". The use of a Linda-based distributed tuple space enables us to create a virtual overlay that can extend across multiple distributed Cloud providers and sites. CometCloud has been demonstrated to integrate both public clouds (based on Amazon EC2/S3) and specialist high performance computing environments (such as TeraGrid) [14].

III. CometCloud

Our federation models are built on top of CometCloud [9] and the concepts that CometCloud is based on. CometCloud is an autonomic computing engine based on the Comet [10] decentralized coordination substrate, and supports highly heterogeneous and dynamic cloud/grid/HPC infrastructures, enabling the integration of public/private clouds and autonomic cloudbursts, i.e., dynamic scale-out to clouds to address extreme requirements such as heterogeneous and dynamics workloads, and spikes in demands.

Conceptually, CometCloud is composed of a programming layer, service layer, and infrastructure layer. The infrastructure layer uses the Chord self-organizing overlay [11], and the Squid [12] information discovery and content-based routing substrate build on top of Chord. The routing engine supports flexible content-based routing and complex querying using partial keywords, wildcards, or ranges. It also guarantees that all

peer nodes with data elements that match a query/message will be located. The service layer provides a range of services to support autonomics at the programming and application level. This layer supports a Linda-like [13] tuple space coordination model, and provides a virtual shared-space abstraction as well as associative access primitives. Dynamically constructed transient spaces are also supported to allow applications to explicitly exploit context locality to improve system performance. Asynchronous (publish/subscribe) messaging and event services are also provided by this layer. The programming layer provides the basic fr for application development and management. It supports a range of paradigms including the master/worker/BOT. Masters generate tasks and workers consume them. Masters and workers can communicate via virtual shared space or using a direct connection. Scheduling and monitoring of tasks are supported by the application framework. The task consistency service handles lost/failed tasks.

IV. Approach

Several scenarios and associated policies in the context of cloud federation are outlined in this section. We consider the following two objectives:

- Evaluate the use of CometCloud in a federated context, between two sites connected over a public network – primarily Rutgers & Cardiff. The scenarios are meant to validate the correct functioning of the capability between the two sites. Although we report on two sites, the approach outlined in this work can scale to multiple sites based on the use of the Comet overlay.
- Demonstrate the development of a market model for resource sharing, based on the use of the CometCloud system between these sites.

In such an environment, the process of outsourcing tasks is the result of a series of decisions that must be made at each site. It is therefore important for each site to decide at what point it is appropriate to offload tasks, how many tasks it should offload in one go and how to distribute the tasks between other sites it is connected to.

Given a number of tasks to be processed, one site should also decide to outsource tasks based on:

- *Time constraints* associated with task processing. Tasks will be outsourced to external sites only if the time for completing the tasks cannot be accomplished within the local site.
- *Existing computing capability* within the site. Tasks will be outsourced to external sites only if the site does not have the required capabilities (software libraries or computing resources) for computing the requested tasks.
- *Budget aspects* – tasks will be outsourced because the costs predicted by the site for computing the tasks (i.e. new infrastructure deployment) are higher than the costs of off-loading the tasks to other sites.

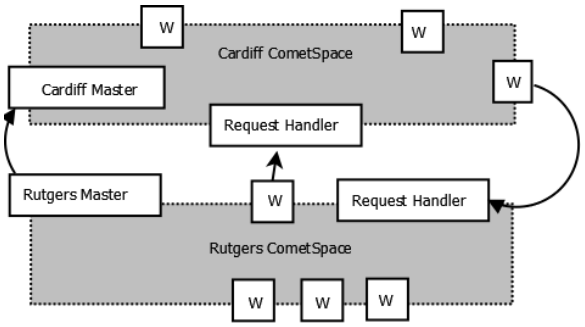


Fig. 1: Federation model

V. System model

We work with a number of $N = \{t_1, t_2, t_3, ..., t_n\}$ tasks in the tuple-space, where each task t_i can be defined as a set $t_i \rightarrow [t, T, P]$ where t is the time per task, T represents the corresponding type of computation of task t_i and P represents the price of the task t_i. Withing the set of tasks N we consider two subsets L identifying local tasks and R identifying remote tasks, such as $L = \{t_1, t_2, t_3, ..., t_m\}$ and $R = \{t_1, t_2, t_3, ..., t_p\}$, $L \subset N, R \subset N$, $m < n$, $p < n$.

A. CometCloud Federation Setup

For the CometCloud federation we consider that a site tuple-space has a number of available workers and a master that receives requests: (i)locally – identifying tasks received from users at the same site; (ii) remotely – requests from remote users at the other site – via the use of a request handler.

As illustrated in Figure 1, the Master must decide how many tasks to accept based on a number of policies. We assume that there is one worker per compute/data access node. All workers are assumed to be the same – i.e. they can execute tasks on resources that are identical. The only differentiating factor, therefore, is the number of workers allocated to local vs. external/remote requests. When one site has a high workload and it is unable to process tasks from its local users within their deadlines it negotiate for the outsourcing of tasks to other remote sites. This could range from two cloud systems sharing workload (as in Figure 1) to a cloud outsourcing some of its workload to multiple other cloud systems. Conversely this ability allows systems with a lower workload to utilise spare capacity by accepting outsourced tasks from other cloud systems. Practically, this process of task exchange is undertaken by the master nodes of the two clouds negotiating how many tasks to be exchanged. Once this has been completed the master node on the receiving cloud informs its workers (using CometSpace) about the number of tasks it is taking from a remote site, and the connection details of the request handler from where the task is to be fetched. Subsequently, when a worker comes to execute a task from an external cloud system, it then connects to the request handler of the remote cloud to collect the task and any associated data. Within such a federation model, for each type of task, we use an associated cost such as:

- *Cost for local jobs* c_l – this is set to a low value – i.e. the worker/resource owner does not gain any

substantial financial benefit for processing a local request.

- *Cost for remote jobs* c_r – this can be varied over a range – but set to be higher than costs for local jobs. In this instance, the worker benefits financially by processing requests for remote jobs.

B. Aggregated CometCloud Federation Setup

The aggregated CometCloud federation model is designed to be dynamically updated as it is created in a collaborative way, where each site communicates with others to identify itself, negotiate the terms of interaction, discover available resources, and advertise their own resources and capabilities. In this way, a federated management space is created at runtime and sites can join and leave at any point. This federation model does not have any centralized component and users can access the federation from any site, which increases the fault tolerance of the overall federation, see Figure 2. Another key benefit of this model is that since each site can differentiate themselves based on the availability of specialist capability, it is possible to schedule tasks to take advantage of these capabilities.

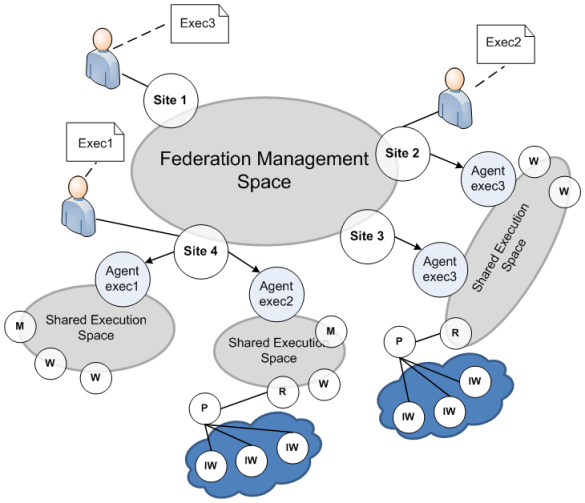


Fig. 2: Aggregated Federation model. Here (M) denotes a master, (W) is a worker, (IW) an isolated worker, (P) a proxy, and (R) is a request handler.

The federation model is based on the Comet [10] coordination "spaces" (primarily an abstraction that enables users and providers of resources to share information with each other). In particular, we have decided to use two kinds of spaces in the federation. First, we have a single federated management space used to create the actual federation and orchestrate the different resources. This space is used to exchange any operational messages for discovering resources, announcing changes at a site, routing users' request to the appropriate site(s), or initiating negotiations to create ad-hoc execution spaces. On the other hand, we can have multiple shared execution spaces that are created on demand to satisfy computing needs of the users. Execution spaces can be created in the context of a single site to provision local resources or to support a *cloudburst* to public clouds or external HPC systems. Moreover, they can be used to create a private sub-federation across several sites. This case can be useful when several sites have some common interest and they decide to jointly target certain types of tasks as a specialized community.

As shown in Figure 2, each shared execution space is controlled by an agent that creates such space and coordinates the resources for the execution of a particular set of tasks. Agents can act as master of the execution or delegate this duty to a dedicated master (M) when some specific functionality is required. Moreover, agents deploy workers to actually compute the tasks. These workers can be in a trusted network and be part of the shared execution space, or they can be part of external resources such as a public cloud and therefore in a non-trusted network. The first type of workers are called secure workers (W) and can pull tasks directly from the space. Meanwhile, the second type of workers are called isolated workers (IW) and cannot interact directly with the shared space. Instead, they have to interact with a proxy (P) and a request handler (R) to be able to pull tasks from the space.

VI. Proposed Policies

In our system we consider a job as a homogeneous grouping of tasks, defined as: $j = [N, T, t, p, pen]$ where N is the number of tasks, T is the types of task, t is the desired time at which the job should be complete, p is the price of the job, and pen is a penalty that should be applied if the deadline is missed. Tasks represent one unit of work mapped as a tuple within CometCloud.

A key policy is that each site must attempt to make maximum revenue from remote tasks without excessively compromising the local tasks running on the system. For developing our policies we use a number of tuning parameters such as: d representing the maximum possible time by which a deadline can be missed for a local task, c representing the cost per second per node and t the average execution time per task.

General Policy: When a new job is submitted into the tuple-space, the following action is taken depending on the type of tasks. For each task within a job, we calculate the time to complete locally such as $ttc = ttc(t) + ttc(j)$, where $ttc(t)$ is the time-to-complete for all jobs (the time until the job can start) in the tuple-space and $ttc(j)$ is the time-to-complete the submitted job.

Policy for Local Tasks: When evaluating a local task the policy is to always accept local tasks, thus local task have a *non-rejection policy*, according to which tasks submitted from local users will never be rejected but queued.

Policy for Remote Tasks: When evaluating a remote task the policy is to accept as many remote tasks as long as $ttc < t$ with an associated price of $p = ttc(j) * c$. Remote tasks have a rejection policy attached according to which remote tasks can be rejected when the site cannot meet the deadline and when accepting remote tasks can affect local tasks processing. When outsourcing tasks, one site should request a price quotation from all connected systems and send as many tasks to the cheapest of these. This policy will be repeated until all tasks have been outsourced.

Market Policy: In this policy both local and remote tasks go to a common market for offers from every site interested in

executing them. As in the previous cases, tasks are discriminated based on their origin to decide the offered price as well as the resources. Sites only place offers if $ttc < t$.

VII. Evaluation

Based on the policies identified in the previous section we develop an experimental infrastructure based on CometCloud. This infrastructure includes all the mechanisms needed for the coordination across computational resources which are used by our experiments. Thus, the only simulated part of our experiment is the execution of tasks to evaluate the different policies more accurately. First, we describe simulation settings and performance metrics and then the experimental results we obtained.

A. CometCloud Federation

In this federation case, we consider two different experimental setups: (i) non-federated setup – where jobs are being executed exclusively "in house" within the local CometCloud infrastructure and (ii) federation aware outsourcing setup – where jobs are split between the federation sites.

1) Simulation metrics: For both of the setups, we use a number of metrics such as:

- *Average Delay*:$AD = \frac{1}{n}\sum_{i=1}^{n}(Delay)$ identifying the average delay associated with the number of n jobs being executed. $Delay = ttc(e) - ttc(a)$ is measured as the difference between the expected time-to-complete $ttc(e)$ and the actual time-to-complete $ttc(a)$.
- *Profit* – identifying the profit of each site obtained after executing jobs, $Pr = AR * NT * c$, where AR is the average runtime per task, NT represents the number of tasks that one site processes and c represents the cost per core per second (in £) derived from Amazon EC2 cost, $c = 0.0000117697$;
- *Average Utilisation*:$AU = \frac{1}{m}\sum_{i=1}^{m}(Utilisation)$ identifies the percentage utilisation within each of the m workers. Utilisation is the resulted utilisation of each worker giving a predefined uniform load distribution for each site.

Tasks processed within the system can have different types such as $TP = \{T_1, T_2, T_3, ...T_r\}$ where each type of task T_i has an associated number of attributes such as $T_i = \{[RT(min : max)], [AR(min + max/2)], [Cost(AR * c)]\}$, where $Runtime(min : max)$ represents an interval defining the time affected with the execution of task type T_i, AR represents the average runtime of task type T_i and $Cost$ is a combination of the average runtime of task type T_i and the price corresponding to a task of type T_i. We use an objective function specifying that each site is trying to minimise the delay in execution and maximise the profit: $f(obj) : [min(delay), max(profit)]$

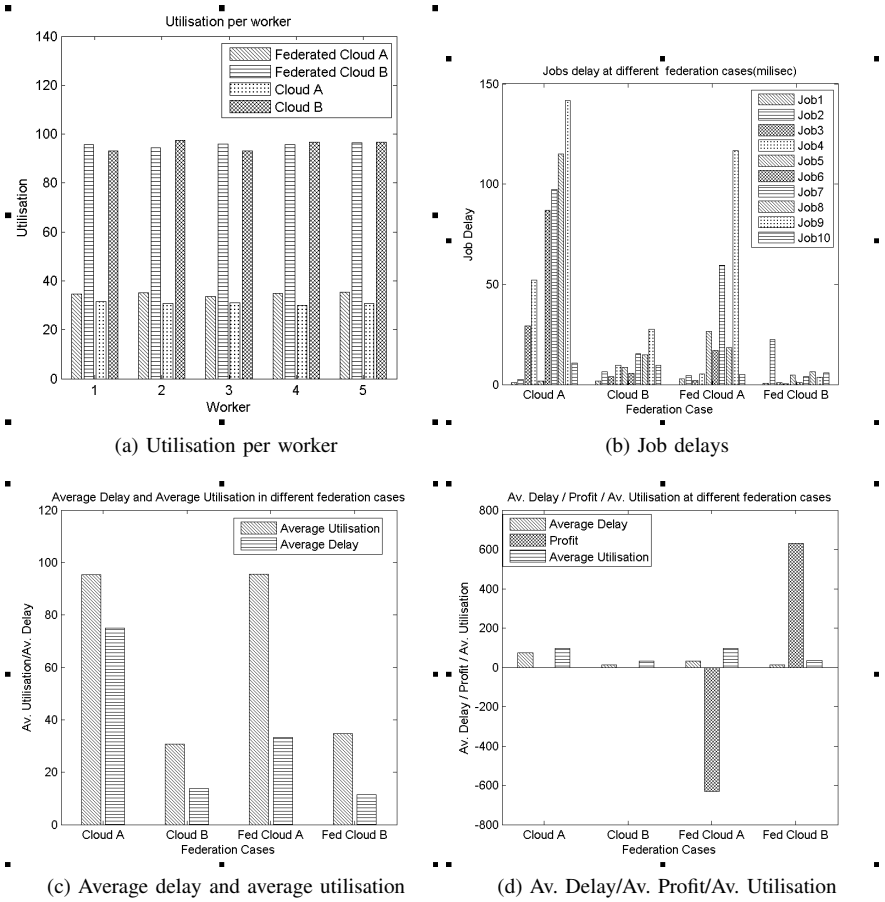
In our experiments we consider that each site within the federation experiences a different level of existing workload (i.e. the number of jobs that are currently running at each site). We simulate a varying workload in the context of a varying number and types of tasks and evaluate how delay, profit and utilisation are impacted. As the workload is variable there are three different options that can be applied for each new inserted job according the federation case to evaluate: (i) schedule for later processing locally, (ii) reject due to high workload or (iii) outsource to remote site according to policies.

2) Experiments: We use two different cloud systems – Cloud A and Cloud B in two different contexts: (a) single cloud context (illustrated as Cloud A and Cloud B) where all the tasks have to be processed locally and (b) federation cloud context (illustrated as Fed. Cloud A and Fed. Cloud B) where the sites have the option of outsourcing tasks to remote sites. When each site deals with an existing high workload, the submission of new tasks from users triggers the process of outsourcing in order to minimise delays and reduce rejection, whereas when each site has a lower workload, there is spare capacity at each site which can be allocated for dealing with new submitted tasks. In our experiments, each site has a total of five workers assigned to process a number of jobs/tasks (10 in our experiment) submitted based on a uniform distribution. In these experiments we consider that Cloud A is the cloud with an existing high workload whereas Cloud B is the cloud with an existing lower workload.

Experiment 1: Utilisation Per Worker:In this experiment we evaluate the level of utilisation per worker giving an existing load. The experiment illustrated in Figure 3a is presenting a comparison between the case of single cloud(Cloud A and Cloud B) and a federation case(Cloud A and Cloud B federated together) when experimenting various levels of load. It can be identified that in the case of single clouds the utilisation is lower than in the case where the two sites are deployed in a federation process. In the context of federation the process of outsourcing is enabled therefore clouds with an increasing load such as Cloud A can decide to offload a percentage of their tasks to remote sites in order to reduce the delays.

Experiment 2: Expected Time-To-Complete(TTC) and Delay: Given a predefined uniform load for each of the sites we investigate what is the impact of this load on the performance of the sites by measuring the delays for each job. From Figure 3b and Figure I can be observed that the jobs with an increasing delay correspond to the sites dealing with high load. Explicitly the site with higher load, Cloud A, imposes the highest delay of the processed tasks. When enabling the federation between the sites(Fed. Cloud A and Fed. Cloud B) is observed that the delay corresponding to jobs processed on Cloud A is diminishing. This happens because in the context of federation Cloud A outsources part of its tasks to Cloud B thus improving the overall delay of jobs.

Experiment 3: Average Delay and Average Utilisation: In this experiment we evaluate the performance of the sites form the perspective of average delay and average utilisation. Evaluating the two configurations where sites can either be involved in a federation context or can be single clouds we observe from Figure 3c that the average utilisation and average delay are depending on the level of load existing within each site. Cloud A identifying an increased level of load has a high level of utilisation and delay, in contrast with Cloud B where the load is lower thus lower are the utilisation and the delay. When moving to a federation context we observe that the average



(a) Utilisation per worker

(b) Job delays

(c) Average delay and average utilisation

(d) Av. Delay/Av. Profit/Av. Utilisation

Fig. 3: Summary of experimental results of CometCloud federation

utilisation of site A remains high whereas the average delay significantly decreases. This reduction in average of delay is caused be the fact that due to an existing high load Cloud A has to outsource part of its tasks to Cloud B determining a reduction of delay of tasks and an increase in the averaged utilisation of Cloud B.

Experiment 4: Averaged Delay, Profit and Averaged Utilisation: In previous experiments we analysed the system from the perspective of performance metrics such as delay, utilisation and load. In this experiment we add profit as a metric to measure how the system behaves in different federation cases from a more economic perspective. Considering that tasks processed from local users have no price and thus no profit, we look at the profit exclusively when the sites are involved in a federation process. From Figure 3d is observed that Cloud A, having a higher level of load, identifies a cost in the context of federation. On the other hand, Cloud B, having assigned a lower load, and thus a spare capacity allowing to process remote tasks identifies a profit. The oscillation of profit and cost between the two sites is caused by the difference in the level of load. As Cloud A has an existing high load, when new tasks are submitted is forced to outsource part of these tasks to Cloud B, paying a corresponding price for each of the tasks but equally significantly increasing the profit of Cloud B.

B. Aggregated CometCloud Federation

In this experiment, we consider three federated sites using the market policy and study how the profit and reputation of each site varies over time when executing tasks.

1) Simulation metrics: We use the following metrics in this experiment:

- *Profit:* The computation of a task involves a cost, but also provides a benefit. Therefore, the total profit of a site Pr is calculated using the benefit b obtained from each task and the cost c of computing it, $Pr = \sum_{i=1}^{n}(b-c)$. For simplicity we consider that all sites have the same infrastructure cost and therefore we do not include it in the equation.
- *Reputation:* The reputation R of a site is calculated using the scores obtained from the execution of tasks, $R = \frac{1}{n}\sum_{i=1}^{n}(Score)$, where score is a value between 0 and 1. A site obtains a score of 1 if the task is completed within the deadline ($ttc <= deadline$)and 0 if the deadline is missed ($ttc > deadline$).

Tasks executed in the system can be of three types and each one has a different cost, completion time and deadline.

TABLE I: Time-to-Complete(TTC) and delays for jobs

Clouds/Metric	Job1(TTC-Delay)	Job2	Job3	Job4	Job5	Job6	Job7	Job8	Job9	Job10
Cloud A	60-1.087	80-2.6	50-29.36	150-52.18	10-1.708	90-86.86	80-97.19	50-114.904	180-141.568	10-10.76
Cloud B	210-1.859	80-6.304	20-4.05	70-9.745	60-8.639	180-5.484	80-15.471	300-14.748	100-27.525	40-9.724
Fed. Cloud A	45-2.823	80-4.371	100-1.968	90-5.307	150-26.49	40-16.905	300-59.454	30-18.393	80-116.704	20-4.994
Fed. Cloud B	5-0.648	40-22.486	20-0.942	40-0.53	40-4.846	20-0.97	210-4.006	100-6.434	90-3.542	60-5.827

The values of these properties are fix for all sites as shown in Table II.

TABLE II: Tasks types properties for all the sites.

Task/Metric	Cost	Completion Time	Deadline
Red	10	9	12
Black	8	7	10
Blue	6	5	8

2) Experiments: In this scenario, the task assignment is done using a blind auction, i.e. a task is put in the federation space and each site places an offer. The client that puts the task into the space decides which site has the best offer and therefore executes the task. Each site has a limited number of resources, which in this case is two workers dedicated to compute local tasks and another two workers for external tasks. Hence, a site only places an offer if the deadline can be met. However, it can happen that one site places multiple offers at the same time before knowing if it won an auction, which could lead to missing deadlines if the site wins many of those tasks. During the experiments each site will submit tasks into the federation using a different Poisson process, where the occurrence of a task is every 4 seconds in average. The distribution of tasks is illustrated in Figure 4.

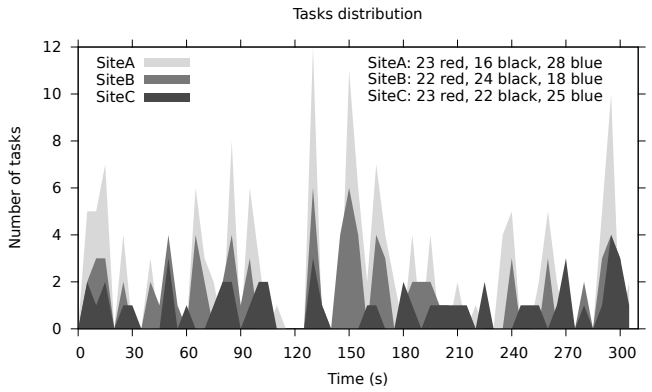


Fig. 4: Task distribution per site following a Poisson process. The type of task was selected randomly for each case.

In these experiments we are going to focus in the effect that the benefit per task and the auction winning criteria have over the profit and reputation of each site:

Benefit per task: This is the benefit that each site wants to obtain from each task. Here it is a percentage of the cost of a task. We will use three different situations:

1) All sites get the same benefit per task, which has been fixed to 5% for local tasks and 10% for external tasks (5%/10% abbreviated).
2) One site has an aggressive price policy where it gets only 5%/10% and two sites have very conservative policies where they get 50%/60%.
3) One site has an aggressive price policy where it gets only 5%/10% and two sites have less conservative policies where they get 20%/30%.

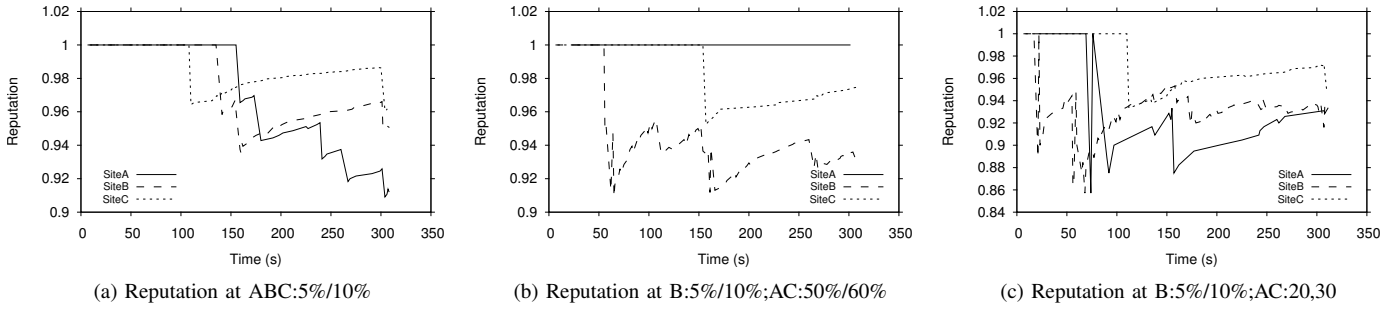
Auction winning criteria: it is the criteria to select the best offer of an auction. Here we consider two different criteria:

1) We only consider the price that the user has to pay to compute the task and chooses the minimum price among all the offers, $f(obj) = min(p)$.
2) We consider the price and the reputation of the site that has to compute the task, $f(obj) = min(p/R)$. Thus, the best offer is the one that has lower price/reputation ratio.

Experiment 1: Auction criteria based on price only - In these experiments we have considered only the price as criteria to select the auction winner and we have modified the benefit policy of each site to see how both parameters affect the overall profit and reputation of the site. Figures 5a and 5d shows how the reputation and profit evolve when all sites have the same benefit policy. Here, each compute computes a similar number of tasks (A=58,B=63,C=79), which is close to the total number of tasks generated from that site. The reason is that each site has the lower price for its own tasks and they will win local tasks until the resources assigned to those tasks are full. Then they will stop bidding for their own tasks and others sites will have the change to execute those tasks. This can represent a scenario where local tasks are outsourced to external resources when the load of the site is high.

Figures 5b to 5f collect the results of the seconds and third benefit situations, where site B has an aggressive price policy and the rest has more conservative ones. We can observe that Site B does not always obtain the highest profit, although it is by far the one that executes more tasks. In both cases case B executes around 130 tasks while the other two sites execute around 35 tasks each. This is due to the limited number of resources and shows that when different sites have similar resources, a very aggressive price policy may not be profitable. We can also observe that the reputation of B changes abruptly because it places many auctions offers before it knows the results of those actions and it end up winning too many tasks for its limited resources.

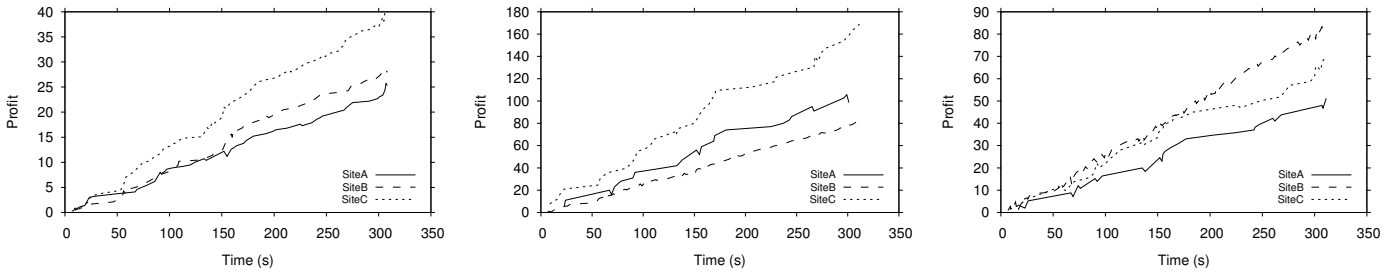
Experiment 2: Auction criteria based on price and reputation - We have repeated the same experiments changing the auction criteria to consider not only the price of the task but also the reputation of the site that places the offer. Figures 6a and 6d show that site B looses a lot of reputation at the beginning of the experiment, which has an important effect in the overall profit of this site. Figures 6b and 6e show an



(a) Reputation at ABC:5%/10%

(b) Reputation at B:5%/10%;AC:50%/60%

(c) Reputation at B:5%/10%;AC:20,30

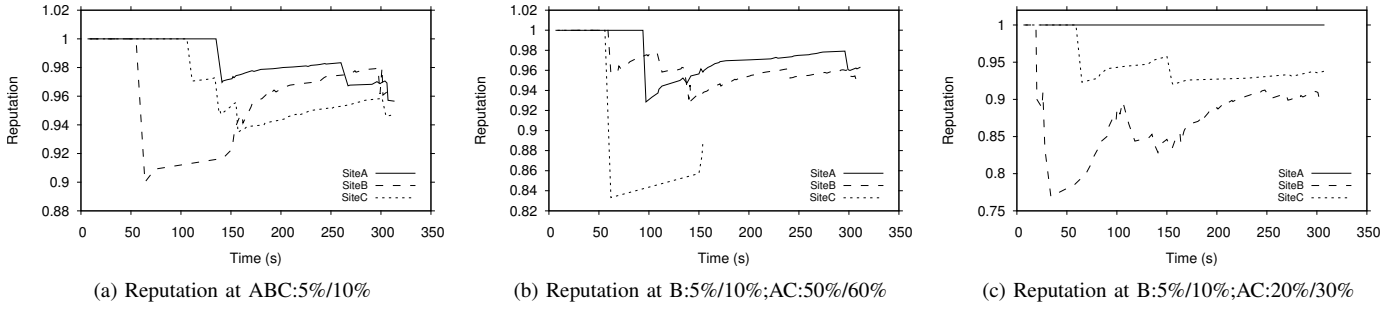


(d) Profit at ABC:5%/10%

(e) Profit at B:5%/10%;AC:50%/60%

(f) Profit at B:5%/10%;AC:20%/30%

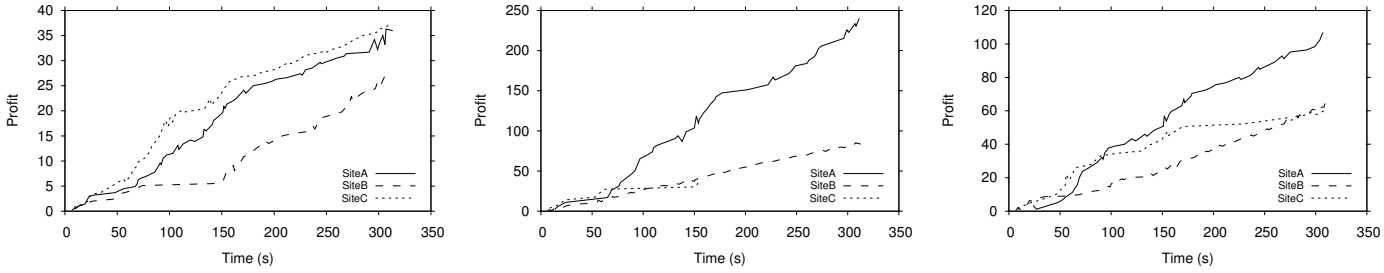
Fig. 5: Summary of experimental results where the criteria to win the auction is the minimum price. There are three set of experiments where each site has a different benefit policy, i.e. B:5,10;AC:20,30 means that site B gets a 5% and 10% of benefit of each local and remote tasks respectively, while sites A and C get 20% and 30%.



(a) Reputation at ABC:5%/10%

(b) Reputation at B:5%/10%;AC:50%/60%

(c) Reputation at B:5%/10%;AC:20%/30%



(d) Profit at ABC:5%/10%

(e) Profit at B:5%/10%;AC:50%/60%

(f) Profit at B:5%/10%;AC:20%/30%

Fig. 6: Summary of experimental results where the criteria to win the auction is the minimum price/reputation ratio. There are three set of experiments where each site has a different benefit policy, i.e. B:5,10;AC:20,30 means that site B gets a 5% and 10% of benefit of each local and remote tasks respectively, while sites A and C get 20% and 30%.

interesting situation. Here, site C looses a lot of reputation at the beginning of the experiment, which combined with its high prices turn out in executing only nine tasks. This clearly benefit site A that executes 54 tasks and gets high profit at the end. Finally, Figures 6c and 6f show how site B can deal with a bad reputation thanks to its low price policy. As opposed to Site C in the previous case, here B keep computing tasks and it can even improve its reputation.

VIII. Conclusions

Federated Cloud systems provide the means for individual, possibly competing, Clouds to cooperate so as to optimize costs and cope with variations of demand. In a community of Cloud providers federation can also enable the process of trading resources, thereby greatly encouraging the emergence of federated markets. In this paper, we have investigated the problem of cloud federation by devising a real federation framework based on CometCloud. The framework provides the advantage of an aggregated tuple-space and enables mechanisms to allocate resources based on a number of different policies. In our CometCloud based federated Cloud system, providers can optimise a number of performance parameters such as delay, utilisation, cost and reputation by using the mechanism of outsourcing tasks.

We have presented the design and implementation of the proposed approach and experimentally evaluated a number of scenarios for individual Clouds and federated Clouds. The experimental results have shown a number of benefits that federation provide with regards to resource utilisation, execution delay, cost, benefit and reputation. When evaluating the utilisation and delays in a CometCloud federation context we observed that the existing workload of each site determines the level of utilisation for each worker. Utilisation, on the other hand can be the cause of high delay especially in a non-federation context. Within a federation aware process, sites can balance between delay and profit by using the mechanism of outsourcing.

The main advantage of aggregated CometCloud federation is the use of a centralized mechanism which enables users to access any site involved in the federation. By undertaking the process of task assignment as a blind auction mechanism, a market process is enabled where each task is put in the federation space and each site places an offer. By using different auction criteria and price strategies we demonstrate that when sites are playing aggressive price strategies, the completion of jobs is strongly affected and consequently also the associated benefit and reputation of sites. As the auction strategies and price policies are strongly related to the number (and type) of resources within each site, it has been demonstrated that when different sites have similar resources, a very aggressive price policy may not be profitable.

IX. Ongoing Work

In the aggregated federation model each site can select the type of tasks they are interested in. Although in the experiments we carry out, all sites where accepting all types of tasks, an extension would be to enable sites to have a dynamic subscription based on task properties. This means that sites can evolve over time to select the type of tasks that give them the most profit, reputation, etc. Moreover, sites could also change dynamically their price policies to increase benefit or recover reputation as needed.

On the other hand, policies can be specified using a variety of different representations. One possible solution is to adapt policies of the federation into functional Service Level Agreements (SLAs) and control the SLA between sites based on a penalty mechanism. When dealing with functional SLAs the advantages of open-markets can appear, thereby leading to an increase in the overall utilisation of resources and therefore maximise revenue.

Acknowledgements: The research presented in this work is supported in part by US National Science Foundation (NSF) via grants numbers OCI 1339036, OCI 1310283, DMS 1228203, IIP 0758566 and by an IBM Faculty Award.

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