An Extensible Performance Evaluation Framework for Cloud Computing Systems

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Abstract

As more and more Cloud systems are designed and deployed in business and science engineering areas, how to evaluate and monitor the system's runtime performance is becoming an important issue. However, few efforts are taken to address such an issue because the resources in Cloud systems often owned by different institutes. In this paper, we present an integrated performance evaluation framework, which is aiming to provide cloud users an easy-to-use toolkit to evaluate their system's runtime performance, or compare the performance under different resource management policies. The design and implementation of our framework is highly extensible and re-useable in most existing cloud systems. Currently, the prototype of our implementation is examined by a series of experiments, and the results indicate that its configurable feature is very useful when users are conducting performance comparing under different contexts.

Keywords: *Cloud Computing; Performance Evaluation; Virtual Machine; Task Scheduling*

1. Introduction

Cloud computing proposes an alternative platform, in which resources are no longer hosted by the researchers' computational facilities, but are leased from big data centers only when needed. So, Cloud computing has emerged as a promising technology that provides large amounts of computing and storage capacity to high-performance applications with increased scalability and high availability, and reduced administration and maintenance costs [1, 2]. Currently, Cloud environments make use of virtualization technologies for both the computing and networking resources. These virtualized resources are interconnected together and are provided to consumers' on-demand. Through well defined interfaces over well known Internet protocols, cloud users are enabled to access to cloud resources anytime and anywhere. Also, the users can deploy their software by creating customized virtual machine images and running them on the virtualized resources in clouds. As a result, many vendors like Amazon, Google, Dell, IBM, and Microsoft are investing billions of dollars to develop their own cloud-oriented solutions and systems [3, 4]. The cloud providers are responsible for maintaining the underlying computing and data infrastructure while at the same time reducing the administration and maintenance costs for the users. This is commonly known as Infrastructure as a Service (IaaS) [2, 5].

As the use of Cloud computing environments increases, it is of great importance to assess the performance of Cloud infrastructure in terms of various metrics, such as the overhead of co-allocating virtual resources, and the performance of applications with different resource configurations [2, 6, 7]. Unfortunately, few systems and techniques are proposed to address this issue. The challenges of performance evaluation in Clouds

are mainly concentrated on: (1) Virtualization technique decouples the physical resources and the end-users requirements, which makes it difficult to evaluating the virtualized resource performance when user's QoS requirements are taken into account [3, 8]; (2) Heterogeneous and distributed resources are dynamically composed and decomposed into abstract virtual machines (VM), the traditional off-line performance evaluation technique is not suitable for such open environments [9]; (3) The runtime performance of virtual resources are effects by two many factors. As a result, effective conclusions on performance evaluation require a flexible and configurable mechanism, which can fix some factors as well as adjust others at the same time [1, 2, 10].

Motivated by these observations, we design and implement an integrated performance evaluation middleware, namely *Cloud Virtual Performance Evaluator* (CVPE), with aiming to provide Cloud users and researchers an easy-to-use toolkit to evaluate their Cloud system's runtime performance, or compare the performance difference when different resource management policy and task scheduling algorithms are taken into account. The rest of this paper is organized as follows. Section 2 presents the related work. In Section 3, we describe the framework and main procedures of the proposed framework; In Section 4, experiments are conducted to investigate the effectiveness of our CVPE. Finally, Section 5 concludes the paper with a brief discussion of future work.

2. Related Work

In many traditional high-performance computing systems, performance evaluation of supercomputers is often achieved by a set of standard benchmark suites [11, 12]. The goal is to measure the peak and average computational capability of the target systems. Such an approach is suitable for tight-couple parallel computing systems. However, it can not be applied to large-scale distributed systems since there are two many factors that will affect the performance of these systems, such as network traffic, unpredictive workload, un-reliabile resources and etc. To overcome these difficulties, researchers tends to uses synthetic workload to evaluate the performance of large-scale distributed systems. Therefore, many random workload generators are proposed, i.e. Lublin-Feitelson model [13], Cirne-Berman model [14] and Tsafrir-Estion model [15]. All these workload generator is based on real-world logs and allows users define their favor features of the generated workloads. As the synthetic workload generator can produce various type of random workload, researchers are enabled to compare the performance of their systems when different resource management policies or scheduling algorithms are adopted. In this paper, we incorporated three most used models to generate synthetic workload in an extensible manner.

In virtual resource environments, many previous effects are taken evaluate the performance of virtualization technology. For instance, an early comparative study of the DawningCloud is deprived from performance comparison method of Eucalyptus [16]. In the study of [17], performance comparsion of executiing a famous scientific workflow (Montage) are presented so as to investigate cost performance trade-offs between Clouds and Grids. In [18], Palankar *et al.*, studied the performance of Amazon S3 when large-size files are transferred between EC2 and S3. In [19], Menon *et al.*, studied the virtual resource performance by using general benchmarks, and the results indicated that the overhead incurred by virtualization can be below 5% for computation and below 15% for networking. All the above studies are based on benchmarks approaches, so their conclusions are only meaningful for the tested systems. On the

contrary, our framework is to provide a generalized middleware to evaluate the performance of virtual resource environments.

To assess and analyze the performance of Cloud platforms, Yigitbasi *et al.*, designed a framework called C-Meter, which is implemented as an extension of GrenchMark [20] and consists of four components including *Workload Generator*, *Job Core*, *Cloud Interaction* and *Utility Toolkit*. By using C-Meter, users can assess the overhead of acquiring and releasing the virtual computing resources, also they can evaluate the performance of different scheduling algorithms under different configurations. Unlike C-Meter, our CVPE framework applies a general model to describe the working status of individual VMs. So, it provides a general approach to evaluate the performance of VMs, which in turn can be used to profiling the execution performance of applications.

3. System Framework

3.1. Architecture

The architecture of CVPE is illustrated in Figure 1, which is consists of four key components including *Service Portal*, *Synthetic Workload Generator*, *VM Scheduler* and *VM Manager*.

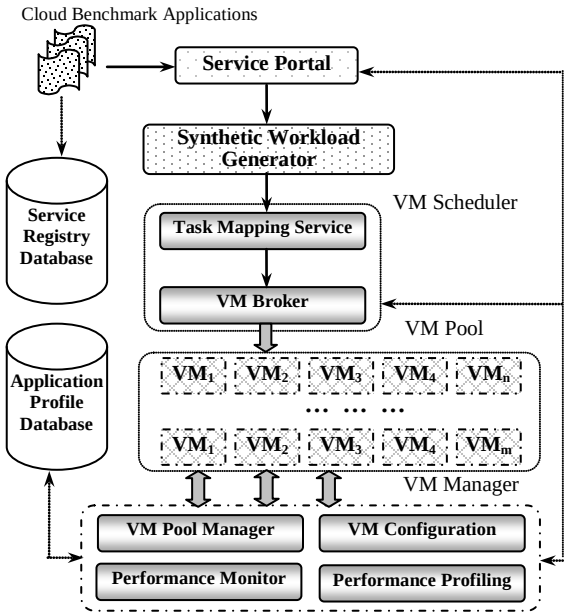

Figure 1. The Framework of CVPE

Service Portal is responsible for accept user's benchmark requirements which is described by a set of XML files. For the convenience of testing, we implements two kinds of *Service Portal* currently: one is implemented as an integrated component of CVPE for quick testing, and the other is implemented as a separated standard Web service which interacts with CVPE's other components through networks.

Synthetic Workload Generator is responsible for translating the user's abstract requirements into a set of workloads. The generated synthetic workloads are characterized by several factors, such as task arriving interval, task execution time, task

resource requirements, task type and etc. The current prototype of CVPE only supports independent task workload, and we plan to implement DAG workload in the next version of CVPE.

VM Scheduler works like conventional meta-scheduler but we separate the task mapping and VM broker by two subcomponents. It is because that we can easily replace the scheduler algorithm or policy when we want to evaluate the performance of different scheduling algorithm.

VM Manager consists of four subcomponents, and they are designed for VM resource pool management and VM performance analysis. For example, the provision of VM is controlled by VM pool manager and VM configuration, and the runtime performance and capability of individual VM are monitored and logged through Performance Monitor and Performance Profiling subcomponents.

Generally speaking, CVPE is designed and implemented as a portable and extensible framework for generating and submitting both real and synthetic workloads to analyze the performance of cloud computing environments. In CVPE, VM management policy and task scheduling algorithm can be flexibly configured at runtime, in this way, researchers and administrators are able to compare the effectiveness and efficiency of different policies and algorithms. So, it can be used as a test-bed middleware for large-scale cloud computing systems.

3.2. Evaluation Procedure

As shown in Figure 1, there are six steps when using CVPE for performance evaluation. The details of each steps are described as following:

(1) The user submits the benchmark files which defines all the requirements of this performance evaluation, including the task type and size, scheduling algorithm, VM configuration and etc, to the *Service Portal*. All of these requirements have a default setting if they are specified in the files. So, users can ignorant many settings and only focus on their most interested parts, *i.e.*, task scheduling algorithm.

(2) According to the benchmark files, *Synthetic Workload Generator* will use proper random workload model to produce a set of corresponding synthetic workloads. Currently, the CVPE use Lublin-Feitelson model [13] as default workload generator, which is derived from real workload logs of large-scale distributed systems. Other candidates including Cirne-Berman model [14] and Tsafrir-Estion model [15]. The VM configurations specified by users are applied to corresponding subcomponents in *VM Manager*.

(3) The *Task Mapping Service* schedules the synthetic workload through pre-defined task algorithms. It is noteworthy that VM resource allocation and task dispatching are carried by *VM Broker* components. So *Task Mapping Service* only produces a scheduling scheme in this step.

(4) *VM Broker* execute the VM allocation and task dispatching. In this step, *VM Broker* maintains several queues of each active VM in the virtual resource pool for monitoring the availability of VMs.

(5) When *VM Broker* obtains enough available VMs for executing current task, it dispatches the task onto one or more VMs to execute.

(6) The subcomponents in *VM Manager* is always monitoring and logging the performance statistics of the VM pools. When it listens a new VM configuration requirement, corresponding action are taken by certain subcomponents. All the performance logs are organized and stored in a separated profiling database, which can be used for results analyzing later.

3.3. Performance Profiling Model

In the framework of CVPE, performance monitor and profiling service are two novel components, which are designed for online performance evaluation for virtual resources in cloud environments. As mentioned above, *VM Broker* maintains task queues of each active VM in virtual resource pool. When these VMs are serving for arriving tasks, the workload of each VM will dynamically changed at runtime. Consequently, the practical serving capability of each VM will fluctuate dramatically with the changing of its workloads.

In order to realize online performance monitoring and profiling service for these virtual resources, we apply the classical Stochastic Queue Model [21] to describe the working status of each VM. Therefore, each active VM can be described by a set of quantitative parameters, such as mean length of waiting queue, mean serving time, parallel serving capability and etc. By collecting this performance information, we can apply queue theory to analyze the performance of each VM, and then evaluate the execution performance of the whole system. So, the flowchart of online performance profiling in CVPE is shown in Figure 2.

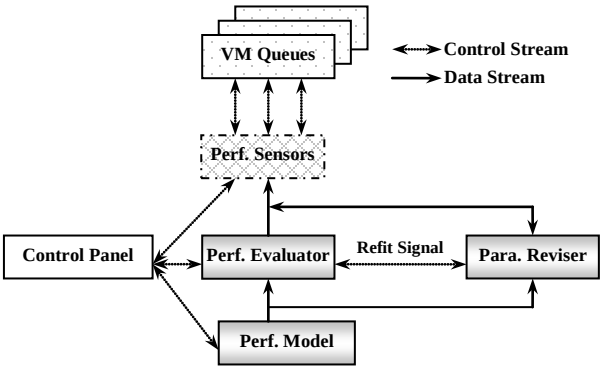

Figure 2. Flowchart of Online Performance Profiling

At first, a set of *performance sensors* are hooked when a VM is in active status. Each sensor is responsible for monitoring a single measurement of all the active VMs. These measurements are analyzed by *performance evaluator* to figure out the statistic features of a certain parameter. Meanwhile, a closed loop controlling is designed for parameter revising and refitting. The *control panel* is a set of options to configure the online performance profiling, such as error limitation, frequency of sampling and etc. Finally, the performance parameters are sent to *performance model* to construct a proper queue model that can properly describe the current performance status of the active VMs. The queue model of an active VM is 6-tuple noted as $<A(t), B(t), C(t) D(t), U(t), F(t)>$, where $A(t)$ is probability density function (PDF) of task arriving interval, $B(t)$ is the PDF of serving time, $C(t)$ mean length of waiting queue, $D(t)$ is the parallel serving capability, $U(t)$ is the real-time rate of utility, $F(t)$ is the fault rate at runtime. After

obtaining such a 6-tuple model, it is stored into the performance profiling database with a time stamp.

4. Experiments and Performance Evaluation

In this section, we present the experimental results on the CVPE framework. At present, we mainly concern about the effects of VM management policy and scheduling algorithm on the performance Cloud systems. So, we conduct extensive experiments with different VM management policies and scheduling algorithms.

4.1. Effects of VM Management Policy on Performance

Generally speaking, VM management policy includes the VM provision policy and VM price policy. The VM provision policy is to decide that how many VMs should be provided so as to satisfy the user demands. We mainly test three policies, which are MTPP (Maximize Throughput Provision Policy) [16], MRPP (Minimize Response-time Provision Policy) [23], MUPP (Maximize Utilization Provision Policy) [16]. So, our first experiment is to test the performance with different VM provision policies.

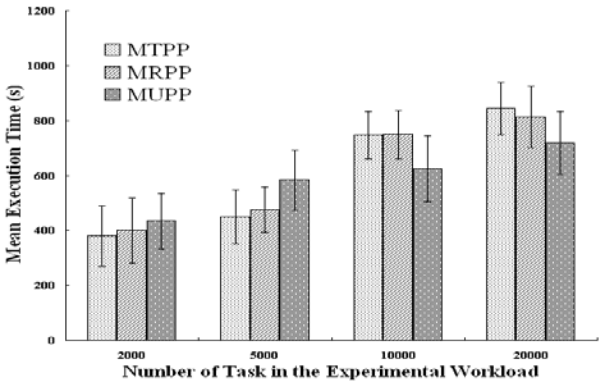

Figure 3. Mean Execution Time with Various VM Provision Policies

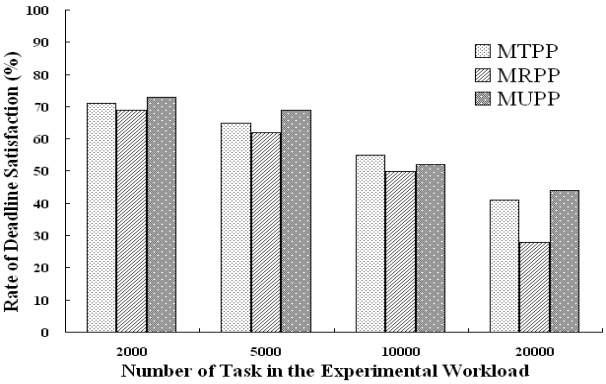

Figure 4. Rate of Deadline Satisfaction with Various VM Provision Policies

In this experiment, we used synthetic workload generator to produce four sets of workloads, and the number of tasks in each workload are 2000, 5000, 10 000 and 20000 respectively. Each task is characterized by its arrival time, resource demands, estimation of execution time and a cost budget. The performance metrics we concern

are *Mean Execution Time* and *Deadline Satisfaction Rate*. The experimental results are shown in Figure 3 and Figure 4.

From the above results, we notice that size of workload is of significant importance when evaluating the performance of a VM provision policy. For example, the MTPP policy outperforms MRPP and MUPP in term of *Mean Execution Time* when the size of workload is less than 10000. However, its performance reduces quickly when workload becomes heavy. On the contrary, the performance of MUPP policy seems relative stable when workload increases from 2000 to 20000. By this result, we might draw a conclusion that MUPP is more adaptive in presence of dynamical workload.

Deadline Satisfaction Rate metric is to measure that how many tasks can be completed before its deadline constraint. This metric is very important for soft real-time tasks since high deadline-missing rate might cause results in execution failure. By out experimental result, we can see that MUPP is most effective to meet the deadline constraint and MRPP performs worst. At same time, workload size also affects this metric. Simply saying, heavy workload will significantly lower down the deadline satisfaction rate. In detail, the effects of workload size are also different when using different VM provision policy. For instance, such negative effects on MRPP policy are biggest.

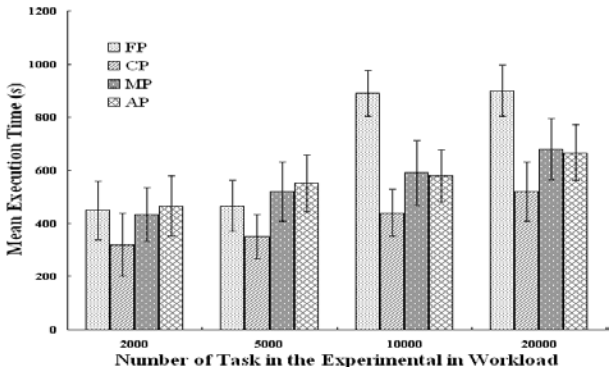

Figure 5. Mean Execution Time with various Price Mechanisms

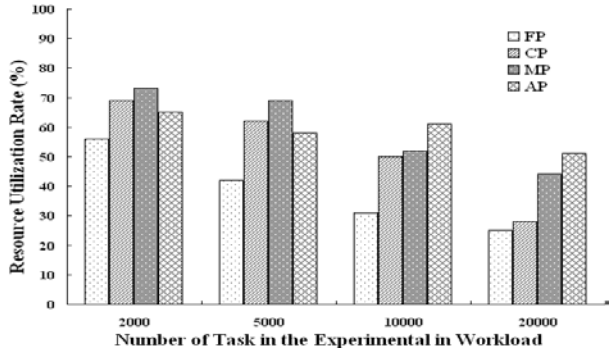

Figure 6. Resource Utilization Rate with various Price Mechanisms

The VM price mechanism is to decide that how much the resource providers should charge when users access their resources. Fixed price mechanism is the most frequently used one in current Cloud systems. Recently, several market-based price mechanisms have been proposed by researchers. We implement four price mechanisms in the prototype of CVPE, including Fixed Price (FP)[18], Capability-based Price (CP)[23],

Market-based Price (MP) [25], Auction-based Price (AP)[24]. In this experiment, each VM price mechanism are examined with MUPP as VM provision policy. The results are shown in Figure 5 and Figure 6.

As shown in Figure 5, VM price mechanism also has effects on the task execution. FP mechanism is very sensitive to the workload size; however other three mechanisms seem insensitive to it. In all the four price mechanism, CP performs best, the performance of MP and AP are almost the same. So, we might conclude that Capability-based price mechanism is effective to improve the task execution efficiency. The other metric we measured are Resource Utilization Rate. It is well known that high price will result in low utilization when resources are allocated by economic computing principle. Our experimental results confirm this again, since MP and AP outperform FP and CP. At present, many real world Cloud systems are using FP mechanism because of its easy implementation. However, out results indicate FP mechanism will results in low resource utilization rate. So, these Cloud systems are of great potential to improve their resource utilization if applying more flexible price mechanisms.

4.2. Effects of Scheduling Algorithm on Performance

In our CVPE framework, task scheduling algorithms are implemented in *Task Mapping Service* component. In order to provide an extensible framework for comparing the performance of different algorithms, *Task Mapping Service* exposes an abstract interface, namely ITaskScheduling, which can be implemented in different approaches. At present, we implement four kinds of scheduling algorithms, which are *Round-Robin Algorithm* (RRA) [26], *Capability-based Random Algorithm* (CRA) [27], *Cluster Minimized Algorithm* [28] (CMA), *Task Duplication Algorithm* [29] (TDA). All these algorithms are widely studied and used in many high-performance distributed systems. Since CVPE only uses abstract interface for task scheduling, anyone can incorporate other algorithms into it.

In order to test the performance of different scheduling algorithms, we need to fix other factors which have effects on the final results. So, we conduct the experiments four times, each with an identical VM price mechanism as mentioned in Section IV.1. Then, we control the provision of VM by increasing the number of VM from 50 to 500. The size of workload is set as 20 times of the VM number in each experiment. In this way, we can clearly comparing the performance of different algorithms under different conditions. For Task Duplication Algorithm (TDA), we set the redundant degree K=2 and K=3. The results of these experiments are shown in Figure 7-Figure 10.

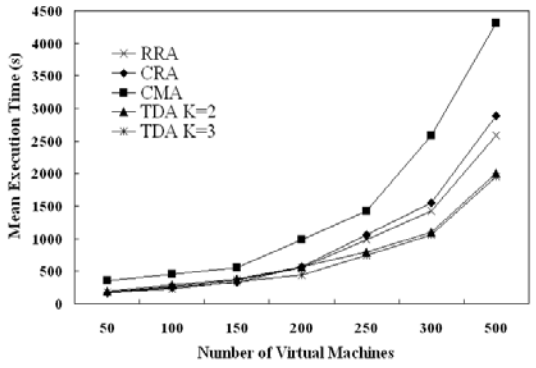

Figure 7. Mean Execution with FP Mechanism

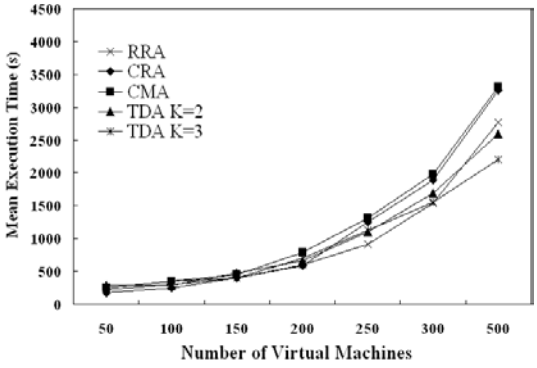

Figure 8. Mean Execution with CP Mechanism

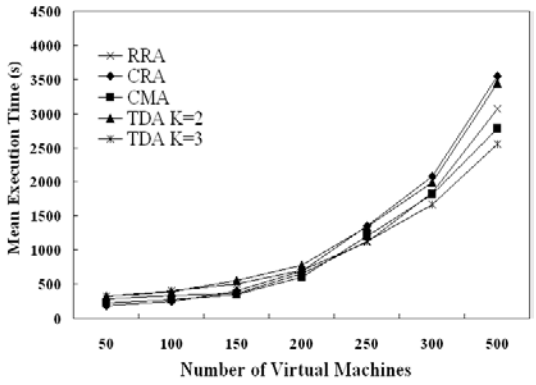

Figure 9. Mean Execution with MP Mechanism

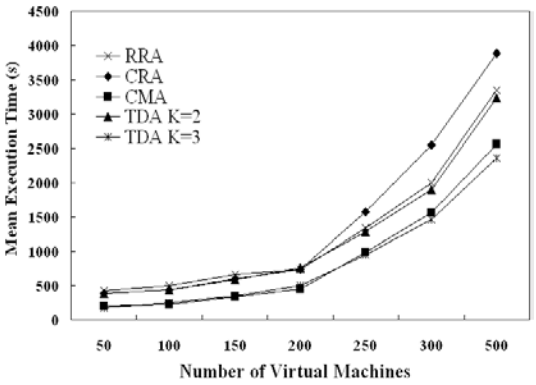

Figure 10. Mean Execution with AP Mechanism

From the above results, we can see that the task execution time increases with the increasing of VM numbers. It is because that our test workload size is always 20 times of VM number. An interesting finding is that four algorithm seem perform the same when MP mechanism is used (as shown in Figure 9). By examining the experimental data in detail, we find that MP mechanism is of great effects on the VM allocation. So, it plays an dominate role when scheduling tasks onto VMs. As to the FP mechanism, the importance of scheduling algorithm is significant great than the VM price mechanism. As shown in Figure 7, the performance differences of these algorithms are most significant. Generally speaking, we notice that TDA outperforms other algorithms in term of *Mean Execution Time*, especially when K=3. It is because that TDA always dispatches multiple tasks replica onto different VMs, and select the quickest results as the task's return. Even thought, we still can not say that TDA is the best algorithm of these four algorithms, since it will result in low effective utilization especially with large *K* value. RRA is a very simple scheduling algorithm; however, we notice that its performance keeps relatively stable when using different VM price mechanisms. Maybe, it is why many practical systems use it as the default task scheduling algorithm.

5. Conclusion

In this paper, we present an integrated performance evaluation middleware, namely CVPE, which is aiming to provide users and researchers an easy-to-use toolkit to evaluate their Cloud system's runtime performance, or compare the performance when different resource management policy and task scheduling algorithms are taken into account. The CVPE is consists of four key components including *Service Portal*, *Synthetic Workload Generator*, *VM Scheduler* and *VM Manager*. In order to realize online performance monitoring and profiling service for these virtual resources, we apply the classical queue model to describe the working status of each VM. Massive experiments are conducted to investigate the effectiveness of the proposed system, and the results indicate that its configurable feature is very useful when users are conducting performance comparing under different conditions.

Acknowledgements

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