A Load Balancing Mechanism Based on Fuzzy Nonparametric Analysis of QoS Parameters

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Abstract **– Load balancing enables the increase the productivity and quality of services being provided by data centers. It is suggested to use virtual machines for a more flexible allocation of data center resources. The proposed two-step method provides a statistical evaluation of service quality without any assumptions about the probability characteristics of the processes occurring in the data center. The result of this evaluation is used in load balancing between several virtual machines. The proposed method is implemented in the management system for the SLA-defined service quality management. The results of this implementation are presented in the paper.**

Keywords – QoS; fuzzy logic; nonparametric statistics; zonoids; load balancing.

I. INTRODUCTION

Data centers provide a scope of services to their customers. Quality of Service (QoS) is specified in the Service Level Agreement (SLA) and directly dependents on the volume of Internet Technology (IT) resources they have allocated, the number of users using this service, etc.

In order to avoid losses due to non-compliance of SLA, the data center manager monitors the quality of provided services. When quality degrades considerably, then the volume of resources that support these services needs to be increased. However, an excessive increase in the volume of resources leads to financial losses for the data centers. Therefore, it is necessary to implement a continuous monitoring of the allocated resource volume in such a way that the quality of this service will correspond to the stipulations in the SLA with a minimum number of allocated resources. Service Level Management and allocation of resources are managed by control systems of the data center. For the distribution of tasks or user requests to the data centers, load balancers interacting with management systems are used.

The remainder of the paper is organized as follows: in Section II, the related work is discussed. The method which enables to determine the quality of service provided is described in Section III. In Section IV, the application of estimated QoS value in load balancing is described. Theoretical calculations have been confirmed by the experiments, results of which are shown in Section V. The paper is concluded with Section VI, where the results and future research directions are addressed.

II. RELATED WORK

In [1], the authors propose a load balancing algorithm to optimally distribute the incoming tasks in the cloud data centers. In [2], the authors propose a virtualization framework that makes background load balancing more flexible and less resource intensive. The authors of article [3] formulate a load balancing problem as a robust optimization problem, that minimizes the worst-case cost of a given data center’s services. Another approach to solving this problem is described in [4]. The authors propose to differentiate the SLA agreements with different kinds of hosting, using several criteria.

In [5], the authors propose a method for aggregating quality metrics of an IT infrastructure component to estimate its functioning. The method is based on the graph-representation of the IT infrastructure and a non-parametric statistic. It enables to aggregate the parameters which have different types and which impact the quality of component functioning in generalized parameters. This method solves the problem of generalization of element parameters by representing them in a single parametric space with the possibility of projection to the quality axis. This generalization takes into account the probabilistic side of consideration of elements not being attached to any distribution by using non-parametric models.

One should also take into account the geolocation of the data center servers. The authors in [6] propose to manage the data center’s servers by activating or deactivating certain servers in data center. This approach takes into account the fact that not all servers of data centers are located at the same place.

III. FUZZY NONPARAMETRIC ANALYSIS OF QOS

A data center is composed of many computation and storage nodes. Each node has a series of IT resources, such as central processing unit (CPU), random access memory (RAM), physical memory, network bandwidth, etc.

The proposed two-step method provides a statistical evaluation of QoS without any assumptions about the probability characteristics of the processes occurring in the data center.

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A. Defining of the IT resources that affect the functioning of data center's services

Assume that the provider offers users a set $S = \{s_i\}$, $i = \overline{1,K}$ of services. For each service, one or several identical virtual machines (VM) $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$, where M_i is the maximum number of VM, can be allocated for the maintenance of the i-th service. Each VM supports only one service.

Resources from a R_m, $m = \overline{1,L}$ are allocated to each virtual machine, where L represents the number of different types of resources at the data center. The volume $r_{m,i}$, $m = \overline{1,L}$, $i = \overline{1,K}$ of resources of the m-th type is allocated to each VM supporting the i-th service. The volume of allocated resources to each VM supporting the i-th service is defined by requirements of the i-th, $i = \overline{1,K}$ service. In the course of operation, each VM $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$ actually involves the volume $r^*_{m,i}$, $m = \overline{1,L}$, $i = \overline{1,K}$ of the m-th resource type. The size $r^*_{m,i}$ dynamically changes and depends on the number of users of the i-th service and the type of user requests.

For each i-th service from a set of services S within process of Service Level Management (SLM) quality indicators are defined. The measure values $q_{b,i}$, $b = \overline{1,D_i}$, $i = \overline{1,K}$ of quality approved by the customer are agreed upon in SLA, where $q_{b,i}$ is a value of the b-th indicator of quality of the i-th service, and D_i is the number of indicators of quality of the i-th service. The services should be monitored to ensure the specifications in the SLA level of QoS. For this purpose, the control system defines the actual values $q^*_{b,i}$, $b = \overline{1,D_i}$, $i = \overline{1,K}$ of quality indicators, and compares them to the approved values. SLM is aimed at the constant maintenance of service quality at the approved level.

$$q_{b,i} - q^*_{b,i} \to 0, \forall b,i \, . \qquad (1)$$

As each service is provided by several VMs $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$, it is rather labor-consuming to trace the current measure values $q^*_{j,b,i}$, $j = \overline{1,M_i}$, $b = \overline{1,D_i}$, $i = \overline{1,K}$ of quality of each VM which provides the i-th service with subsequent assessment of the final quality level of apply the service provided by the data center. Therefore, authors proposed to use the indirect method of a quality evaluation of services by applying the methods of non-parametric analysis and fuzzy logic. Use of fuzzy logic in case of a quality evaluation of services is caused by the fact that the assessment by the user of the services is received by the service provider with use of the linguistic variable accepting values from "it is very bad" to "perfect".

The essence of a method is that, on the basis of the saved-up statistics for VM providing the i-th service, the dependence of values $q^*_{b,i}, \forall b,i$ of quality indicators on values $r^*_{m,i}, \forall m,i$ of the involved volumes of the data center resources is established. The management of services quality comes down to the fact that the management system permanently makes determination of the involved volumes $r^*_{m,i}$ of resources of each VM $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$. Then the management system estimates the current level $q^*_{j,b,i}$ of the b-th, $b = \overline{1,D_i}$ quality indicator of service, provided by VM $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$ and causes the decision on management of the level of services. At the same time, two controlling mechanisms on the maintenance of the level of services within SLA level are applied. One mechanism is based on the scope of changes of the resources allocated for service maintenance. In this work, an increase or reduction of the number of VM providing services is performed. Other mechanisms use load balancing for VM. At the same time, for each i-th service, $i = \overline{1,K}$ a new load balancer is initiated, which is a component of the management system.

In the absence of assumptions about the nature of the dependencies between the value $q^*_{j,b,i}$, $j = \overline{1,M_i}$, $b = \overline{1,D_i}$, $i = \overline{1,K}$ of the service quality and the values $r^*_{m,i}$, $m = \overline{1,L_i}$, $i = \overline{1,K}$ of used resource types, as well as the possibility of the existence of any kind of relationship between the quality of service provided by separate VMs and the total quality of service provided by data center, it is expedient to apply expert estimation, the fuzzy logic apparatus and the apparatus of nonparametric analysis.

As in this paper homogeneous servers are being considered, and VMs $V_{j,i}$, $j = \overline{1,M_i}$, which provide the i-th service, have identical characteristics, then the dependence established between an indicator of quality $q^*_{j,b,i}$, and volume of the involved resources $r^*_{m,i}$ the index j can be excluded.

Geometric estimation of nonparametric statistics is used in analysis of dependences between values of volumes $r^*_{m,i}, \forall m,i$ of resources which consume VMs providing the i-th service and values of indicators of quality $q^*_{b,i}$, $b = \overline{1,D_i}$, $i = \overline{1,K}$ of the i-th service which it provides. The projection of the zone responding to a certain value of the linguistic QoS variable establishes connection of measured values of quality with the VM resources.

B. Converting the quality indicators to fuzzy variables

By means of a fuzzy logical conclusion [7] the dependence between values $q^*_{b,i}$, $b = \overline{1,D_i}$, $i = \overline{1,K}$ and integral quality estimation Q_i, $i = \overline{1,K}$, of the i-th service which is also fixed within SLA is established. The integral quality estimation Q_i, of the i-th service is usually described by a linguistic variable and linguistic value, which correspond to the quality estimation of the user.

Integral quality estimation Q_i of the i-th service and indicators of quality $q^*_{b,i}, \forall b$ of the i-th service are described by linguistic values from sets of $\{l^Q_{i,\omega}\}$, $i=\overline{1,K}$, $\omega=\overline{1,\Omega_i}$ and $\{l^q_{b,i,\gamma}\}$, $\gamma=\overline{1,\Gamma_{b,i}}$, where Ω_i is the amount of the linguistic values corresponding to integral quality estimation of the i-th service, $\Gamma_{b,i}$ is the amount of the linguistic values describing the quality indicators $q_{b,i}$, $b=\overline{1,D_i}$ of the i-th service $i=\overline{1,K}$. To each $l^Q_{i,\omega}$, $\omega=\overline{1,\Omega_i}$ and $l^q_{b,i,\gamma}$, $\gamma=\overline{1,\Gamma_{b,i}}$ are mapped to fuzzy sets $\Psi^Q_{i,\omega}$ and $\Psi^q_{b,i,\gamma}$ respectively.

At the fuzzification stage, a degree of belonging $L^q_{b,i,\gamma}$ of the values $q_{b,i}, \forall b,i$ to fuzzy sets $\Psi^q_{b,i,\gamma}$ $\gamma=\overline{1,\Gamma_{b,i}}$ is defined.

For each service s_i, $i=\overline{1,K}$, the L_i-dimentional space is defined where to each axis the type R_m, $m=\overline{1,L}$ of the data center´s resource is mapped. At points of such space, the value of coordinates corresponds to a certain value of the volume of the involved resources $r^*_{m,i}$ of VM.

For all fuzzy values $l^q_{b,i,\gamma}, \gamma\in[1,\Gamma_{b,i}]$ the $P_{b,i}$ reference points having property (4) are chosen.

$$L^q_{b,i,\gamma'} \square L^q_{b,i,\gamma''}, \qquad (4)$$

where $\gamma',\gamma''\in[1,\Gamma_{b,i}]$ and $\gamma'\neq\gamma''$. Such points set reference area in space for the fuzzy set $\Psi^q_{b,i,\gamma}$.

For such point set the central ordered regions of the given depth α is constructed. Due to a number of useful properties described in the definitions [8] of central ordered regions, the most suitable notation is zonoid [9] – a convex polyhedron with such useful properties as:

- the affinity equivariance that "binds" the location estimate to elements;
- the completeness of information that provides a unique evaluation;
- the continuity in depth (depth defines the region centrality);
- the distribution that ensures stability of the solution to the input data;
- the bulge that simplifies the calculation of degree of belonging.

The zonoid has an appearance of a convex polyhedron and is set by formulas:

$$Z(\alpha)=conv\{U_1,U_2,\ldots,U_P\}, \qquad (5)$$

for $\alpha\in]0,\frac{\mathrm{B}}{P}]$, and

$$conv\left\{\frac{1}{\alpha\square P}\sum_{\beta=1}^{\mathrm{B}}U_{p_\beta}+\left(1-\frac{1}{\alpha\square P}\right)U_{p_{\mathrm{B}+1}}\right\}, \qquad (6)$$

for $\alpha\in[\frac{\mathrm{B}}{P},\frac{\mathrm{B}+1}{P}]$, where $\mathrm{B}\in\{1,2,...,P-1\}$, $\{p_1,p_2,...,p_{B+1}\}\subset\{1,2,...,P\}$, and $\{U_1,U_2,\ldots,U_P\}$ – points on the basis of which the zonoid is constructed, P – the number of such points.

To define the degrees of belonging $L^q_{b,i,\gamma}$ within the point in time t, there is a point $U_{i,b}(t)$ in space, corresponding to the current values of the involved VM resources in point t:

$$U_{i,b}(t)=\left\{r^*_{i,b,1}(t),...,r^*_{i,b,L_i}(t)\right\}. \qquad (7)$$

For each linguistic value $l^q_{b,i,\gamma}$, $\gamma=\overline{1,\Gamma_{b,i}}$ the smallest Euclidean distance $d_{b,i,\gamma}$ from a point $U_{i,b,\gamma}(t)$ to the zonoid corresponding to this linguistic value is defined. The value $L^q_{b,i,\gamma}$ is estimated by the formula:

$$L^q_{b,i,\gamma}=1-\frac{1}{\max\left\{d_{b,i,1},d_{b,i,2},...,d_{b,i,\Gamma_{b,i}}\right\}-d_{b,i,\gamma}}, \qquad (8)$$

where $\Gamma_{b,i}$ – amount of the linguistic values describing quality indicators $q_{b,i}$, $b=\overline{1,D_i}$ of the i-th service.

C. Reduction of service quality indicators, specified in the SLA, to a single integral quality indicator

In order to establish the dependence of an integral quality indicator Q_i, $i=\overline{1,K}$, from all quality indexes $q_{b,i}$, $b=\overline{1,D_i}$ of the i-th service, the fuzzy database is used. Rules of such base are represented as follows:

$$IF \wedge\left(L^q_{b,i,\gamma}\mid\gamma\in[1,\Gamma_{b,i}]\right)THEN\left(l^Q_{i,\omega}\mid\omega\in[1,\Omega_i]\right), \qquad (9)$$

for $b=\overline{1,D_i}$.

Indicate $L^Q_{i,\omega}$ as the degree of belonging to the fuzzy set $\Psi^Q_{i,\omega}$, $\omega=\overline{1,\Omega_i}$. Its value is defined as the minimum of all values derived from the fuzzy database rules (9) corresponding to fuzzy value $l^q_{b,i,\gamma}$.

D. Calculation of the integral quality indicator of service

At a defuzzification stage for the i-th service the numerical value of its integral quality indicator Q_i is calculated by a formula:

$$Q_i = \frac{\int_{x=0}^{1} x \cdot F_i(x)\,dx}{\int_{x=0}^{1} F_i(x)\,dx}, \qquad (10)$$

where $F_i(x)$ is calculated by the formula:

$$F_i(x) = agg\left(imp\left(L^Q_{i,\omega}, \mu_{i,\omega}(x)\right)\right), \qquad (11)$$

where $\mu_{i,\omega}$ is the membership function of integral quality indicator Q_i to the fuzzy set $\Psi^Q_{i,\omega}$, $i = \overline{1,K}$, $\omega = \overline{1,\Omega_i}$.

IV. Load Balancing

Two control mechanisms are implemented in the management system "SmartBase ITS Control", developed by the National Technical University of Ukraine "Kyiv Polytechnic Institute" for the SLA-defined service quality management. The first of them assumes a change of the number of VMs providing the *i*-th service, and the second – the VM load balancing.

The algorithm of "SmartBase ITS Control" management system during quality management of the *i*-th service consists in the following.

For each VM $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$ the current quality of the provided service is defined. For this purpose, the value of the involved volumes of resources $r^*_{m,i}$, $m = \overline{1,L}$, $i = \overline{1,K}$ is defined for each VM.

Proceeding from value $r^*_{m,i}$, $m = \overline{1,L}$, $i = \overline{1,K}$ taking into account expressions (6)–(8) the values $L^q_{b,i,\gamma}$, $b = \overline{1,D_i}$, $\gamma \in \left[1, \Gamma_{b,i}\right]$ are calculated.

The calculated values $L^q_{b,i,\gamma}$, are substituted in rules (9) of fuzzy database and degree of belonging to $L^Q_{i,\omega}$, $\omega = \overline{1,\Omega_i}$ is defined.

To find a numerical value of an integral quality indicator Q_i of the *i*-th service for *j*-th VM, the center of mass is determined by a formula (10) which represents the result of aggregation of belonging functions $\mu_{i,\omega}$, bound above by the values $L^Q_{i,\omega}$ determined by formula (11).

If for all VMs $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$, the received values of integral quality indicators Q_i are lower than stipulated within SLA, then the manageent system makes the decision to increent the number of VMs that provide the *i*-th service.

If for all VMs $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$ the received values of integral quality indicators Q_i exceed the stipulations within SLA, then the decision to decrement the consumption of resources of the data center is made. Specifically the number of available VMs for the *i*-th service is decremented.

If the received values of integral quality indicators Q_i are in norm limits, then the balancer distributes the user's requests between VMs $V_{j,i}$, $j = \overline{1,M_i}$, $i = \overline{1,K}$ in proportion to values Q_i for each VM.

V. Experimental Results and Analysis

As the experimental service, a Web service, which works using the HTTP protocol had been selected (denoted as s_1). The indicator of HTTP-service quality is the time of reaction of the server for the user's request.

As there are no well-defined standards for the time of any given loaded page, it had been decided to follow the recommendations by [14] and to follow the recommendations by Yandex. In said recommendations, it was stipulated that the quality of HTTP service is considered excellent if a server response time is less than 3 seconds, satisfactory – from 3 to 6 seconds, and unsatisfactory if the time of the server response is longer than 6 seconds.

The VM resources are determined by the parameters that are indirectly influencing HTTP server response time. Based on the paper [14], it was defined, that the time of the page loading, and the quality of HTTP-service are influenced by following resources: the involved processor time, the free RAM, and throughput of the communication channel.

For carrying out an experiment, three homogeneous virtual machines $V_{1,1}, V_{1,2}, V_{1,3}$. are deployed. On VMs the Apache Server and Java were installed. As test service the Atlassian Jira was selected. It is rather resource-intensive service. It is rather resource-intensive service therefore even insignificant increase in the number of the users' requests for such service leads to noticeable increase in the value of resources spent by VMs. At the initial point in time, only one virtual machine is active. Other machines are in the sleep mode to decrease data center resource consumption.

As VMs are homogeneous, the data center operators are able to increase quickly the number of machines, if necessary. CPU load (parameter r_{11}), free RAM (parameter r_{21}) and bandwidth of network interface (parameter r_{31}) are resources that may be allocated for service s_1 for $V_{1,1}, V_{1,2}, V_{1,3}$.

The workload is formed by Apache Jmetter during the experiment. From 1 to 100 users' requests per second have been emulated. The emulation results without load balancing are displayed in Fig. 1.

Fig. 1 shows that the load time increases dramatically on the 20th second approximately. This is due to the increase in the number of users' requests from 1-25 to 75-100.

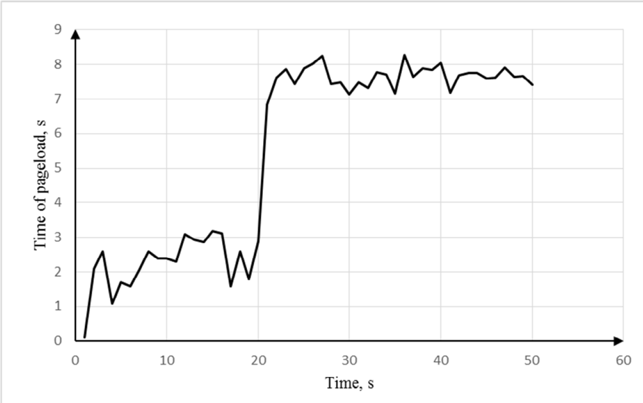

Figure 1. Emulation results without management system

The results of the same experiment, while using the management system, are shown in Fig. 2.

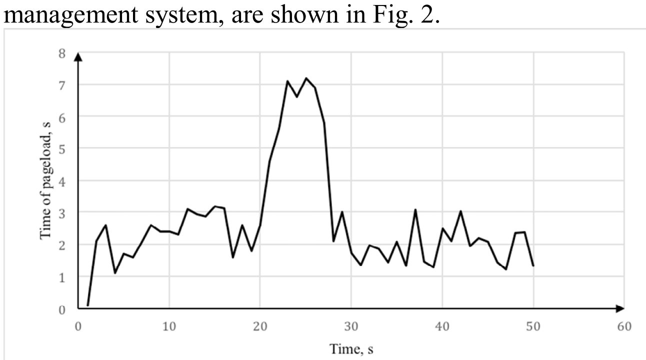

Figure 2. Emulation results with management system

When the management system has determined that there are not enough resources for providing service quality, it launches an additional virtual machine. This happens after 20 seconds. Then, the load balancer begins distributing users' requests between the virtual machines evenly.

With a more uniform VM workload increase, the management system allowed to exclude unwanted delays completely. Fig. 3 shows the simulation results without control, but with a uniform workload increase.

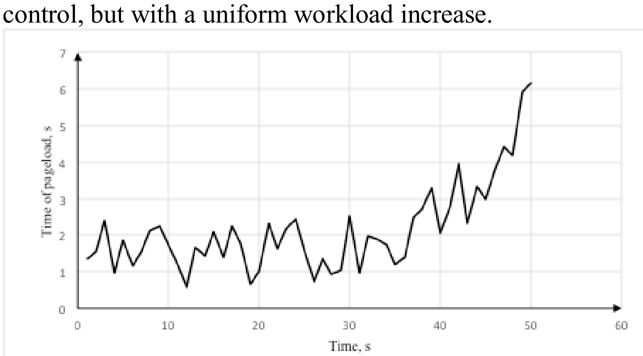

Figure 3. Emulation results with a uniform workload increase without management system

Fig. 4 displays the simulation results with the activated management system, as proposed in the paper, with a uniform workload increase.

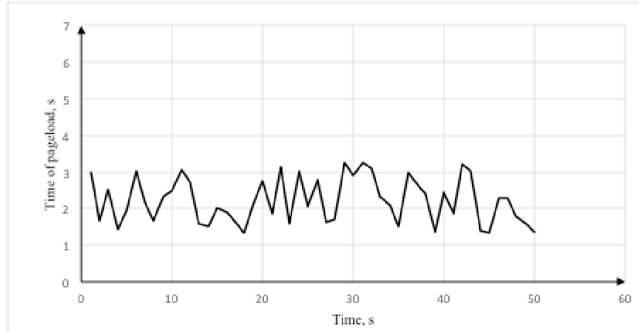

Figure 4. Emulation results with a uniform workload increase with management system

Simulation results have shown that the proposed load balancing method works satisfactorily when the number of user's requests changes slightly. When a workload increases sharply up to the critical point, the management system needs some time to adjust to the new conditions.

This problem arises from the fact that the new virtual machines need time to turn on. And even the fact that they are in the sleep mode, but are not turned off completely, did not allow them to react quickly enough to sudden changes in the server's workload.

If one of the backup virtual machines is left enabled, but the load balancer for it is disabled, so that it does not send requests until the moment when the active virtual machines fully cope with the current workload, the response to sudden workload surges will be more rapid.

Only providing unlimited resources would completely eliminate the problems associated with the sharp increase in workload at the servers, which is not feasible. But it is possible to use the methods described in [2] to decrease the reaction time.

VI. CONCLUSION AND FUTURE WORK

In this work, a load balancing management system for data center servers based on the current quality of service is proposed. It is suggested to use virtual machines for a more flexible allocation of data center resources.

The advantage of this method of load balancing is that a balancer determines the need for additional resources, being based not on the number of resources involved, but on the value of the integral quality indicator of services. The proposed two-step method provides a statistical evaluation of QoS without any assumptions about the probability characteristics of the processes occurring in the data center.

In contrast to the method proposed in [5], the method described in this paper allows to determine in advance the time when there is a need for additional resources for the given service. In [3], the authors have proposed a load balancing algorithm, which operates at a consistently high workload at the servers. The disadvantage of this method is the increased consumption of data center resources at low

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workloads. In [4], the authors have proposed to define SLA service compliance of service quality on the proposed criteria. In this study a similar method has been suggested. But the use of fuzzy inferencing, when aggregating the quality indicators overall, integral quality indicator provides a more accurate assessment of the service quality.

HTTP-service experiments were carried out as an example for showing operability of the proposed management system. The experiments have shown the efficiency of this method. The quality of the service under consideration did not go beyond the norm in the experiments.

However, the authors of this work have not considered the problems described in [2], and [6]. The balancing method proposed in this paper, in combination with the algorithms described in [2], and [6], will improve the current method. Also, the time of VM switching on will be reduced.

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