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Simple Estimation Model and Energy-efficient Virtual Machine Migration Algorithm in a Server Cluster

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Abstract

In this thesis, we propose a virtual machine migration approach to reducing the electric energy consumption of servers. In our previous algorithms, one virtual machine migrates from a host server to a guest server. While the electric energy consumption of servers can be reduced by migrating some number *b* of processes, there might not be a virtual machine with the same number *b* of processes on a host server. In this thesis, we newly propose an ISEAM2T algorithm where multiple virtual machines can migrate from a host server to a guest server. Here, multiple virtual machines on a host server are selected so that the total number of processes on the virtual machines can be more easily adjusted to the optimal number *b* of processes. In the evaluation, we show the total electric energy consumption and active time of the servers can be reduced in the proposed algorithm.

Key words: Virtual machine migration, Energy-efficient migration, ISEAM2T algorithm

1 Introduction

We have to reduce electric energy consumption of servers in clusters like cloud computing systems in order to realize eco society. We aim at reducing the total electric energy consumed by a server to perform application processes in our macro-level approach [1, 2]. Here, types of power consumption and computation models are proposed [1, 2].

If an application process is issued to a cluster of servers, one energy-efficient server is selected to perform the process in types of server selection algorithms [3]. Furthermore, an application process performed on a host server migrates to a guest server which is expected to consume smaller electric energy than the host server in the migration approach. Here, a virtual machine with application processes can easily migrate from a host server to another guest server without suspending the processes like the live migration. Algorithms for energy-efficient migrating virtual machines [4, 5, 6, 7] are so far proposed. Here, one virtual machine is selected to migrate. In papers [6], the mathematical relation among the electric energy consumed by a host server s_t and a guest server s_u and the number of processes to migrate is discussed. By using the relation, we can find such number b_{tu} of processes to migrate from a host server s_t to a guest server s_u that the total electric energy to be consumed by the servers s_t and s_u is minimized. However, it is not easy to find a virtual machine by migrating which the electric energy consumption of the host and guest servers can be mostly reduced. In this thesis, we proposed an ISEAM2T algorithm where multiple virtual machines can migrate to a guest server where the total number of processes on the virtual machines is near to the optimal number b_{tu}.

We evaluate the ISEAM2T algorithm in terms of the total electric energy consumption compared with other non-migration and migration algorithms.

In section 2, we present a system model. In section 4, we propose the ISEAM2T algorithm. In section 5, we evaluate the ISEAM2T algorithm.

2 System Model

A cluster is composed of servers $s_1, \ldots, s_m$ ($m \geq 1$) and supports applications on clients with virtual service on computation resources by using virtual machines vm_1, $\ldots$, vm_v ($v \geq 1$). If a client issues an application process p_i, one virtual machine vm_h is selected to perform the process p_i. $VCP_h(\tau)$ is a set of resident processes on vm_h at time τ. Here, $|VCP_h(\tau)|$ shows the number nv_h of processes on vm_h. $CP_t(\tau)$ is a set of processes on a server s_t at time τ.

Let $nap_t(n), nac_t(n)$, and $nat_t(n)$ be numbers of active CPUs, cores, and threads of a server s_t where n ($= |CP_t(\tau)|$) processes are performed. Hence, we can assume $nap_t(n) = n$ if $n \leq np_t$, else np_t. $nac_t(n) = n$ if $n \leq nc_t$, else nc_t. $nat_t(n) = n$ if $n \leq nt_t$, else nt_t. In in the MLPCM model [2], the electric energy consumption $NCE_t(n)$ of a server s_t to perform n (≥ 0) processes is:

$$NCE_t(n) = minE_t + nap_t(n) \cdot bE_t + nac_t(n) \cdot cE_t + nat_t(n) \cdot tE_t. \quad (1)$$

The total electric energy consumed by a server

s_t from time st to time et is defined to be $\sum_{\tau=st}^{et} NCE_t(|CP_t(\tau)|)$ [W tu].

Each process p_i is performed on a host server s_t. It takes T_{ti} time units [tu] to perform a process p_i on a thread of a server s_t. If only a process p_i is performed on a server s_t without any other process, the execution time T_{ti} of the process p_i is shortest, i.e. $T_{ti} = minT_{ti}$. In a cluster S of servers $s_1, \ldots, s_m$ $(m \geq 1)$, $minT_i$ shows a shortest one of $minT_{1i}, \ldots, minT_{mi}$. If $minT_{fi} = minT_i$, a thread of a server s_f is $fastest$ and the server s_f is $fastest$. We assume one virtual computation step [vs] is performed on a thread of a fastest server s_f for one time unit [tu], i.e. the computation rate TCR_f of the thread is one [vs/tu]. The total number VC_i of virtual computation steps of a process p_i is defined to be $minT_i$ [tu] $\cdot$ TCR_f [vs/tu] = $minT_i$ [vs]. The maximum server computation rate $maxSR_t$ of a server s_t is $nt_t \cdot TCR_t$. The server computation rate $NSR_t(n)$ of a server s_t is:

$$NSR_t(n) = \begin{cases} n \cdot TCR_t & \text{if } n < nt_t. \\ maxSR_t & \text{if } n \geq nt_t. \end{cases} \quad (2)$$

The server computation rate $NSR_t(n)$ is fairly allocated to each process p_i of n current processes. The process computation rate $NPR_{ti}(n)$ [vs/tu] of a process p_i with $(n-1)$ processes on a server s_t is $NSR_t(n)/n$. VC_i shows the total number of computation steps to be performed by a process p_i. At time τ a process p_i starts, $lc_{ti}(\tau)$ = VC_i. Then, $lc_{ti}(\tau)$ is decremented by the computation rate $NPR_{ti}(|CP_t(\tau)|)$, i.e. $lc_{ti}(\tau + 1) = lc_{ti}(\tau) - NPR_{ti}(|CP_t(\tau)|)$ at each time τ. If $lc_{ti}(\tau) > 0$ and $lc_{ti}(\tau+1) \leq 0$, p_i terminates at time τ.

3 Estimation Model

3.1 Expected electric energy consumption

A client issues a process p_i to a set VM of virtual machines $vm_1, \ldots, vm_v$ $(v \geq 1)$ in a cluster S of servers $s_1, \cdots s_m$. We assume the total number VC_i of virtual computation steps of each process p_i to be a constant, $VC_i = 1$. Suppose n processes are currently performed on a server s_t and k new processes are issued to the server s_t.

The total number of virtual computation steps to be performed by n active processes on a server s_t is $\alpha_t(n) \cdot n$. In this thesis, the function $\alpha_t(n)$ is given for number nt_t of threads as follows:

$$\alpha_t(n_t) = \begin{cases} 0.5 & \text{for} \quad n \leq nt_t. \\ 0.6 & \text{for} \quad nt_t < n \leq 2 \cdot nt_t. \\ 0.8 & \text{for} \quad 2 \cdot nt_t < n \leq 4 \cdot nt_t. \\ 1 & \text{for} \quad n > 4 \cdot nt_t. \end{cases} \quad (3)$$

For example, $\alpha_t(n) \cdot n = 0.8 \cdot 4 \cdot nt_t = 3.2 \cdot nt_t$ for $n = 4 \cdot nt_t$. The more number of active processes, the more number of virtual computation steps each active process has to perform.

The expected termination time $SET_t(n,k)$ [tu] and electric energy consumption $SEE_t(n,k)$ [W tu] of a server s_t to perform n current processes and k new processes are given as follows:

$$SET_t(n,\, k) = (\alpha_t(n) \cdot n + k)/NSR_t(n+k). \quad (4)$$
$$SEE_t(n,\, k) = SET_t(n,k) \cdot NCE_t(n+k). \quad (5)$$

Let n_t be the number $|CP_t(\tau)|$ of processes performed on each server s_t. First, suppose no virtual machine on the server s_t migrates to the server s_u. The servers s_t and s_u consume electric energy $EE_t (= SEE_t(n_t, 0))$ by time $ET_t (= SET_t(n_t, 0))$ and $EE_u (= SEE_u(n_u, 0))$ by $ET_u (= SET_u(n_u, 0))$ to perform n_t and n_u current processes, respectively. The servers s_t and s_u totally consume the electric energy EE_{tu} until every current process on s_t and s_u terminates:

$$EE_{tu} = \begin{cases} EE_t + EE_u + (ET_t - ET_u) \cdot minE_u \\ \quad \text{if } ET_t \geq ET_u. \\ EE_t + EE_u + (ET_u - ET_t) \cdot minE_t \\ \quad \text{if } ET_t < ET_u. \end{cases} \quad (6)$$

Next, suppose a virtual machine vm_h on the host server s_t migrates to the guest server s_u. Here, $(n_t - nv_h)$ processes are performed on the server s_t while $(n_u + nv_h)$ processes on the server s_u. The servers s_t and s_u totally consume the electric energy $NE_t = SEE_t(n_t - nv_h, 0)$ by time $NT_t = SET_t(n_t - nv_h, 0)$ and the electric energy $NE_u = SEE_u(n_u + nv_h, 0)$, $NT_u = SET_u(n_u + nv_h, 0)$, respectively, to perform every process. The servers s_t and s_u totally consume the electric energy NE_{tu}:

$$NE_{tu} = \begin{cases} NE_t + NE_u + (NT_t - NT_u) \cdot minE_u \\ \quad \text{if } NT_t \geq NT_u. \\ NE_t + NE_u + (NT_u - NT_t) \cdot minE_t \\ \quad \text{if } NT_t < NT_u. \end{cases} \quad (7)$$

If $EE_{tu} > NE_{tu}$, the virtual machine vm_h can migrate from the host server s_t to the guest server s_u.

3.2 Selection of a virtual machine

In order to make simple the estimation of the termination time and electric energy consumption, we assume the computation rate $NSR_t(n)$ of a server s_t to be the maximum server computation rate $maxSR_t$. In addition, we assume the electric power $NCE_t(n)$ of a server s_t to be the maximum electric power $maxE_t$ as discussed in the SPC model [1].

If no virtual machine migrates from a host server s_t to a guest server s_u, the expected termination time ET_t is $n_t/maxSR_t$ [tu] and the expected electric energy consumption EE_t is $ET_t \cdot maxE_t = n_t \cdot maxE_t/maxSR_t$ [W tu] for $n_t > 0$ for a host server s_t. $ET_u = n_u/maxSR_u$ and $EE_u = ET_u \cdot maxE_u = n_u \cdot maxE_u/maxSR_u$ for a server s_u.

Next, suppose a virtual machine vm_h with nv_h processes migrates from a host server s_t to a guest server s_u. The expected termination time NT_t is $(n_t - nv_h)/maxSR_t$ and the expected electric energy consumption NE_t is $(n_t - nv_h) \cdot maxE_t/maxSR_t$ for the host server s_t. NT_u is $(n_u + nv_h)/maxSR_u$ and NE_u is $(n_u + nv_h) \cdot maxE_u/maxSR_u$ for a guest server s_u. The expected termination time $NT_t(nv_h)$ and $NT_u(nv_h)$ of the servers s_t and s_u are $(n_t - nv_h)/maxSR_t$ and $(n_t + nv_h)/maxSR_u$, respectively. The total electric energy consumption $EC_{tu}(nv_h)$ of the servers s_t and s_u is given for the size nv_h of the virtual machine vm_h:

$$EC_{tu}(nv_h) = \begin{cases} A_{1tu} \cdot nv_h + C_{1tu} \\ \quad \text{if } NT_t(nv_h) \geq NT_u(nv_h). \\ A_{2tu} \cdot nv_h + C_{2tu} \\ \quad \text{if } NT_t(nv_h) < NT_u(nv_h). \end{cases} \tag{8}$$

$$\begin{aligned} A_{1tu} &= (maxE_u - minE_u)/maxSR_u \\ &\quad - (maxE_t + minE_u)/maxSR_t. \end{aligned} \tag{9}$$

$$\begin{aligned} A_{2tu} &= (maxE_u + minE_t)/maxSR_u \\ &\quad - (maxE_t - minE_t)/maxSR_t. \end{aligned} \tag{10}$$

$$\begin{aligned} C_{1tu} &= n_u \cdot (maxE_u - minE_u)/maxSR_u \\ &\quad + n_t \cdot (maxE_t + minE_u)/maxSR_t. \end{aligned} \tag{11}$$

$$\begin{aligned} C_{2tu} &= n_u \cdot (maxE_u + minE_t)/maxSR_u \\ &\quad + n_t \cdot (maxE_t - minE_t)/maxSR_t. \end{aligned} \tag{12}$$

For example, if $A_{1tu} \geq 0$ and $A_{2tu} \geq 0$, the total electric energy consumption $EC_{tu}(nv_h)$ linearly increases as the size nv_h of a virtual machine vm_h increases. If $A_{1tu} < 0$ and $A_{2tu} < 0$, $EC_{tu}(nv_h)$ linearly decreases as nv_h increases. If $A_{1tu} < 0$ and $A_{2tu} > 0$, $EC_{tu}(b_{tu})$ is minimum. If a virtual machine vm_h migrates whose size nv_h is b_{tu}, the electric energy consumption of the servers s_t and s_u can be minimized as shown in Figure 1. If $A_{1tu} > 0$ and $A_{2tu} < 0$, $EC_{tu}(0)$ or $EC_{tu}(n_t)$ is minimum and $EC_{tu}(b_{tu})$ is maximum.

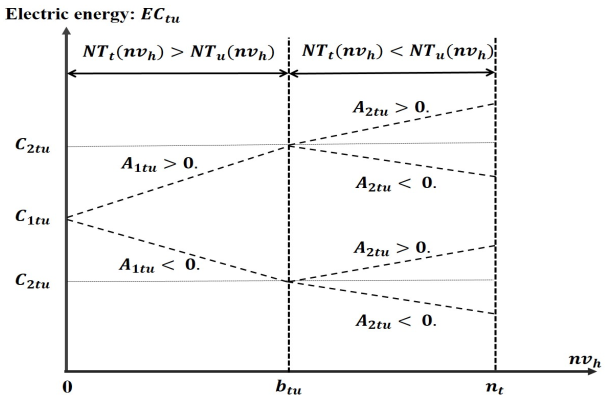

Fig. 1: Energy consumption $EC_{tu}(nv_h)$.

4 Energy-aware Migration Algorithms

Each server s_t is periodically checked. For each server $s_u (\neq s_t)$, a virtual machine vm_h on the server s_t is selected where the total electric energy can be consumed by a pair of the servers s_t and s_u is minimum:

[ISEAM2T algorithm]

X = a set of active servers in a cluster S;
for each server s_t **in** X,
while $(|X| > 0)$ {
  for each engaging server $s_u (\neq s_t)$ in S,
  $EE_t = SEE_t(n_t, 0)$; $EE_u = SEE_u(n_u, 0)$;
  $EEE_{tu} = EE_t + EE_u$;
  $b_{tu} = \dfrac{n_t \cdot maxSR_u - n_u \cdot maxSR_t}{maxSR_t + maxSR_u}$;
  if $b_{tu} \leq 0$, {
    if $A_{2tu} < 0$, {
      select all virtual machines on the server s_t as target ones **in** TMV_t;
      $NE_t = SEE_t(0, 0)$;
      $NE_u = SEE_u(n_u + n_t, 0)$;
    };
  }; /* **if** $b \leq 0$ end */
  else /* $0 < b_{tu} < n_t$ */, {
  if $A_{1tu} < 0$ and $A_{2tu} < 0$, {
    select all virtual machines on the server s_t as target ones **in** TMV_t;
    $NE_t = SEE_t(0, 0)$;
    $NE_u = SEE_u(n_u + n_t, 0)$;
  };
  if $A_{1tu} < 0$ and $A_{2tu} \geq 0$, {
    $tnv_{tu} = 0$;
    while $(b \geq tnv_{tu})$ {
      select a smallest virtual machine vm_{tu} on the server s_t as a target one **in** TMV_t **where** $|b_{tu} - nv_{tu} - tnv_{tu}|$ is minimum;
      $tnv_{tu} = tnv_{tu} + nv_{tu}$;
    }; /* **while** end */
    $NE_t = SEE_t(n_t - tnv_{tu}, 0)$;
    $NE_u = SEE_u(n_u + tnv_{tu}, 0)$;
  };
  if $A_{1tu} \geq 0$ and $A_{2tu} < 0$,
    if $EC_{tu}(n_t) < C_{1tu}$, {
      select all virtual machines on the server s_t as target ones **in** TMV_t;
      $NE_t = SEE_t(0, 0)$;
      $NE_u = SEE_u(n_u + n_t, 0)$;
    };
  }; /* **else** end */
  $NEE_{tu} = NE_t + NE_u$;
  select a server s_u **where** $EEE_{tu} > NEE_{tu}$ and NEE_{tu} is smallest;
  if s_u is found, {
    migrate the target virtual machines in TMV_t **from** s_t **to** s_u;
    if s_u is **in** X, $X = X - \{s_u\}$;
  }; /* **if** found end */
  $X = X - \{s_t\}$;
}; /* **while** X end */

Here, a set TMV_t of virtual machines on a host server s_t are selected for each guest server s_u, where $tnv_{tu} = \sum_{vm_h \in TMV_t} nv_h$ is nearest to b_{tu}. Then, a server s_u is selected where expected electric energy consumption $EC_{tu}(tnv_{tu})$ is minimum. If a guest server s_u is found, the virtual machines in TMV_t migrate to s_u. Otherwise, no virtual machine migrates from the host server s_t.

5 Evaluation

We evaluate the proposed ISEAM2T algorithm in terms of the total electric energy consumption of servers. We consider a cluster S of four heterogeneous servers s_1, s_2, s_3, and s_4 (m = 4), respectively, in our laboratory and 40 virtual machines $vm_1, \ldots, vm_{40}$ (v = 40). A virtual machine vm_h is on a host server s_t where $t = (h-1)$ module $4+1$. Initially, each server s_t hosts ten virtual machines. The performance parameters like TCR_t and electric energy parameters like $maxE_t$ of each server s_t are shown in Table 1. In the simulation, the total electric energy consumption EE_t is obtained for each server s_t.

In the cluster S, n (> 0) processes $p_1, \ldots, p_n$ are performed. Here, $xtime$ is 1,000 time units [tu]. In this thesis, the starting time $stime_i$ of $3n/4$ processes are randomly taken from time 0 to $xtime$ -1. Then, $stime_i$ of each process p_i of the other $n/4$ processes is randomly taken around time $xtime/4$. In fact, one time unit [tu] shows 100 [msec] [2]. The number VC_i of virtual computation steps of each process p_i is 5.0 to 20.0 [vs].

We consider the random (RD), round robin (RR), SGEA [3], and ISEAM2T algorithms. In the RD, RR, and SGEA algorithms, virtual machines do not migrate. In the ISEAM2T algorithm, multiple virtual machines migrate.

Figure 2 shows the total electric energy consumption TEE [kW · tu] of the four servers in the cluster S for number n of processes. The total electric energy consumption TEE of the ISEAM2T algorithm is smallest. For example, the TEE of the ISEAM2T is about 35 % smaller than the RD and RR algorithms and about10% smaller than SGEA algorithm for n = 2,000.

Table. 1: Parameters of servers.

parameters	DSLab2 (s_1)	DSLab1 (s_2)	Sunny (s_3)	Atira (s_4)
np_t	2	1	1	1
nc_t	8	8	6	4
nt_t	32	16	12	8
TCR_t [vs/tu]	1.0	1.0	0.5	0.7
$maxSR_t$ [vs/tu]	32	16	6	5.6
$minE_t$ [W]	126.1	126.1	87.2	41.3
$maxE_t$ [W]	301.3	207.3	131.2	89.5
bE_t [W]	30	30	16	15
cE_t [W]	5.6	5.6	3.6	4.7
tE_t [W]	0.8	0.8	0.9	1.1

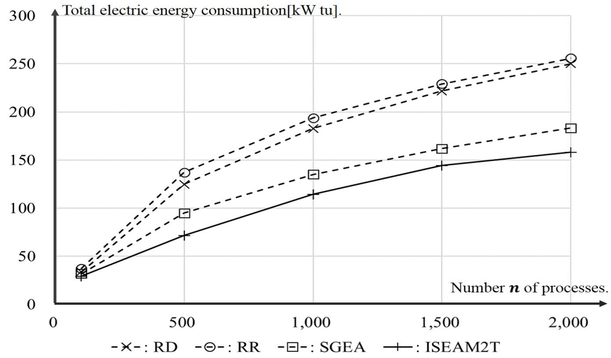

Fig. 2: Total electric energy consumption (m = 4, v = 40).

6 Concluding Remarks

A virtual machine on a host server migrates to an energy-efficient guest server which is expected to consume smaller electric energy while processes are being performed. In this thesis, we newly proposed the ISEAM2T algorithm where multiple virtual machines migrate to more energy-efficient servers. In the evaluation, we showed the total electric energy consumption of servers in the ISEAM2T algorithm is smallest in the other algorithms. We are now considering a new algorithm in scalable heterogeneous clusters where more number of processes and virtual machines are performed on more number of servers.

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