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Energy Efficient Task Consolidation Algorithms for Cloud Computing Systems

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The task consolidation is a method to maximize utilization of cloud computing resources. However, maximizing resource utilization does not ensure efficient energy use. The energy consumption and resource utilization in clouds are highly coupled. Some of the earlier works aim to decrease the resource utilization in order to save energy, while others try to reach a balance between resource utilization and energy consumption. Hence, minimizing the energy consumption in a cloud computing environment is one of the key research issues. In this paper, we propose two energy efficient task consolidation algorithms for cloud computing systems. The first one aims to minimize energy consumption by considering service level agreement (SLA) and the other reduces energy consumption by restricting virtual machines (VMs) with pre-defined utilization threshold values. Both these algorithms are compared with the existing algorithm, called first come first serve (FCFS). The experimental results show that both the proposed algorithms are quite efficient in terms of energy consumption and the total number of task completion.

Keywords : Cloud Computing, Energy Consumption, Resource Utilization, Virtual Machine, Task Consolidation,

1. INTRODUCTION

In recent days, the cloud computing has become highly popular for its recent advances in various technologies such as virtualization, hardware components, software applications and network devices. The adoption of clouds has many attractive benefits such as scalability and reliability. To integrate and make good use of resources at various scales, the cloud computing needs some efficient methods to manage them [1]. Consequently, the focus of the research in recent years has been on how to utilize resources with efficient energy consumption. The relationship between resource utilization and energy consumption and its application on task consolidation has also been studied extensively in literatures [2-10].

According to the recent research reports, the energy consumed by the information and communication technology (ICT) equipment is roughly 8% of the total energy consumption. It may also increase to 50% within a decade [11][12]. In addition to energy consumption, the ICT equipment has a large amount of CO_2 emissions and it is also responsible for 2% of global CO_2 emissions and it is expected to quadrupled by 2020 [13][14]. So, the energy consumption has appeared as a crucial issue for cloud computing systems. In order to meet these requirements, several attempts have been made in the past to develop energy efficient algorithms [3, 15]. Some of the research aims to improve resource utilization while others aim to reduce energy consumption. The goals of both research issues are to reduce costs for data centers. On the other hand, the energy consumption may also vary according to CPU uti-

47699.5 Watts.

The above illustrations clearly show that the energy consumption is reduced for proposed STC and DTTC algorithm as compared to FCFS algorithm.

4.2. Time Complexity

The time complexity of our proposed algorithms.are presented as follows.

Theorem* 1: *The time complexity of the STC algorithm is O(lm(f-s)) time.

Proof: Let the total number of tasks be l and the total number of VMs be m. First of all, the STC picks the first task T_1 and call SCHEDULE_BY_SLA (T_1, ST, FT, SLA). To find whether the task is schedulable or not, the Procedure 1 takes $O(m(f - s))$ time (in worst case for m VMs) where f and s are the finish time and start time respectively (Lines 1 to 7 of Procedure 1). To assign the task to a VM, it takes $O(f - s)$ time (Lines 8 to 14). If the task properties are not satisfied by Procedure 1, then the algorithm calls SCHEDULE_BY_FCFS (T_1, ST, FT) (Procedure 2). Procedure 2 takes $O(m(f - s))$ time (in worst case for m VMs) (Lines 1 to 8). To assign the task T_1 to VM V_j, it takes $O(f - s)$ time (Lines 9 to 15). If task T_1 is not schedulable by both procedures then it rejects task T_1. So, the overall time complexity of STC algorithm is $O(lm(f - s))$ time as STC invoke Procedure 1 or Procedure 2 l times.

Theorem* 2: *The time complexity of the DTTC algorithm is $O(lm(f\text{-}s))$ time.

Proof: The proof of Theorem 2 is same as Theorem 1.

5. EXPERIMENTAL RESULTS

We evaluate the proposed algorithms through simulation run. The experiments were carried out using MATLAB R2014a version on an Intel Core $i3$ processor, 2.20 GHz CPU and 2 GB RAM running on Microsoft Windows 7 platform.

5.1. Datasets

In this simulation, we considered five different datasets generated using MATLAB random function. Each dataset has five instances. The first dataset contains 100 tasks to be scheduled to the available virtual machines and we denote it by 100_*ix*_*yy*. Note that *ix* denotes the instance number (e.g., instance 1 ($i1$), instance 2 ($i2$) and so on) and *yy* shows the number of virtual machine *i.e.*, 10, 15 or 20 as used by [15, 25]. Similarly, the second dataset contains 200 tasks and we denote it by 200_*ix*_*yy* and so on. Therefore, five different datasets make 75 different instances. The range of simulation parameters are shown in Table 9. We denote the range by [a - b] which indicates the parameter value lies between a and b.

5.2. Experiments

We consider that the VMs 1 to 5 has threshold of 50%, 52%, 55%, 58% and 60% respectively and so on. We also consider the task completion (TC) of FCFS, STC and DTTC algorithm and we call these algorithms as TC-FCFS, TC-STC and TC-DTTC respectively. The energy consumption and the number of task completion of FCFS algorithm are compared with the STC algorithm which are shown in Tables 10 to 14. Next we compare FCFS with DTTC algorithm and the comparison is clearly shown in Tables 15 to 19. The comparison of results show that 75 out of 75 instances (*i.e.*, 100%) give better result for the proposed algorithms.

6. CONCLUSIONS

In this paper, we presented two task consolidation algorithms for cloud computing systems. The algorithms have been shown to require $O(lm(f - s))$ time for l iterations. It was simulated on several datasets. The experimental results show that the proposed algorithms STC and DTTC reduce energy consumption to a greater extent. The results of the proposed algorithms outperforms FCFS in terms of two performance metrics namely, energy consumption and the total number of task completion.

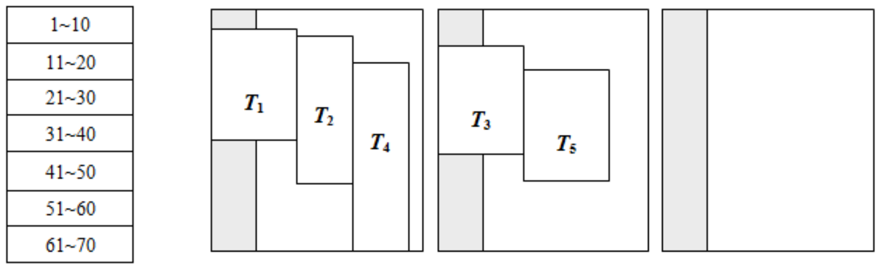

Figure 1. Task-VM Mapping for FCFS Algorithm

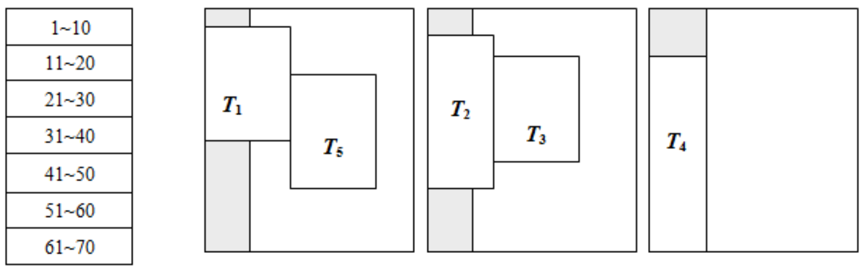

Figure 2. Task-VM Mapping for the proposed STC Algorithm

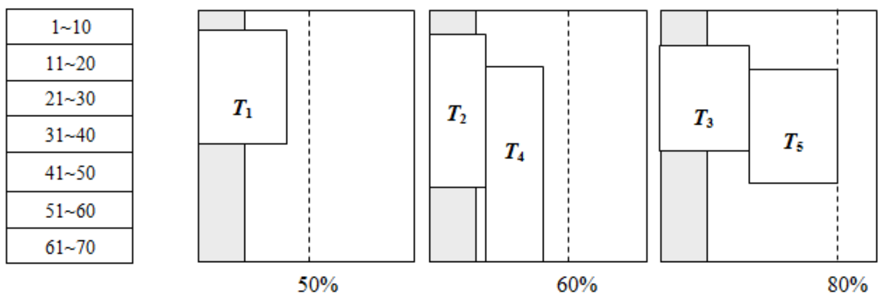

Figure 3. Task-VM Mapping for the proposed DTTC Algorithm

Table 9
Range of Experimental Parameters

Parameter	100_*ix_yy*	200_*ix_yy*	300_*ix_yy*	400_*ix_yy*	500_*ix_yy*
Start Time	[1-51]	[1-101]	[1-151]	[1-201]	[1-251]
Finish Time	[52-100]	[102-150]	[152-200]	[202-250]	[252-300]
Utilization	[1-30]	[1-30]	[1-30]	[1-30]	[1-30]
SLA	[40,70,100]	[40,70,100]	[40,70,100]	[40,70,100]	[40,70,100]

Table 10
Comparison of Energy Consumption and Task Completion for FCFS and STC using `100_`*ix_yy*

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
100_*i1_yy*	FCFS	4.7070e+05	6.9096e+05	7.6846e+05	TC-FCFS	70	95	100
	STC	4.4273e+05	6.3981e+05	6.6592e+05	TC-STC	72	96	100
100_*i2_yy*	FCFS	4.8159e+05	7.1054e+05	7.8787e+05	TC-FCFS	63	93	100
	STC	4.6445e+05	6.6832e+05	7.1259e+05	TC-STC	64	93	100
100_*i3_yy*	FCFS	4.3856e+05	6.5293e+05	7.3940e+05	TC-FCFS	62	92	100
	STC	4.0726e+05	5.7905e+05	6.2443e+05	TC-STC	65	92	100
100_*i4_yy*	FCFS	4.8546e+05	6.4652e+05	6.8577e+05	TC-FCFS	73	100	100
	STC	4.5164e+05	5.8738e+05	6.2663e+05	TC-STC	74	100	100
100_*i5_yy*	FCFS	4.7721e+05	6.9426e+05	7.7335e+05	TC-FCFS	66	93	100
	STC	4.3956e+05	6.2980e+05	6.7073e+05	TC-STC	66	93	100

Table 11
Comparison of Energy Consumption and Task Completion for FCFS and STC using `200_`*ix_yy*

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
200_*i1_yy*	FCFS	8.3310e+05	1.1957e+06	1.5411e+06	TC-FCFS	72	101	126
	STC	8.1908e+05	1.1616e+06	1.4987e+06	TC-STC	72	105	129
200_ *i2_yy*	FCFS	8.9115e+05	1.2996e+06	1.6548e+06	TC-FCFS	80	105	138
	STC	8.7508e+05	1.2651e+06	1.5994e+06	TC-STC	80	109	139
200_*i3_yy*	FCFS	9.0018e+05	1.3028e+06	1.6622e+06	TC-FCFS	65	101	131
	STC	8.8711e+05	1.2556e+06	1.5880e+06	TC-STC	65	102	132
200_*i4_yy*	FCFS	8.8066e+05	1.2835e+06	1.6568e+06	TC-FCFS	66	99	128
	STC	8.5795e+05	1.2376e+06	1.5757e+06	TC-STC	71	104	133
200_*i5_yy*	FCFS	8.7433e+05	1.2605e+06	1.6187e+06	TC-FCFS	65	98	127
	STC	8.6157e+05	1.2282e+06	1.5523e+06	TC-STC	69	102	130

Table 12
Comparison of Energy Consumption and Task Completion for FCFS and STC using `300_`*ix_yy*

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
300_*i1_yy*	FCFS	1.2997e+06	1.8922e+06	2.4356e+06	TC-FCFS	66	100	134
	STC	1.2841e+06	1.8408e+06	2.3740e+06	TC-STC	67	109	137
300_*i2_yy*	FCFS	1.2818e+06	1.8515e+06	2.3853e+06	TC-FCFS	67	98	132
	STC	1.2606e+06	1.8187e+06	2.3373e+06	TC-STC	71	102	139
300_*i3_yy*	FCFS	1.2813e+06	1.8681e+06	2.4192e+06	TC-FCFS	71	100	132
	STC	1.2603e+06	1.8422e+06	2.3774e+06	TC-STC	74	103	137
300_*i4_yy*	FCFS	1.3227e+06	1.9291e+06	2.4890e+06	TC-FCFS	72	106	141
	STC	1.3045e+06	1.8817e+06	2.4155e+06	TC-STC	75	112	149
300_*i5_yy*	FCFS	1.2981e+06	1.8791e+06	2.3982e+06	TC-FCFS	66	103	140
	STC	1.2832e+06	1.8434e+06	2.3410e+06	TC-STC	72	110	150

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Table 13
Comparison of Energy Consumption and Task Completion for FCFS and STC using 400_ix_yy

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
400_i1_yy	FCFS	1.7206e+06	2.4933e+06	3.2033e+06	TC-FCFS	68	105	136
	STC	1.7026e+06	2.4554e+06	3.1358e+06	TC-STC	74	111	146
400_i2_yy	FCFS	1.7304e+06	2.5234e+06	3.2662e+06	TC-FCFS	70	106	139
	STC	1.7094e+06	2.4908e+06	3.2213e+06	TC-STC	75	112	143
400_i3_yy	FCFS	1.7114e+06	2.4721e+06	3.1842e+06	TC-FCFS	70	106	140
	STC	1.7001e+0	2.4445e+06	3.1331e+06	TC-STC	70	109	146
400_i4_yy	FCFS	1.6953e+06	2.4739e+06	3.2148e+06	TC-FCFS	69	99	132
	STC	1.6678e+0	2.4439e+06	3.1606e+06	TC-STC	78	108	148
400_i5_yy	FCFS	1.7383e+06	2.5457e+06	3.3008e+06	TC-FCFS	69	100	128
	STC	1.7193e+06	2.4948e+06	3.2145e+06	TC-STC	73	109	142

Table 14
Comparison of Energy Consumption and Task Completion for FCFS and STC using 500_ix_yy

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
500_i1_yy	FCFS	2.1367e+06	3.1080e+06	4.0252e+06	TC-FCFS	72	108	139
	STC	2.1174e+06	3.0819e+06	3.9888e+06	TC-STC	80	113	148
500_i1_yy	FCFS	2.1530e+06	3.1354e+06	4.0648e+06	TC-FCFS	73	112	148
	STC	2.1314e+06	3.0994e+06	4.0017e+06	TC-STC	80	118	155
500_i1_yy	FCFS	2.1647e+06	3.1570e+06	4.1059e+06	TC-FCFS	75	110	138
	STC	2.1479e+06	3.1288e+06	4.0672e+06	TC-STC	82	118	146
500_i1_yy	FCFS	2.1630e+06	3.1638e+06	4.0798e+06	TC-FCFS	65	97	129
	STC	2.1472e+06	3.1315e+06	4.0222e+06	TC-STC	69	103	144
500_i1_yy	FCFS	2.1704e+06	3.1464e+06	4.0607e+06	TC-FCFS	66	103	140
	STC	2.1572e+06	3.1064e+06	3.9787e+06	TC-STC	67	107	143

Table 15
Comparison of Energy Consumption and Task Completion for FCFS and STC using 100_ix_yy

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
100_i1_yy	FCFS	5.7953e+05	9.3803e+05	1.0864e+06	TC-FCFS	70	95	100
	DTTC	5.1451e+05	8.0465e+05	1.0377e+06	TC-DTTC	71	95	100
100_i2_yy	FCFS	5.9359e+05	9.6516e+05	1.1144e+06	TC-FCFS	63	93	100
	DTTC	5.4912e+05	8.0611e+05	1.0549e+06	TC-DTTC	67	94	100
100_i3_yy	FCFS	5.3839e+05	8.8711e+05	1.0530e+06	TC-FCFS	62	92	100
	DTTC	4.8397e+05	7.5192e+05	9.6839e+05	TC-DTTC	65	92	100
100_i4_yy	FCFS	5.9765e+05	8.5794e+05	9.3969e+05	TC-FCFS	73	100	100
	DTTC	5.3969e+05	7.4875e+05	9.2086e+05	TC-DTTC	75	100	100
100_i5_yy	FCFS	5.8815e+05	9.4106e+05	1.0939e+06	TC-FCFS	66	93	100
	DTTC	5.3757e+05	8.3056e+05	1.0346e+06	TC-DTTC	66	93	100

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Table 16
Comparison of Energy Consumption and Task Completion for FCFS and STC using 200_*ix*_*yy*

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
200_*i*1_*yy*	FCFS	1.0188e+06	1.6058e+06	2.2551e+06	TC-FCFS	72	101	126
	DTTC	9.8541e+05	1.5314e+06	2.1162e+06	TC-DTTC	73	104	133
200_*i*2_*yy*	FCFS	1.0926e+06	1.7519e+06	2.4181e+06	TC-FCFS	80	105	138
	DTTC	1.0483e+06	1.6566e+06	2.2746e+06	TC-DTTC	80	111	142
200_*i*3_*yy*	FCFS	1.1042e+06	1.7538e+06	2.4271e+06	TC-FCFS	65	101	131
	DTTC	1.0785e+06	1.6680e+06	2.2883e+06	TC-DTTC	68	106	138
200_*i*4_*yy*	FCFS	1.0803e+06	1.7301e+06	2.4305e+06	TC-FCFS	66	99	128
	DTTC	1.0413e+06	1.6095e+06	2.2501e+06	TC-DTTC	71	105	134
200_*i*5_*yy*	FCFS	1.0703e+06	1.6939e+06	2.3664e+06	TC-FCFS	65	98	127
	DTTC	1.0319e+06	1.6113e+06	2.2074e+06	TC-DTTC	72	103	135

Table 17
Comparison of Energy Consumption and Task Completion for FCFS and STC using 300_*ix*_*yy*

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
300_*i*1_*yy*	FCFS	1.5905e+06	2.5448e+06	3.5605e+06	TC-FCFS	66	100	134
	DTTC	1.5612e+06	2.4613e+06	3.4368e+06	TC-DTTC	70	109	136
300_*i*2_*yy*	FCFS	1.5666e+06	2.4851e+06	3.4829e+06	TC-FCFS	67	98	132
	DTTC	1.5282e+06	2.4035e+06	3.3600e+06	TC-DTTC	72	107	142
300_i3_yy	FCFS	1.5668e+06	2.5118e+06	3.5418e+06	TC-FCFS	71	100	132
	DTTC	1.5357e+06	2.4466e+06	3.4230e+06	TC-DTTC	74	109	143
300_*i*4_*yy*	FCFS	1.6195e+06	2.5959e+06	3.6417e+06	TC-FCFS	72	106	141
	DTTC	1.5881e+06	2.5094e+06	3.4948e+06	TC-DTTC	74	115	147
300_*i*5_*yy*	FCFS	1.5884e+06	2.5244e+06	3.4948e+06	TC-FCFS	66	103	140
	DTTC	1.5579e+06	2.4501e+06	3.3685e+06	TC-DTTC	75	115	155

Table 18
Comparison of Energy Consumption and Task Completion for FCFS and STC using 400_*ix*_*yy*

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
400_*i*1_*yy*	FCFS	2.1054e+06	3.3490e+06	4.6734e+06	TC-FCFS	68	105	136
	DTTC	2.0762e+06	3.2794e+06	4.5373e+06	TC-DTTC	74	112	154
400_*i*2_*yy*	FCFS	2.1164e+06	3.3922e+06	4.7782e+06	TC-FCFS	70	106	139
	DTTC	2.0860e+06	3.3227e+06	4.6657e+06	TC-DTTC	74	115	151
400_*i*3_*yy*	FCFS	2.0917e06	3.3167e+06	4.6459e+06	TC-FCFS	70	106	140
	DTTC	2.0610e+06	3.2429e+06	4.5188e+06	TC-DTTC	73	114	156
400_*i*4_*yy*	FCFS	2.0735e+06	3.3265e+06	4.7089e+06	TC-FCFS	69	99	132
	DTTC	2.0345e+06	3.2614e+06	4.5851e+06	TC-DTTC	76	109	151
400_*i*5_*yy*	FCFS	2.1277e+06	3.4269e+06	4.8354e+06	TC-FCFS	69	100	128
	DTTC	2.0998e+06	3.3559e+06	4.7163e+06	TC-DTTC	72	110	145

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Table 19
Comparison of Energy Consumption and Task Completion for FCFS and STC using 500_*ix*_*yy*

	Algorithm	**10**	**15**	**20**	**Algorithm**	**10**	**15**	**20**
500_*i1*_*yy*	FCFS	2.6120e+06	4.1742e+06	5.8842e+06	TC-FCFS	72	108	139
	DTTC	2.5713e+06	4.0999e+06	5.7771e+06	TC-DTTC	81	116	156
500_*i2*_*yy*	FCFS	2.6333e+06	4.2134e+06	5.9458e+06	TC-FCFS	73	112	148
	DTTC	2.5989e+06	4.1380e+06	5.8404e+06	TC-DTTC	80	122	157
500_*i3*_*yy*	FCFS	2.6484e+06	4.2446e+06	6.0126e+06	TC-FCFS	75	110	138
	DTTC	2.6171e+06	4.1763e+06	5.8915e+06	TC-DTTC	81	122	144
500_*i4*_*yy*	FCFS	2.6462e+06	4.2548e+06	5.9620e+06	TC-FCFS	65	97	129
	DTTC	2.6167e+06	4.1867e+06	5.8587e+06	TC-DTTC	70	110	148
500_*i5*_*yy*	FCFS	2.6548e+06	4.2242e+06	5.9286e+06	TC-FCFS	66	103	140
	DTTC	2.6236e+06	4.1538e+06	5.8116e+06	TC-DTTC	75	115	156

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