An Integrated Power Consumption Model for Distributed Systems

SEMINAR REPORT

submitted by

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for the award of the degree

of

Bachelor of Technology

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
GOVERNMENT ENGINEERING COLLEGE SREEKRISHNAPURAM

PALAKKAD - 678633

April 2013

CERTIFICATE

This is to certify that the seminar report entitled **An Integrated Power Consumption Model for Distributed Systems** submitted by **SANAL DAVIS** to the **Department of Computer Science and Engineering, Government Engineering College, Sreekrishnapuram, Palakkad - 678633**, in partial fulfilment of the requirement for the award of B.Tech Degree in Computer Science and Engineering is a bonafide record of the work carried out by him.

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Acknowledgement

First and foremost I wish to express my wholehearted indebtedness to God Almighty for his gracious constant care and blessings showered over me for the successful presentation of the seminar.

I am deeply indebted to Dr. P.C Reghu Raj, Head of the Department of Computer Science and Engineering, Govt. Engineering College Sreekrishnapuram, for providing and availing me all the required facilities for undertaking the seminar in a systematic way.

I am also thankful to Mr. Ali Akbar, Lecture of Computer Science and Engineering, Govt. Engineering College Sreekrishnapuram, for his well co-ordination of the seminar and availing me all the required facilities for undertaking the seminar.

Gratitude is extended to all teaching and non teaching staff of the Department of Computer Science and Engineering, Govt Engineering College Sreekrishnapuram for the sincere directions imparted and the cooperation in connection with the seminar.

I am also thankful to my parents for the support given in connection with the seminar. Gratitude may be extended to all well-wishers and friends who supported me to present over the seminar.

Table of Contents

List of Figures

Abstract

In order to realize green ecosocieties, the total electric power consumption of computers and networks is required to be reduced. In applications on distributed systems, clients issue service requests to servers and then servers send replies to clients. Here, we discuss how much electric power a server consumes since the power consumption of a client is neglectable compared with a server. We classify applications into transaction- and communication-based ones. A server mainly consumes CPU resources to perform the transaction-based applications. On the other hand, a server consumes communication resources to transmit a large volume of data to a client in communication-based applications. In our previous studies, the power consumption laxity-based and extended power consumption-based algorithms are proposed to select one of servers so that the total power consumption of servers is reduced for transaction- and communication-based applications, respectively. However, most applications are mixed types, i.e., composed of both the transaction and communication processing modules. Hence, we consider the mixed types of applications in this paper. First, we integrate the power consumption models of transaction- and communication-based applications into a modified simple power consumption(MSPC) model of a server. Based on the MSPC model, we propose an algorithm to select one of servers for mixed types of applications so that the total power consumption of servers can be reduced. We show the power consumption of servers can be reduced in the algorithm through the simulation.

CHAPTER 1

Introduction

In digital control systems, huge volume of data is gathered from various kinds of system components such as computers, networks, and sensors. In order to realize these digital control systems, high-performance and scalable computing systems are required. Scalable information systems are composed of huge number of servers and consume a large amount of electric power. In 2010, the Google data centers consumed the electric power 2 259 998 MWh for a year, which is about 1 percentage of the electricity usage of data centers in the world. So, it is critical to reduce the total electric power consumption of computers and networks.

Various hardware technologies, such as energy-efficient CPUs are now developed to reduce the power consumption of a server. Even if the power consumption rate of each hardware device could be made clear in a computer, it is difficult, maybe impossible, to estimate the total power consumption of a whole server by synthesizing the power consumption rates of the devices since the power consumption of the computer depends on what kind of software like application processes are performed. In this paper, we would rather discuss software-oriented aspects of information systems to reduce the electric power consumption of a set of servers to realize the high-performance and scalable digital control systems.

There are various kinds of applications on distributed systems such as Web applications and Google file systems. In applications are classified into transaction-and communication-based applications. In the transaction-based applications, a client issues a request to a server, and the server mainly consumes CPU resources to process the request. Scientific applications are typical examples of the transaction-based applications. On the other hand, a server transmits a large volume of data to a client in the communication-based applications such as file transfer protocol applications. In the power consumption laxity-based (PCLB) and extended power consumption-based (EPCB) algorithms are proposed to select one server in a cluster of servers so that the total power consumption of servers can be reduced for each of transaction-and communication-based applications, respectively.

In reality, most applications are composed of both the transaction and communication processing modules such as the Deflate module on Apache 2.0. Suppose a client c_s issues a request to a Web server s_t that is implemented in Apache 2.0 to obtain Web pages including data satisfying the request. On receipt of the request, the Web server s_t obtains data in requested Web pages and compresses the data into a file f by using the Deflate module. Then, the Web server s_t transmits the compressed file f to the requesting client c_s . In this paper, we consider a general type of application that is composed of transaction and communication processing modules. In the PCLB and EPCB algorithms, the total power consumption of servers cannot be reduced for applications of general type.

In order to propose an algorithm to select one of servers so that the total power consumption of the servers is reduced for applications of the general type, it is necessary to define the computation model, the transmission model, and the power consumption model of a server to perform the general type of application processes. First, we measure the power consumption of types of servers to perform application processes of the general type. By abstracting essential parameters dominating the power consumption of a server in the experimental results, we integrate the power consumption models for transaction-and communication-based applications into one general modified simple power consumption (MSPC) model of a server. Based on the MSPC model, we newly propose an extended power consumption laxity-based (EPCLB) algorithm to select one of servers so that the total power consumption of servers can be reduced. We evaluate the EPCLB selection algorithm compared with the round-robin (RR) algorithm in terms of total power consumption and total transmission time. Types of RR algorithms are widely used in load balancers in clouds of servers, particularly Web servers to achieve performance objectives such as response time but no power consumptionobjective. We show the power consumption of servers can be reduced to 71 percentage of the RR algorithm, whereas the performance is the same as the RR algorithm.

CHAPTER 2

Simple Power Consumption (SPC) model

In order to reduce the power consumption of a server, Intel produces Xeon processor 5600 series, where the power consumption can be automatically regulated so that server performance is adjusted for traffic. Advanced MicroDevices (AMD), Inc. also produces Opteron processors where the power efficiency is improved. In a JXTA-based P2P platform that can be used not only for efficient and reliable distributed computing in cyber world but also for collaborative activities and ubiquitous computing by integrating the platform end-devices. In wireless sensor networks and ad hoc networks, routing algorithms to reduce the power consumption of the battery in each node are discussed. Bianchini and Rajamony and Heath et al,discuss how to reduce the power consumption of a data center with a cluster of homogeneous server computers by turning off servers that are not required for executing a collection of Web requests.

In order to reduce the total power consumption of a collection of servers, it is critical to discuss how to select a server for each request in addition to turning off servers. In addition, peers that support service cannot be turned off without agreement of the owners in P2P overlay networks. In a pair of the simple model and the multi-level model for computation and power consumption of a server in transaction-based applications are discussed by abstracting essential parameters that dominate the power consumption of the server from experimental results of computers. In the simple power consumption (SPC) model, a server maximally consumes the electric power as long as at least one application process is performed. In order to reduce the total power consumption, it is critical to discuss how to select a server for each request in a pool of possible servers. There are many algorithms to select a server. Types of RR algorithms are widely used in load balancers in clouds of servers, particularly Web servers. However, the algorithms aim at achieving objectives on performance such as minimization of response time and maximization of throughput but not reduction in power consumption. It is critical to discuss a novel algorithm to select a server in a set of possible servers so that the total power consumption of the servers can be reduced. The computation laxity and the power consumption laxity for transaction-based applications are defined. The computation and power consumption laxities show how much computation and electric power a server has to spend to finish a request process. The laxity-based (LB) algorithm is proposed to select a server in a collection of servers for a request process so as to not only satisfy a deadline constraint but also reduce the total power consumption of servers on the basis of the laxity concept. In the LB algorithm, a server that consumes the minimum power consumption is selected for a request process. However, in the computation model, the computation degradation ratio is not considered. The computation rate of a server depends on the number of concurrent processes performed on the server. If more number of processes are concurrently performed on a server, the computation rate of the server is degraded due to overhead like process switch, and it takes a longer time to perform each of the processes on the server. In the computation and power consumption models are improved by considering the computation degradation ratio of a server. As the result, the computation and power consumption laxities can be correctly estimated for transaction-based applications. Here, the PCLB algorithm is proposed to select a server in a collection of servers so as to not only satisfy a deadline constraint but also reduce the total power consumption of servers on the basis of the improved laxity concept. In the PCLB algorithm, the power consumption of servers and total computation time can be more reduced than the LB algorithm and the traditional RR algorithm since the computation and power consumption laxities can be more correctly estimated.

On the other hand, a power consumption model for servers to transmit files to clients is discussed, where the electric power consumption of the server depends on the total transmission rate of the server through the experimental results.In the approximated linear function to show how much electric power a server computer consumes for the transmission rate is derived from the experimental studies of file transfer between servers and clients. In the power consumption-based (PCB) algorithm is proposed to select a server in a collection of possible servers so that the total power consumption can be reduced for communication-based applications based on the power consumption model. In the PCB algorithm, a server is selected for a client where the estimated power consumption to transmit a file to the client is the smallest.In the PCLB algorithm is evaluated in terms of the total power consumption of servers and the total transmission time of files compared with the traditional RR algorithm. According to the evaluation results, the total power consumption and the total transmission time can be reduced in the PCB algorithm compared with the RR algorithm. However, only the power consumption of a server st that transmits a file f to a client cs at time when the server st starts transmitting the file f is considered in the PCB algorithm. Therefore, the power consumption of the server st that transmits files to other clients has to be considered for estimating the total power consumption of the server st to transmit the file f to the client cs . The EPCB algorithm is proposed by improving the PCB algorithm by taking into consideration how much amount of power a server consumes to transmit files to every requesting client. According to the evaluation results, the total power consumption can be reduced in the EPCB algorithm compared with the PCB algorithm. The difference in the total transmission time of the EPCB and PCB algorithms is neglectable. Therefore, the EPCB algorithm is more useful than the PCB algorithm for reducing the total power consumption in the communication-based applications.

The power consumption models can adopt to only one of the transaction- and communication-based applications but not to both of them. In this paper, we propose a general power consumption model of a server to perform both transaction- and communication-based applications. The PCLB and EPCB algorithms cannot be adopted to the general type of applications where both transaction and communication modules are performed. In this paper, we propose an algorithm to select one of servers so that the total power consumption of servers can be reduced for general type of applications. To the best of our knowledge, there has not been any other work on making a power consumption model and developing algorithms to select a server for each request so that the total power consumption can be reduced.

CHAPTER 3

Experimentations

3.1 Experimental Environment

Here, show the experimental results for defining the computation model, the transmission model, and the power consumption model of a server to perform general type of application processes. In the computation model, the transmission model, and the power consumption model of a server for the general type of application based on the experimentations.

We consider a general type of application that is composed of both the transaction and communication processing modules such as Web applications using a Deflate function. Fig.3.1 shows the experimental environment. Here, a server s_1 is interconnected with three clients c_1 , c_2 , and c_3 in 1-Gb/s networks. The bandwidth $b_1 s$ from a server s_1 to each client c_s is 1 Gb/s. fig 3.2 shows the specification of the server s_1 . The server s_1 holds data d, whose size is 544 MB long. Each client c_s issues a request to the server s_1 to obtain the data d (s = 1, 2, 3). On receipt of the request from a client c_s , the server s_1 compresses the data d to a file f_s , and then, the server s_1 transmits the compressed file f_s to the client c_s . The size of each compressed file f_s is 530 MB.

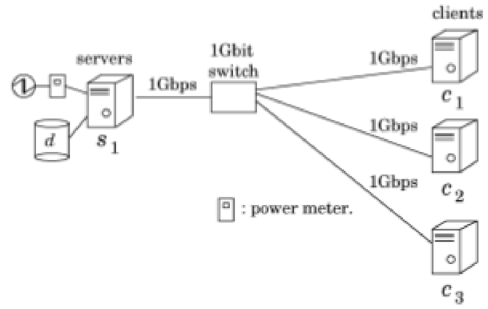

Figure 3.1: Experimental environment

Server	s_1
Number of CPUs	1
Number of cores / CPU	1
CPU	AMD Athlon 1648B (2.7GHz)
Memory	4,096MB
DISK	150GB 7200rpm
NIC	Broadcom Gbit Ether (1Gbps)

Figure 3.2: Server s_1

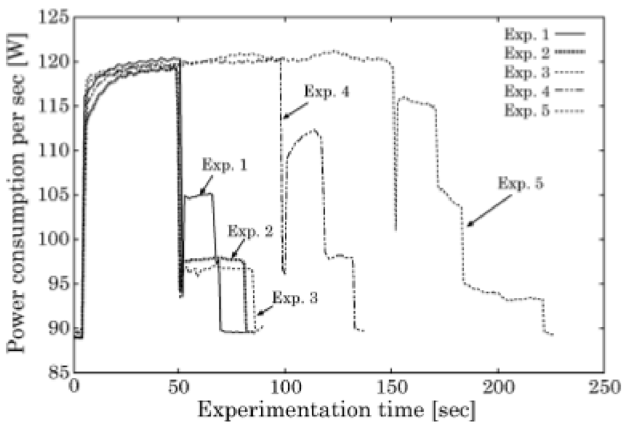

Figure 3.3: Graph-Concurrent executions of requests

Experimentations (Exp.)	Compression time [sec]	Power consumption rate of compression [W]	Transmission rate [Mbps]	Power consumption rate of transmission [W]	Transmission time [sec]
1	46	120	241	105	18
2	44	119	140	98	30
3	45	119	124	97	34
4	93	120	234 (c_1) 131 (c_2)	112 (c_1 and c_2) 99 (c_2)	18 (c_1) 33 (c_2)
5	146	121	219 (c_1) 137 (c_2) 61 (c_3)	116 (c_1, c_2, and c_3) 106 (c_2 and c_3) 95 (c_3)	19 (c_1) 31 (c_2) 69 (c_3)

Figure 3.4: Table-Concurrent executions of requests

3.2 Concurrent Execution of Requests

First, we measure how much electric power the server s_t consumes to perform the following five types of experimentations by using the power meter

1. a client c_1 issues a request to the server s_1 ;
2. a client c_2 issues a request to the server s_1 ;
3. a client c_3 issues a request to the server s_1 ;
4. a pair of clients c_1 and c_2 concurrently issues requests to the server s_1 ;
5. three clients c_1 , c_2 , and c_3 concurrently issue requests to the server s_1 ;

Fig. 3.3 shows the power consumption rate (in watts) for experimentation time (in seconds). fig 3.4 summarizes the processing time, the transmission time, and the power consumption rate obtained in the experimental results. It takes 46,44, and 45 s to compress the data in Experimentations 1, 2, and 3, respectively. On the other hand, it takes 93 and 146 s in Experimentations 4 and 5, respectively. It takes 2.1 and 3.2 longer time to compress the data in Experimentations 4 and 5, respectively, than in Experimentations 1, 2, and 3. According to the experimentations, the concurrent executions of compression processing modules of multiple files follow the simple computation (SC) model. That is, any process is performed on a server with the maximum clock frequency. The more number of processes are concurrently performed, the larger computation resource is consumed and the longer it takes to perform all the concurrent processes due to overhead like process switch.

The server s_1 consumes the electric power to compress the data at rates 120, 119, 119, 120, and 121 W in Experimentations 1, 2, 3, 4, and 5, respectively. Following Fig. 3.4, the power consumption of the compression processing module follows the SPC model. That is, if at least one compression process is performed on a server, the electric power is maximally consumed on the server s_1 . A server s_1 sends each client c_s a file f_s obtained by compressing the data. Hence, the size of each file f_s is the same, i.e., $|f1| = |f2| = |f3|$.

In Experimentations 1, 2, and 3, the average transmission rates of the server s_1 with clients c_1 , c_2 , and c_3 are 241, 140, and 124 Mb/s, respectively. The average power consumption rates during transmission in Experimentations 1, 2, and 3 are 105, 98, and 97 W, respectively. In Experimentation 4, the server s_1 transmits compressed files f_1 and f_2 to a pair of clients c_1 and c_2 , respectively, after the compression processing. Then, the server s_1 ends up the transmission of the file f_1 to the client c_1 before the transmission to the client c_2 . Here, the average transmission rates for clients c_1 and c_2 are 234 and 131 Mb/s, respectively. The total transmission rate at which the server s_1 concurrently transmits files f_1 and f_2 to a pair of the clients c_1 and c_2 is $365 (= 234 + 131)$ Mb/s. Here, theaverage power consumption rate is 112 W. The average power consumption rate at which the server s_1 transmits the file f_2 to a client c_2 is 99 W. In Experimentation 5, the server s_1 transmits compressed files f_1 , f_2 , and f_3 to three clients c_1 , c_2 , and c_3 , respectively, after the compression processing. Then, the server s_1 ends the transmission of the file f_1 to the client c_1 before other transmissions. Next, the transmission for the client c_2 is ended before c_3 . Here, the average transmission rates for the clients c_1 , c_2 , and c_3 are 219, 137, and 61 Mb/s, respectively. The total transmission rate at which the server s_1 concurrently transmits files f_1 , f_2 , and f_3 to three clients c_1 , c_2 , and c_3 is $417 (= 219 + 137 +$

61) Mb/s. This means that the maximum transmission rate of the server s_1 is 417 Mb/s. The transmission rate for the client c_3 (61 Mb/s) reduced to 51 percentage of the transmission rate (124 Mb/s) in Experimentation 3. In the experimentations, the total rate of the maximum receipt rates of three clients is larger than the maximum transmission rate (417 Mb/s) of the server s_1 . Hence, the transmission rate for the client c_3 is degraded. The average power consumption rate at which the server s_1 transmits files to three clients c_1 , c_2 ,and c_3 is 116 W. The average power consumption rate at which the server s_1 transmits the files f_2 and f_3 to a pair of clients c_2 and c_3 , respectively, is 106 W. The average power consumption rate at which the server s_1 transmits the file f_3 to the client c_3 is 95 W. According to the experimentations, the power consumption rate of the server s_1 depends on the transmission rate in the file transmission processing. In addition, the maximum power consumption rate of the server s_1 for transmitting the file is smaller than the maximum power consumption rate for compressing the data.

3.3 Concurrent Execution of Compression and Transmission

We consider how much amount of power a server s_1 consumes to concurrently perform the compression and transmission processes. The following three types of experimentations are concurrently performed with a computation process to compress data:

1. The server s_1 transmits the file f_1 to only a client c_1 ;
2. The server s_1 concurrently transmits the files f_1 and f_2 to a pair of clients c_1 and c_2 , respectively;
3. The server s_1 concurrently transmits the files f_1 , f_2 , and f_3 to three clients c_1 ,c_2 , and c_3 , respectively.

Fig.3. 5 shows the power consumption rate of a server s_1 for the experimentation time. fig 3.6 summarizes computation time and power consumption in the experimen-

tations (Exp). In Experimentations 1, 2, and 3, the transmission time is shorter than the compression time. Then, the power consumption rates of the server s_1 during the compression and transmissions in Experimentations 1, 2, and 3 are 120, 121, and 122 W, respectively. This means that even if the server s_1 transmits files concurrently to multiple clients, the server s_1 consumes the maximum power consumption as long as at least one compression process is performed. On the other hand, the more number of concurrent processes are performed, the longer is the compression time. In Experimentations 1, 2, and 3, it takes 46, 55, and 62 s to compress the data, respectively. If one more transmission process is additionally executed, it takes 1.2 longer time to execute the compression process. That is, the computation resource for a compression process is decreased if more number of current transmissions are executed. It takes similar time for a server s_1 to transmit files in Experimentations 1, 2, and 3, as presented in the preceding subsection. Hence, even if compression processes are concurrently performed with a transmission process, it takes almost the same time for the transmission process to transmit data. That is, transmission processes can be considered to be independent of computation processes in terms of the execution time.

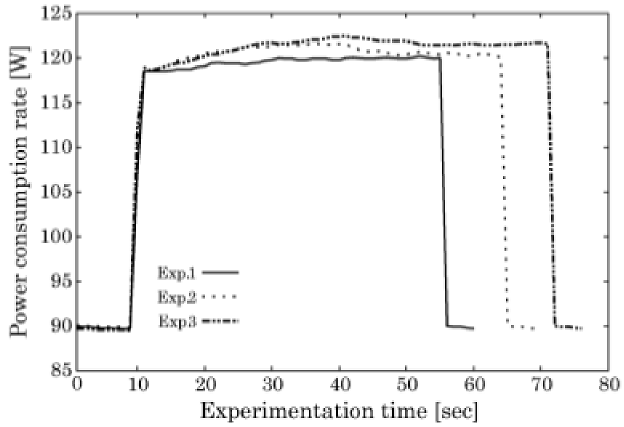

Figure 3.5: Power consumption rates for concurrent executions of compressions and transmissions.

Exp.	Compression time [sec]	Transmission rate [Mbps]	Transmission time [sec]	Power consumption rate [W]
1	46	240	18	120
2	55	217 (c_1) 134 (c_2)	20 32	121
3	63	212 (c_1) 134 (c_2) 71 (c_3)	20 32 60	122

Figure 3.6: concurrent execution of compression and transmissions

3.4 ClientServer Communication Model

Let S be a set of multiple servers $s1, ..., sn(n \geqslant 1)$, each of which provides the same data d like Web pages. Each server s_t holds a full replica of the data d. Let C be a set of clients $c1, ..., cm(m \geqslant 1)$ that issue requests to servers in the set S to obtain the data d. A client c_s issues a request to a load balancer K, as shown in Fig. 3.7. The load balancer K selects one server s_t in the server set S and forwards the request to the server s_t . On receipt of a request, the server s_t performs the request as a process that manipulates the data d. Then, the server s_t transmits a reply file f_s to the requesting client c_s . Each request is performed as a process p_i in the server s_t .

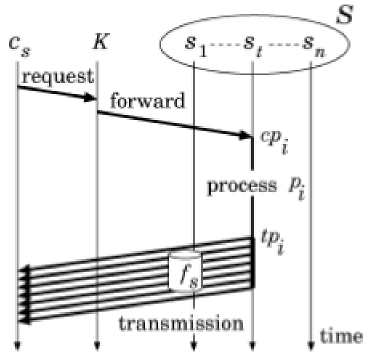

Figure 3.7: Clientserver communication model

A term process means an application process created for a request in this paper. A process being performed at time is current. A process that already terminates before time is previous. A process is composed of a pair of a computation subprocess cp_i and a transmission subprocess tp_i . The computation process cp_i mainly consumes CPU resource. On the other hand, a reply file is transmitted to a requesting client in the transmission process tp_i . A process p_i is, thus, composed of a pair of cp_i and tp_i , i.e., $p_i = cp_i$, tp_i .

CHAPTER 4

Power Consumption Model

We introduce the following parameters to discuss the electric power consumption of a server $s_t (t = 1, ..., n)$:

- max E_t = maximum electric power consumption rate of the server s_t (in watts).
- min E_t = minimum electric power consumption rate, i.e., the server s_t is in idle state (in watts).
- $E_t(\tau)$ = electric power consumption rate of the server s_t at time τ (in watts), where min $E_t \leqslant E_t(\tau) \leqslant$ max E_t .

According to the experimentations, a power consumption rate $E_t(\tau)$ of a server s_t depends on the total transmission rate if only transmission processes are performed on the server s_t . The electric power consumption rate $PC_t(tr(\tau))$ of a server s_t at time τ, when only transmission processes are being performed and the total transmission rate is $tr(\tau)$, is given as follows:

$$PC_t(tr_t(\tau)) = \beta_t(|NT_t(\tau)|) \;\; \delta_t \;\; tr_t(\tau) + \min E_t .$$

Here, δ_t is the power consumption rate to transmit 1 Mb (in watts per megabit).δ_t depends on a server s_t . m shows the number $|NT_t(\tau)|$ of transmission processes in the server s_t . $\beta_t(m)$ shows how much power consumption rate is increased for the number m of transmission processes, $\beta_t(m) \geqslant 1$ and $\beta_t(m) > \beta_t(m\text{-}1)$. There is a fixed point max m_t such that $\beta_t(\max m_t - 1) \leqslant \beta_t(\max m_t) = \beta_t(\max m_t + h)$ for $h \;\; 0$. The number max m_t shows the maximum number of transmission processes that can be performed on a server s_t . min E_t gives the minimum power consumption rate of the server s_t where no file is transmitted. max PC_t $=\beta_t$ (max m_t) δ_t Maxtr_t + min E_t gives the maximum power consumption rate max E_t of the server s_t for transmission processes.

According to the experimentations, even if a server s_t concurrently transmits files to multiple clients at the same time,the server s_t consumes the power at a maximum rate if at least one compression process is performed. In addition, the maximum power consumption rate max PC_t of a server s_t for the transmission processes is smaller than the maximum power consumption rate max E_t for the computation process. Here, we propose an MSPC model for a server s_t of the SC model.[MSPC model]

- max $E_t \geqslant$ max PC_t $(tr) \geqslant$ min E_t , where tr is the total transmission rate of a server s_t
- The power consumption rate E_t (τ) (in watts) of a server s_t at time τ is

  E_t $(\tau) =$

$$
\begin{array}{ll}
\max E_t, & \text{if } NC_t(\tau) \geqslant 1 \\
PC_t(tr_t(\tau)), & \text{if } NC_t(\tau) = 0 \text{ and } NT_t(\tau) \geqslant 1 \\
\min E_t, & \text{otherwise}
\end{array}
$$

This means, if at least one computation process cp_i is performed on a server s_t , the electric power is maximally consumed on the server s_t . If only transmission processes are performed on the server s_t , the power consumption rate of the server s_t depends on the total amount of transmission rates to the clients. If no process is performed on the server s_t , E_t $(\tau) =$ min E_t .The power consumption TE_t (τ_1 , τ_2) (in watt-seconds) of a server s_t from time τ_1 to time τ_2 is given as follows:

$$TE_t(\tau_1, \tau_2) = \oint E_t(\tau).\ d\tau$$

CHAPTER 5

Conclusion

In order to realize the digital control systems, high performance and scalable computing systems are required since huge volume of data is gathered and processed to control systems. Higher performance and scalable systems are composed of huge number of servers and consume a large amount of electric power. In this paper, we have discussed how to reduce the electric power consumption of a set of servers to realize the high-performance and scalable computing systems in green IT technologies.

In the previous studies the power consumption models for each of the transaction- and transmission-based applications are discussed. The PCLB and EPCB algorithms are proposed to select one of servers so that the total power consumption of the servers is reduced for transaction- and communication-based applications, respectively. In this paper,we consider general types of applications where both transaction and communication processing modules are performed. It is critical to make a formal model to discuss the power consumption of a server. First, we proposed the novel integrated model named the MSPC model for showing the computation and power consumption of a server where general types of application processes are performed, i.e., with not only computation but also transmission. Based on the MSPC model, we proposed the EPCLB algorithm to select one of servers so that the total power consumption of servers is reduced.

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