2015 International Conference on Computational Science and Computational Intelligence

# A Taxonomy and Survey of Green Data Centers

*Aryan Azimzadeh*
Department of Computer Science
East Carolina University
Greenville, NC 27858

*Nasseh Tabrizi*
Department of Computer Science
East Carolina University
Greenville, NC 27858

***Abstract*—An issue of great concern as it relates to global warming is power consumption and efficient use of computers especially in large data centers. Green computing is emerging as a solution to this problem as evidenced by a recent boom in publications in this area including those articles published between 2009 and 2014. Here we classify these recent publications by subject, fields of application, and recommended techniques and further categorize them according to environmental, timing, algorithms, and other aspects. We compare and analyze proposed green computing solutions in terms of features like server system power management, green cloud computing employing various types of energy efficient algorithms, data center cooling systems, and processor architecture. We explore future directions in the field and present a guideline for those interested in green computing.**

***Keywords— Energy Consumption, Data Centers.***

## I. Introduction

The concept of green computing is to save energy, improve efficacy, and achieve environmental protection and energy saving [1]. Recent advances have yielded huge improvements in both desktop and server computer technology. However, at the same time, we are facing with contributing problems that relates to computer system, including the energy consumption, exhausted emissions, building resources, high maintenance costs, global warming and high water enterprise [2, 3].

Green computing can reduce the energy consumption of computer system, improve their operational efficiency, emissions and increase recycling efficiency, which will achieve the environmental protection and conservation of energy [4]. From technical aspects, Green computing can be studied in software and hardware technologies. Software technology includes design methods that enhance program efficiency, computing models such as High Performance computing, Distributed computing, and Cloud computing. Hardware aspects include technologies that reduce energy consumption, emissions footprint, and can increase economic efficiency and recycling technology.

Energy consumption is now the major issue for data centers. The results of study showed that data centers consume about 2.8% of the total electricity in the USA [5], moreover these centers' energy consumption represents about 3% of global energy use [6]. The main consumers of power within data centers are cooling systems and computing resources. Researchers estimate that cooling is around 30 % of total energy consumption [7].

The green data center study is classified into the following categories: computing, cooling, georaphical, and network. In this study we consider the recent approaches in data centers form energy prospective. The remainder of the paper is organized as follow. In section II we discuss current research related to improving the energy efficiency of data centers, and conclude this paper in section III.

## II. Green Data Center Taxonomy

### A. Cooling

There is extensive literature supporting the approaches to make data centers greener. One aspect of these approaches is effect of climate condition, which is reported in [8, 9]. The authors have reported that evaporative cooling and the use of waste heat from IT equipment were sufficient to support direct fresh air-cooling system. They used two methods for fresh air cooling: indirect and direct fresh air cooling [8]. In another study the authors [9] present a methodology, which consists of classification of cooling efficiency from sampled sensor and calculation of the priority metrics from statistics on cooling efficiency classes. One can see the features of temperature variation in its inlet temperature and power consumption of IT equipment. To save cooling energy, historical sensor data was used to prioritize IT equipment for workload performance.

### B. Computing

The further studies in green data centers include Distributed Resource Management with temperature constraint [10] and Green Resource Management under Fault Tolerance constraint [11]. These studies propose new resource management algorithms to optimally control load distribution and reduce the operational costs of data centers. There are three major challenges to this approach. These include data centers' stringent IT peak power budget, over heating problems, and distributed resource management in data centers in highly desired for system scalability [10]. Other publications have focused on minimum energy consumption constraints to prevent SLA violation. Their results show that the energy increase by migration has an exponential relationship with the

978-1-4673-9795-7/15 $31.00 © 2015 IEEE
DOI 10.1109/CSCI.2015.70

failure rate [11]. A novel approach for managing power consumption in modern processors is dynamic voltage and frequency scaling. This allows processors to work at a suitable frequency, thus eventually reducing the energy consumption of servers [12-14]. Other approaches include the migration of virtual machines such that a minimum number of physical machines perform a specific task while the rest are kept idle [11]. The authors consider server failure when a server breaks down unusually and timing failure when processor can't finish a task in a specific time.

The two main approaches for reducing energy consumption in computer servers are dynamic voltage frequency scaling, and dynamic power management [15, 16]. While the dynamic voltage frequency and scaling focuses on optimizing the energy use of CPUs keeping the remaining server components function at their usual energy level, the dynamic power management focuses on saving energy by powering down all the server's components. The significant one is effectiveness of sleep states in data centers [17]. A different study proposes optimal power management for each server farm [18]. The method proposed reduces server power consumption by turning the servers to sleep mode. Performance metrics used in this method are delays and job blocking probability while minimizing the energy consumption. They discuss the advantages of sleep states by focusing on i. the variability in the workload trace, ii. how they use dynamic power management and at the end the size of the data centers. Their results show that sleep state enhances dynamic power management; correct sleep state management can thus be very effective in large data centers. In the related article the authors find out how many servers to keep active and how much workload to delay to maximize energy saving while meeting their latency constraint. In this method they focused on how large of a workload they can execute at a given time and how much of the workload can be deferred to a later time. This research contributes an LP formulation for capacity provisioning by using dynamic management on deferent workloads this method determines when and how much workload each server should take . It also presents their designs, which are optimization-based online algorithms relying on the latency requirement [19]. Other authors propose finding the minimum number of servers that should be active at a specific time to meet the necesary requirements. They explore offline and an online solution called "lazy capacity provisioning" is proposed exploited from the offline solution. Their findings show that the lazy capacity materials are 3-competitive that it gives a substandard solution not larger than 3 times the optimal solution [20].

One of the effective approaches in computing aspect of green data centers is power mapping management. The authors [21] show a new technique that reduces by over an order of magnitude the amount of signaling power necessary to less than 2.5W. They show that USB device is able to generate a signal allowing non-intrusive plan(s) to identify the power connectivity of a system.

The related work to reduce CO2 emission in data centers is about the architecture of integrated gas district cooling [22]. One of the approaches in this area is to introduce the chilled water supply gap model and approaches show a combined gas district cooling and data center control model. Their results show the precision of their model strongly depends on the difference between room and outdoor temperature, and functioning steam absorption chillers. Their work suggests gas district cooling with room and outdoor temperature sensor; steam absorption chillers and heat storage tank can reduce CO2 emission.

Using optimized MapReduce energy efficiency the researchers successfully reduced energy consumption by focusing on reducing the energy impact of data movement [23]. They proposed an analysis framework for evaluating costly built in MapReduce data movement. They use a Hadoop MapReduce computer cluster to evaluate the energy efficiency of MapReduce data movement and manage the power and energy of the three major MapReduce data movements: Hadoop file system read, Hadoop file system write, and data shuffle. The reasons why they focused on data movement are: a) Data movement consumes a lot of energy in data centers because it keeps computer servers waiting for data, b) MapReduce right now is a very important major in data centers for large scale processing, c) efficient storing and processing of large scale data is a practical challenge to most data centers. Many studies have been conducted in this area, which include reducing the volume of data in motion using data compression, increasing data movement speed using high speed interconnects, and applying dynamic voltage and frequency scaling to reduce CPU power consumption during data movement [23].

### *C. Geographical Factors*

There have been some geographical studies related to green data centers. In [24] the authors propose a workload-scheduling algorithm to reduce brown energy consumption in geographically distributed data centers. They targeted different factors of green energy usage. Using their algorithm, users can dynamically schedule their workloads when the solar energy supply best satisfies their energy demand. This algorithm achieve the goal of 40% and 21 % less brown energy than other green approaches [24].

Further research on the geographical determinants of green computing proposes the idea to take wind farm location as an example to stabilize the variable and intermittent wind power. Their results are based on the real climate traces from 607 wind farms that can save 59.5% of energy. Their algorithm relies on the weight of the portfolio, which is out of renewable energy portfolio optimization. If the algorithm removes one location its weight is set to zero. and if it is selected by the algorithm its weight is assigned a percentage of the balance of the total installed capacity constructed there [25].

The review of our study is summarized in Table 1.

TABLE I. TAXONOMY SUMMARY OF GREEN DATA CENTERS

| ***Branch*** | ***Approach*** | ***Methodology*** | ***Comments*** | ***References*** |
|---|---|---|---|---|
| Cooling | equalizing effect of 1.3 degree C in server room thermal environment | Classification, Optimization | | [5] |
| Computing | Resource management with temperature constraints | Optimization | Good way to reduce temperature | [6] |
| Computing | Resource management under fault tolerance | Experimental, Optimization | Good to reduce operational cost | [7] |
| Computing | Effectiveness of sleep state | Experimental | Adaptive sleep modes | [13] |
| Computing | Server sleep scheduling | CMDP | Assign jobs to specific time slot | [14] |
| Computing | Server workload Delay scheduling | CMDP /Optimization | | [15] |
| Network | Power Mapping management | Simulation, Optimization | Reduce effective cost from power consumption | [17] |
| Architecture | Energy efficient gap model for gas district cooling systems | Simulation | Good method to reduce heat | [18] |
| Computing /Network | Optimizing Map Reduce energy efficiency | Optimization | Good For heterogeneous environment | [19] |
| Geographical /Cloud | Energy efficient workload scheduling | Optimization | | [20] |
| Geographical | Stabilizing the variable in wind farms | Analytical modeling | Suitable for big data centers | [21] |

## III. CONCLUSION

Data centers are consuming significant energy nowadays and most of concentrations are on data centers. much researche has been done untill now on hardware and software aspect of data centers to reduce the energy consumption and how to build the data centers more efficiently.

In this paper we presented recent advances in various areas of green data centers, focusing on techniques to reduce energy consumption. We brought up the recent studies on server idle and sleep modes and highlighted their methods. In practice it is hard to get ideal energy corresponding in data centers design. As we have previously shown, designing computing devices with multiple sleep states -each having different power consumption characteristics- is a good strategy.

We have highlighted recent cooling strategies in data centers and their methodologies to reduce energy consumption in Table 1. We also showed different aspect of green computing in data centers.

A large amount of scientists are currently developing green design and methods for data centers. The goal of this paper is to show the different aspects of green computing in data centers and show the importance of energy consumption in data centers.

## REFERENCES


[1] *Zhang, Xiaodan, Lin Gong, and Jun Li. "Research on green computing evaluation system and method." In Industrial Electronics and Applications (ICIEA), 2012 7th IEEE Conference on, pp. 1177-1182. IEEE, 2012.*

[2] Li, Qilin, and Mingtian Zhou. "The survey and future evolution of green computing." In *Proceedings of the 2011 IEEE/ACM International Conference on Green Computing and Communications*, pp. 230-233. IEEE Computer Society, 2011.

[3] http://www.zdnet.com.cn/server/2007/1210/676572.shtml.

[4] Guo Bing, Shen Yan, and Shao ZL, "The Redefinition and Some Discussion of Green Computing", Chinese Journal of Computers, vol. 32, Dec. 2009, pp. 2311-2319.

[5] www.cisco.com/en/US/prod/collateral/switches/ps5718/ps10195/ CiscoEMSWhitePaper.pdf •

[6] A. Rallo, "Industry Outlook: Data Center Energy Efficiency." [Online]. Available: http://www.datacenterjournal.com/it/industry-outlook-data-center-energy-efficiency/. [Accessed: 02-Sep-2014].

[7] Cavdar, Derya, and Fatih Alagoz. "A survey of research on greening data centers." In *Global Communications Conference (GLOBECOM), 2012 IEEE*, pp. 3237-3242. IEEE, 2012.

[8] Endo, Hiroshi, Hiroyoshi Kodama, Hiroyuki Fukuda, Toshio Sugimoto, Takashi Horie, and Masao Kondo. "Effect of climatic conditions on energy consumption in direct fresh-air container data centers." *Sustainable Computing: Informatics and Systems* (2014).

[9] Mase, Masayoshi, Jun Okitsu, Eiichi Suzuki, Tohru Nojiri, Kentaro Sano, and Hayato Shimizu. "Cooling efficiency aware workload placement using historical sensor data on IT-facility collaborative control." In *Green Computing Conference (IGCC), 2012 International*, pp. 1-6. IEEE, 2012.

[10] slam, Mohammad A., Shaolei Ren, Niki Pissinou, Hasan Mahmud, and Athanasios V. Vasilakos. "Distributed resource management in data center with temperature constraint." In *Green Computing Conference (IGCC), 2013 International*, pp. 1-10. IEEE, 2013.

[11] Ghoreyshi, Seyed Mohammad. "Energy-efficient resource management of cloud datacenters under fault tolerance constraints." In *Green Computing Conference (IGCC), 2013 International*, pp. 1-6. IEEE, 2013.

[12] Garg, Saurabh Kumar, Chee Shin Yeo, Arun Anandasivam, and Rajkumar Buyya. "Environment-conscious scheduling of HPC applications on distributed cloud-oriented data centers." *Journal of Parallel and Distributed Computing* 71, no. 6 (2011): 732-749.

[13] Von Laszewski, Gregor, Lizhe Wang, Andrew J. Younge, and Xi He. "Power-aware scheduling of virtual machines in dvfs-enabled clusters." In *Cluster Computing and Workshops, 2009. CLUSTER'09. IEEE International Conference on*, pp. 1-10. IEEE, 2009.

[14] Kim, Kyong Hoon, Rajkumar Buyya, and Jong Kim. "Power Aware Scheduling of Bag-of-Tasks Applications with Deadline Constraints on DVS-enabled Clusters." In *CCGRID*, vol. 7, pp. 541-548. 2007.

[15] Pouwelse, Johan, Koen Langendoen, and Henk Sips. "Energy priority scheduling for variable voltage processors." In *Low Power Electronics and Design, International Symposium on, 2001.*, pp. 28-33. IEEE, 2001.

[16] Benini, Luca, Alessandro Bogliolo, and Giovanni De Micheli. "A survey of design techniques for system-level dynamic power management." *Very Large Scale Integration (VLSI) Systems, IEEE Transactions on* 8, no. 3 (2000): 299-316.

[17] Gandhi, Anshul, Mor Harchol-Balter, and Michael Kozuch. "Are sleep states effective in data centers?." In *Green Computing Conference (IGCC), 2012 International*, pp. 1-10. IEEE, 2012.

[18] Niyato, Dusit, Sivadon Chaisiri, and Lee Bu Sung. "Optimal power management for server farm to support green computing." In *Proceedings of the 2009 9th IEEE/ACM International Symposium on Cluster Computing and the Grid*, pp. 84-91. IEEE Computer Society, 2009.

[19] Adnan, Muhammad Abdullah, Ryo Sugihara, Yan Ma, and Rajesh K. Gupta. "Energy-optimized dynamic deferral of workload for capacity provisioning in data centers." In *Green Computing Conference (IGCC), 2013 International*, pp. 1-10. IEEE, 2013.

[20] Minghong, Adam Wierman, Lachlan LH Andrew, and Eno Thereska. "Dynamic right-sizing for power-proportional data centers." *IEEE/ACM Transactions on Networking (TON)* 21, no. 5 (2013): 1378-1391.

[21] Ferreira, Alexandre, Wael El-Essawy, Juan C. Rubio, Karthick Rajamani, Malcolm Allen-Ware, and T. Keller. "BCID: An effective data center power mapping technology." In *Green Computing Conference (IGCC), 2012 International*, pp. 1-10. IEEE, 2012.

[22] Okitsu, Jun, Mohd Fatimie Irzaq Khamis, Nordin Zakaria, Ken Naono, and Ahmad Abba Haruna. "Toward an architecture for integrated gas district cooling with data center control to reduce CO 2 emission." *Sustainable Computing: Informatics and Systems* (2014).

[23] Wirtz, Thomas, Rong Ge, Ziliang Zong, and Zizhong Chen. "Power and energy characteristics of MapReduce data movements." In *Green Computing Conference (IGCC), 2013 International*, pp. 1-7. IEEE, 2013.

[24] Chen, Changbing, Bingsheng He, and Xueyan Tang. "Green-aware workload scheduling in geographically distributed data centers." In *Cloud Computing Technology and Science (CloudCom), 2012 IEEE 4th International Conference on*, pp. 82-89. IEEE, 2012.

[25] Dong, Chuansheng, Fanxin Kong, Xue Liu, and Haibo Zeng. "Green power analysis for geographical load balancing based datacenters." In *Green Computing Conference (IGCC), 2013 International*, pp. 1-8. IEEE, 2013.