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SPECIAL SECTION ON EMERGING TRENDS, ISSUES, AND CHALLENGES IN ENERGY-EFFICIENT CLOUD COMPUTING

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A Survey and Taxonomy of Energy Efficiency Relevant Surveys in Cloud-Related Environments

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ABSTRACT The problem of energy consumption in the cloud related environments has attracted a great deal of attention in research and industry communities. In the past ten years, a large number of studies have been done on energy efficiency algorithms, methods, strategies, or techniques. Over the past five years, many scholars have conducted surveys on those energy efficiency strategies from different perspectives. In this paper, we conduct a survey and build the taxonomy on current existing energy efficiency relevant surveys, that is, a survey on surveys of energy efficiency. We classify current existing surveys into five categories, including surveys on the energy efficiency of the whole cloud related systems, surveys on energy efficiency of the certain level or component of the cloud, surveys on all of energy efficient strategies, surveys on a certain energy efficiency techniques, and other energy efficiency related surveys. The survey and taxonomy on the energy efficient relevant surveys conducted in this paper provide comprehensive knowledge on the current level of this research filed. Furthermore, observations are exhibited by the statistic data graphs exacted from the investigated surveys. The observations hidden in those surveys on energy efficiency will make it clear the future research directions in the energy related research field. Future research directions are listed in the final section.

INDEX TERMS Energy consumption, cloud storage system, surveys and taxonomy, observations, energy efficiency.

I. INTRODUCTION

A. MOTIVATION

Currently, the volume of data is increasing at a rate of 50% every year, and the total volume of the data is predicted to reach 40ZB in 2020 [1]. The rapid increase in data volume has led to larger and larger storage systems, thus, the problem of the energy consumption in the cloud storage system is becoming more and more serious. The literature [2] has reported that the data center will consume more than 1000TWh energy in the next ten years (2013-2025), which will surpass the total energy consumption of Japan and Germany. And the percentage of the energy consumption by the data centers and cooling equipments will reach 5% of the total energy consumption in the world. In addition, increasing energy consumption brings with it high carbon and GHG (Greenhouse Gases) emissions. Figure 1 shows that energy consumption is a major GHG emitter [3].

With increasing energy prices and data center scaling, the high energy consumption has become an impediment to the development of the data center. Therefore, the energy efficiency is the necessary not only to reduce the operational costs of the data center but also to improve the environment. The energy efficiency optimization problem in data centers and the cloud-related components has attracted a great deal of attention recently. Many of the researchers propose or design various algorithms or strategies to reduce the energy consumption of cloud-related components. Energy-aware software techniques, such as, workload consolidation [4], [5], job or task scheduling [6]–[8], data concentration [9], data placement [10], data replication [11], [12],

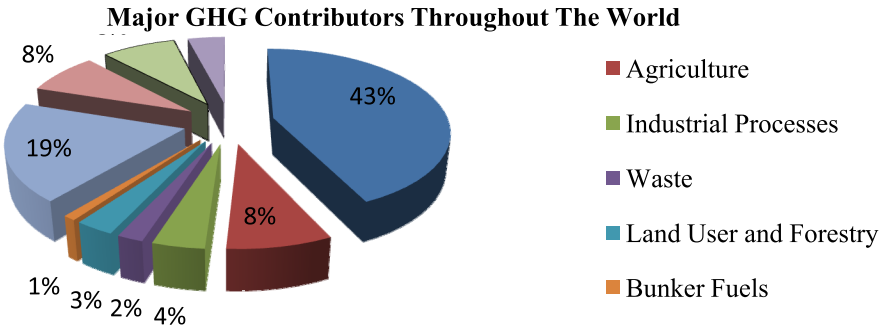

FIGURE 1. Different industrial sectors and service contribute to the GHG emissions.

VM consolidation [13], [14], VM migration [15], [16] and VM scheduling [17], [18] etc are utilized to improve energy efficiency in the cloud related environment. And the energy efficient hardware techniques [19], [20] are adopted in the related component, such as multi-speed disks, SSD disks, DVFS-enabled CPU and Flash memory etc. The above mentioned software techniques and hardware components are utilized to improve the energy efficiency of the clouds from the different layer, such as application layer [21], data center layer [22], [23], cluster layer [24], [25], RAID layer [26], [27], Node layer [28], Virtualization Layer [29], [30], OS layer [31], Processor Layer [32], [33], Disk Layer [34], [35], Memory Layer [36], [37] and Network Layer [38], [39] etc. Figure 2 summarizes the different energy efficient techniques and the different layers with energy efficient techniques employed.

The techniques or strategies employed in the different layers or components of the clouds have a favorable impact on the energy efficiency of the clouds to some degree. However, the energy proportionality is a persistent pursuit in the developing clouds and data centers. Much improvements still necessary in reducing the energy consumption or improving energy efficiency. In this paper we address ways of improving energy efficiency in the cloud-related environments. As many studies have been performed on the energy efficiency in the cloud-related environments, there are many perspectives on this subject. However, according to our observations, there are no surveys or taxonomies on energy-aware data management strategies And the surveys and taxonomies of improving energy efficiency utilizing the data management strategies, such as data classification, data placement and data replication can create more opportunities to reduce the energy consumption in the cloud-related environments, especially for the data-intensive related applications in developing data centers. Therefore, the survey and taxonomy on energy-aware strategies may be the subject matter of future work, whose purpose is saving energy consumption in the cloud storage systems.

B. FOCUS OF THE SURVEY

There are many related surveys on the energy efficiency in the cloud-related environments. These include surveys on reducing energy consumption in whole clouds, surveys on improving energy efficiency utilizing different techniques or strategies, surveys on reducing energy consumption in the certain component of the clouds (such as disks, CPUs, memory and networks etc.), the surveys on improving energy efficiency on a specific layer (such as IaaS layer and PaaS layer etc.), and surveys on reducing energy consumption through specific techniques or strategies (such as, energy-aware scheduling, energy-aware work load consolidation, energy-aware VM migration and energy-aware VM scheduling etc.). The focus of this survey is classifying current existing surveys into different categories, which will provide additional comprehensive knowledge to the energy efficiency researching.

C. OUR GOALS AND CONTRIBUTIONS

Our survey aims to graph the current level of research on energy efficiency and discover future directions to achieve additional energy consumption savings in the cloud-related environments. In order to achieve these goals, we conduct a survey on the current existing energy efficiency relevant surveys and classify them into different categories from different perspectives. On the whole, the main contributions of this paper are as follows:

1) *A comprehensive investigation of energy efficiency relevant surveys on the cloud is conducted;*
2) *Current existing energy efficiency surveys are classified into five categories from different perspectives;*
3) *Observations are exhibited by statistical data graphs that are exacted from those surveys;*
4) *Future research on how to comprehensively reduce energy consumption is suggested in this paper.*

II. ENERGY EFFICIENCY-RELEVANT SURVEYS IN CLOUD-RELATED ENVIRONMENTS

As mentioned before, the energy efficiency issue has attracted a great deal of research on. Researchers have tried to reduce energy consumption to improve the energy efficiency by utilizing the different energy-aware strategies, energy-enabled techniques and energy savings algorithms from various perspectives. Therefore, many surveys and taxonomies of have been done on energy efficiency in the cloud

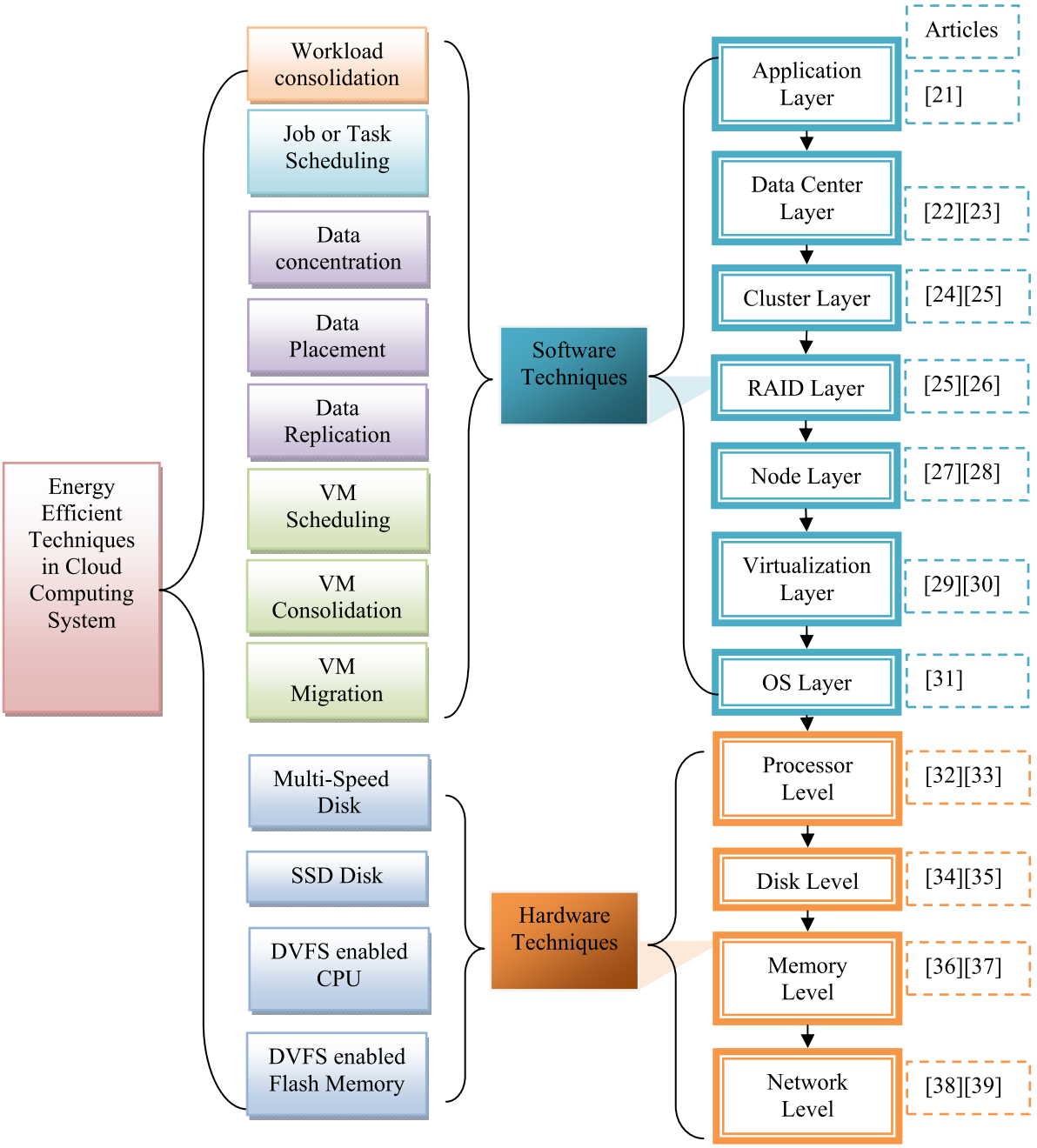

FIGURE 2. Different energy efficient techniques with different layer employed.

related environments. There are surveys on reducing energy consumption in whole clouds, surveys on different techniques or strategies to improve energy efficiency, surveys on reducing energy consumption in certain components of the clouds (such as disks, CPUs memory and networks etc.), surveys on improving energy efficiency at a specific layer (such as the IaaS layer and PaaS layer etc.) and surveys on reducing energy consumption through specific techniques or strategies (such as energy-aware scheduling, energy-aware work load consolidation, energy-aware VM migration and energy-aware VM scheduling). The survey and taxonomy of the energy efficiency related surveys are described in this section.

A. SURVEYS ON ENERGY EFFICIENCY OF THE WHOLE CLOUD-RELATED SYSTEMS

A.Beloglazov et al firstly surveyed the energy-efficient data centers and cloud and cloud computing systems [40]. They comprehensively summarize the energy efficient or power reduction techniques from the layers of the

hardware/firmware, the operating system, virtualization and the data center. Furthermore, the energy efficient techniques (such as DCD, DVFS, Resource throttling, workload consolidation) in each layer are described according to the different workload types (such as Arbitrary, Real-time application, and HPC application), different goals (such as Minimize power/energy consumption, minimize performance loss, meet power budget) and different target systems (homogeneous or heterogeneous). Energy efficiency techniques in cluster computing systems are overviewed in the article [41], in which the static power management methods utilizing low-power components and dynamic power management techniques utilizing the power-scalable components (such as power-scalable processors and power-scalable memory) are surveyed and classified. A.C.Orgerie et al review the techniques for improving the energy efficiency of large scale distributed systems. And the solutions (such as resource allocation, scheduling and network traffic management) and the state of the art of energy efficiency are also discussed in this article [42]. A survey and taxonomy on energy efficiency techniques in Cloud Computing are done in the study [43]. They comprehensively survey the energy efficiency techniques from the perspective of infrastructure, hardware-oriented, and software-oriented. The infrastructural energy efficiency techniques include Energy Star Rating IT/Not-IT Equipment Air Conditioning Units and Cooling Equipment, and Flooring Choices. The hardware-oriented energy efficiency techniques can be Energy-Efficient Servers, Parallel Architecture, Multi-core Architectures, Power Management Schemes Network and Storage Level Optimizations. And the software-oriented energy efficiency techniques may be Parallel programming, Resource Throttling, Resource Provisioning and Resource Scheduling Techniques. This survey mainly focuses on the software-oriented energy efficiency techniques. Energy reduction techniques (DVFS, Scheduling, Re-scheduling, Virtualization) and the energy measurement methods in the context of Grid, Cluster, High Performance and simple systems, that is the cloud related environment are surveyed and summarized in the literature [44]. Moreover, the cloud simulation environments, such as GreenCloud [45], MDCSim [46], CloudSim [47] and GSSIM [48] are described. The survey, perspectives and future directions are described in the paper [49], in which the energy efficient aware framework is designed for the data center. And the energy efficiency related concepts, such as resources management, thermal control and green metrics are also investigated. Techniques and architectures for designing energy-efficient Data Centers are surveyed in the literature [50], which discusses and summarizes the software-oriented, hardware-oriented and architecture-oriented energy efficient techniques in the components Data Centers (Server, Memory, Network equipment). In the Server, the power reduction methods include Server architecture RISC, CISC and SoC, Server Power distribution, and Server Cooling. As for storage systems, the energy efficient techniques may include Storage Architecture SAN, NAS or DAS, Storage technologies SSDs, HDDs, magnetic, optical storage, and flash memory. And in the network component, the energy efficient techniques include Data center network architecture, optical data centers, and data center routing. Summary of the surveys on energy efficiency for the whole system is shown in Table 1.

B. SURVEYS ON ENERGY EFFICIENCY OF THE CERTAIN LEVEL OR COMPONENT OF THE CLOUD

Improving the energy efficiency of a cloud computing system may be achieved in every level of the cloud, as described in literatures [40], [41], [43], [50]. As the network is the main layer or component of the cloud computing system, there are many reviews on the network energy efficiency. K.Bilal et al first performed a survey on the green communication using adaptive link rate in 2012 [51], in which the state-of-art to designing network communication channels is also reviewed. And then they review the energy efficiency network design in 2014 [52], which consists of Data Center Network (DCN) Architecture, Data Center Network performance monitoring, Network traffic management and characterization, network-aware resource allocation and Data Center Network experiment techniques etc. A survey on architectures and energy efficiency in Data Center Networks is discussed in the literature [53], in which the switch-centric and server-centric energy efficiency network architecture design is reviewed. F.A.Moghaddam et al review on energy-efficient networking solutions in a cloud-based environment [54], in which the energy efficiency strategies, solutions and technology at the network level of a cloud-based environment are summarized and classified. In addition, a survey on energy-aware design and operation of core networks is conducted by Idzikowski *et al.* [55], in which the energy efficiency techniques in the design and operation stages are addressed. Recently, Dabashi *et al.* [56] performed a survey on green routing protocols using sleep-scheduling in wired networks. There are also some representative surveys on the energy efficiency for the network component in literatures [38], [39], [57]. Except for surveys on the energy efficiency at the network level or component level, as far as we known, there is only one paper conducts a survey at the IaaS layer of the cloud computing system, in which the energy efficiency techniques and strategies of the components of the IaaS, such as the processor, server, storage system, cooling and network are reviewed and discussed [58]. Summary of the surveys on energy efficiency of a certain level of the cloud related environment is shown in Table 2.

C. SURVEYS ON ENERGY EFFICIENT STRATEGIES IN THE CLOUD RELATED SYSTEM

In order to improve the energy efficiency of the cloud-related systems, a number of the techniques, strategies, methods or solutions are employed. Recently, surveys have been conducted on energy efficient strategies, which will be reviewed in this section. T.Mastelic et al conduct a survey on energy efficiency in cloud computing, in which all of the energy efficient strategies in the different levels or the components of

TABLE 1. Summary of the surveys on energy efficiency for the whole system.

Title	Survey Focus	Perspective	Target System	Publish Year
A Taxonomy and Survey of Energy-Efficient Data Centers and Cloud Computing Systems[40]	Different energy efficiency techniques in different level	From the levels perspective	Data Center and Cloud Computing Systems	2011
An overview of energy efficiency techniques in cluster computing systems [41]	Static and Dynamic and static energy efficiency techniques of the components	From component perspective	Cluster Computing Systems	2013
A Survey on Techniques for Improving the Energy Efficiency of Large Scale Distributed System [42]	Techniques, solutions or state of art on energy efficiency	From management strategies perspective	Large Scale Distributed System	2014
Energy Efficiency Techniques in Cloud Computing: A Survey and Taxonomy[43]	Software orient energy efficiency techniques	From level perspective	Cloud Computing System	2015
A Survey on Energy-Aware Cloud. [44]	Energy measurement, Energy-related simulation	From management strategies perspective	Cloud Computing	2015
Green data centers: A survey, perspectives, and future directions [49]	Thermal control, green metrics	From survey perspective	Data Centers	2016
Survey of Techniques and Architectures for Designing Energy-Efficient Data Centers [50]	Energy efficiency techniques on the Server component	From component perspective	Data Centers	2016

the cloud computing systems are reviewed and classified [59]. As for the hardware part, energy efficiency in network (such as Data Center Network, Inter-Data Center Network), and Servers (such as enclosure, racks and components) is surveyed. And as for the energy efficient cloud management software, such as virtualization, the monitoring system and scheduler are also reviewed. In addition, energy efficient appliances, such as applications, runtime environment and operating system are surveyed. Energy efficient techniques in network are wireless network architecture, low-complexity processing in wireless networks and traffic engineering and routing in wired networks, scaling of energy consumption with loads. And the energy efficient strategies in server have server cooling, DVFS and alternatives, processor architecture and design, storage systems SSD and RAID, and cache management. As regards cloud management systems, the energy efficient strategies may include VM placement, VM reconfiguration, VM scheduling, VM migration and consolidation. In Appliances part, the energy efficient solutions can be application platforms, application monitoring, compliers, design and development. And in the literature [60], various energy efficient techniques and algorithms are overviewed. Energy efficient techniques, such as VM consolidation, VM migration and DVFS are reviewed, and the energy efficient algorithms, such as random choice, highest potential growth, power expand min-max and minimization migrations, and maximum bin packing are overviewed. And a survey on energy efficient modern tools, architectures, techniques and algorithms is conducted by Kong, and Liu [62] conduct the surveys on the energy efficient methods at different levels of the datacenter. Workload scheduling, virtual machine management and energy capacity planning strategies are mainly focused. Literature [63] reviews the energy efficiency state-of-the-art in green cloud computing, in which the evolution of green cloud computing and associated integrated green cloud architecture are investigated. A summary of surveys on energy efficient strategies in the cloud-related systems is shown in Table 3.

D. SURVEYS ON CERTAIN ENERGY EFFICIENCY TECHNIQUES IN THE CLOUD RELATED SYSTEM

As many energy efficient techniques or strategies can be employed in the cloud-related systems, there are considerable surveys on certain energy efficiency techniques

TABLE 2. Summary of the surveys on energy efficiency of the certain level.

Title	Survey Focus	Perspective	Target System	Publish Year
A survey on Green communications using Adaptive Link Rate[51]	Adaptive Link Rate Approaches	From certain energy efficient techniques perspective	Green Networks	2012
A taxonomy and survey on Green Data Center Networks[52]	Energy efficient strategies in network level	From global perspective	Green Data Center Networks	2014
A survey on architectures and energy efficiency in Data Center Networks[53]	Energy efficient switch-centric and server-centric topologies design	From certain energy efficient techniques perspective	Data Center Networks	2014
Energy-Efficient Networking Solutions in Cloud-Based Environments [54]	Energy efficient networking solutions	From certain energy efficient techniques perspective	Cloud-based Environments	2015
A review on the recent energy-efficient approaches for the internet protocol stack [57]	Energy efficient internet protocol	From certain energy efficient techniques perspective	Cloud-based Environments	2015
Survey on Energy-Aware Design and Operation of Core Networks [55]	Energy efficient network design and operation	From certain stage perspective	Core Networks	2016
A survey on green routing protocols using sleep-scheduling in wired network [56]	Energy efficient routing protocols	From certain energy efficient techniques perspective	Wired network	2017

in the cloud related system. Firstly, J.Sekhar et al conducted a survey on energy efficient server consolidation through VM live migration in 2012 [64]. Then a survey on energy efficiency with task consolidation was conducted by Mkoba *et al.* in 2014 [65]. A survey into the energy-aware workload characterization in HPC, cloud and big data environments was performed by Inacio *et al.* [66]. Pavithra and Ranjana [67] conduct the survey on energy-aware resource allocation in cloud computing. Survey on energy aware scheduling of VMs in Cloud Data Centers is described in the literature [68]. Survey on energy aware load balancing techniques is discussed by Bose and Kumar [69]. An energy-aware resource allocation related survey for cloud computing is conducted in literature [70]. A taxonomy and survey of power management strategies in cloud data centers is conducted in article [71], in which energy-aware VM consolidation algorithms are focused on. Nasseera and Imanager [72] conduct a survey on energy-aware job scheduling algorithms in cloud environment. Jin *et al.* [73] focuses on the survey on software methods to improve the energy efficiency of parallel computing. Most recently, Piraghaj *et al.* [74] conducted a survey and taxonomy of energy efficient resource management techniques in platform as s Service Cloud, in which the environment aware energy saving (Bare metal environment or virtualized environment) techniques, workload aware energy efficient techniques and application aware energy saving techniques are deeply discussed. In addition, there is classification of techniques for energy efficient load distribution in Clouds, which is a survey of the survey on the energy-aware load distribution [75]. A summary of surveys on certain energy efficient strategies in the cloud related system is shown in Table 4.

E. OTHER RELATED SURVEYS ON ENERGY EFFICIENCY TECHNIQUES IN THE CLOUD RELATED ENVIRONMENT

There are some surveys on energy efficiency techniques that do not belong to the above categories. Ma *et al.* [76] review the energy efficiency on a location based application in mobile cloud computing. They perform a survey on energy saving techniques, such as trajectory simplification, i.e., multiple LABs management utilized on the application based on location. In literature [77], reliability and energy efficiency in cloud computing is reviewed. And the relationship and interaction of the reliability and energy efficiency are discussed. Furthermore, the trade-off methods

TABLE 3. Summary of surveys on energy efficient strategies in the cloud related system.

Title	Survey Focus	Perspective	Target System	Publish Year
Cloud Computing: Survey on Energy Efficiency[59]	Energy efficiency in Hardware, Cloud management software and appliances	From different level of cloud computing perspective	Cloud Computing System	2014
Energy Efficiency in Cloud Computing: A Review [60]	Energy efficient techniques, such as VM consolidation, VM migration and DVFS	From different energy efficient strategies perspective	Cloud Computing System	2015
Energy efficiency in big data complex systems: a comprehensive survey of modern energy saving techniques [61]	Energy efficient techniques and algorithms	From different energy efficient strategies perspective	Big Data Complex Systems	2015
A Survey on Green-Energy-Aware Power Management for Datacenters [62]	Workload scheduling, virtual machine management and energy capacity planning strategies	From different energy efficient techniques in different level perspective	Datacenters	2015
Survey of State-of-Art in Green Cloud Computing[63]	Evolution and architecture	From evolution perspective	Green Cloud Computing	2016

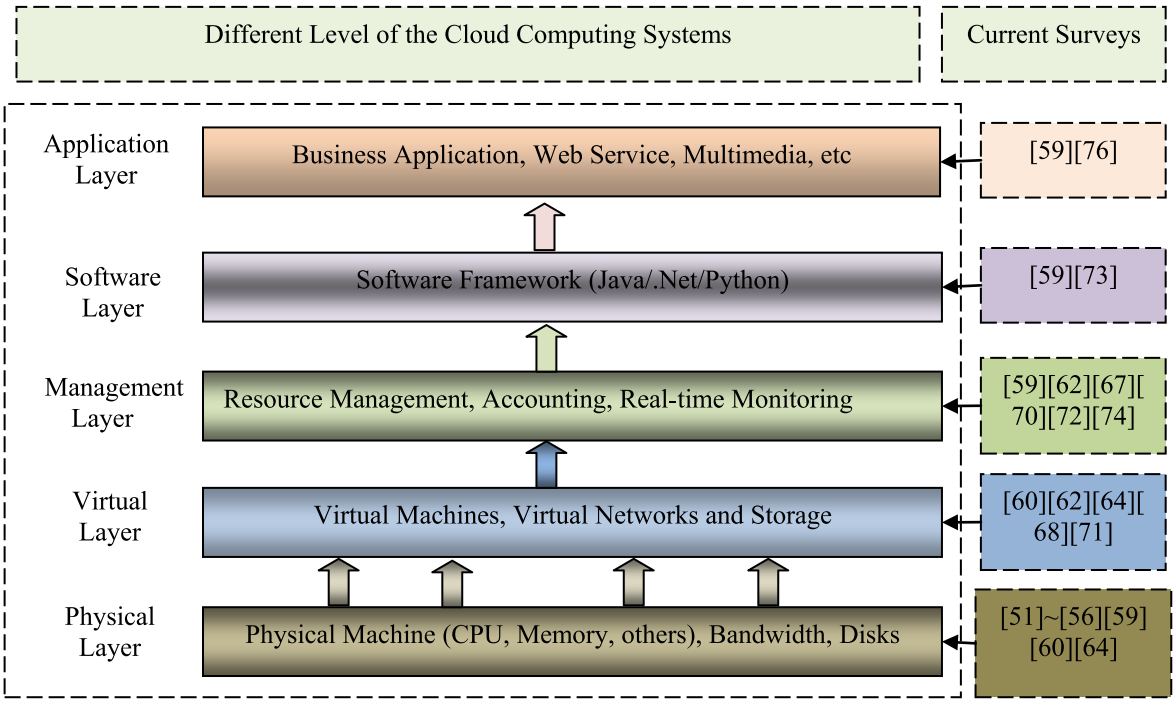

FIGURE 3. Surveys on the different aspects of the cloud computing systems.

or techniques between reliability and energy efficiency are also investigated. Finally, they suggest research directions and the concept framework of the new cloud computing.

Karpowicz and Niewiadomska-Szynkiewicz [78] conduct a survey on the power model, energy usage profiles and the method of energy measurement, which is a survey of energy

TABLE 4. Summary of surveys on certain energy efficient strategies in the cloud related system.

Title	Energy Efficient Techniques	Objective	Target System	Publish Year
A Survey on Energy Efficient Server Consolidation through VM Live Migration [64]	Server Consolidation, VM Live Migration	Keep the number of power-on nodes as few as possible	Cloud Computing System Data Center	2012
A Survey on Energy Efficient with Task Consolidation in the Virtualized Cloud Computing Environment[65]	Task Consolidation	Reduce operational and capital expenditure	Virtualized Cloud Computing	2014
A survey into performance and energy efficiency in HPC, cloud and big data environments [66]	Workload characterization	Improve Performance and Energy Efficiency	HPC, cloud and big data environment	2014
A Survey on Energy Aware Resource Allocation Techniques in Cloud [67]	Resource Allocation	Minimize the energy consumption	Cloud Computing System	2015
A Survey on Energy Aware Scheduling of VMs in Cloud Data Centers [68]	VM Scheduling	Minimize the energy consumption	Cloud Data Center	2015
A Survey on Energy Aware Load Balancing Techniques in Cloud Computing [69]	Load Balancing	Enhance resource utilization, minimize overall cost	Cloud Computing	2015
A Survey on Energy Aware Resource Allocation for Cloud Computing [70]	Resource Allocation	Minimize the energy consumption	Cloud Computing	2016
A Taxonomy and Survey of Power Management Strategies in Cloud Data Centers [71]	VM Consolidation	Minimize energy consumption with QoS constraint	Cloud Data Centers	2016
A Survey on Energy Aware Job Scheduling Algorithms in Cloud Environment [72]	Job Scheduling Algorithms	Reduce the operation cost and CO2 emission	Cloud Environment	2016
A survey on software methods to improve the energy efficiency of parallel computing [73]	Software Methods	Improve power usage at different granularities	Parallel Computing	2016
A Survey and Taxonomy of Energy Efficient Resource Management Techniques in Platform as a Service Cloud [74]	Resource Management	Minimize the energy consumption	Service Cloud	2017

efficient related techniques. Most recently, a taxonomy and survey of energy efficiency among the clusters, grids and clouds were conducted by Zakarya and Gillam [79], in which they review the effects and the side effects of the different energy saving techniques employed in clusters, grids, and clouds. A summary of surveys other related energy efficiency in the cloud related system is shown in Table 5.

III. OBSERVATIONS OF THE ABOVE SURVEYS ON ENERGY EFFICIENCY

The problem of energy efficiency in cloud related environment has aroused extensive concern in research or industry communities during the past 10 years. Many of the energy efficiency techniques have designed for the different layers in the cloud computing system. Therefore, there is considerable number of surveys on the energy efficiency from different perspectives in recent 5 years. From all of the surveys, we have the following observations.

A. OBERSERVATION 1: SURVEYS ON ENERGY EFFICIENCY INVOLVED MANY ASPECTS OF THE CLOUD RELATED SYSTEMS

There are surveys on energy efficiency for overall cloud-related systems, on energy efficiency for a certain level of cloud-related systems, on energy efficient techniques in cloud-related systems, on certain energy-aware techniques

TABLE 5. Summary of surveys on other related energy efficiency in the cloud related system.

Title	Survey Focus	Perspective	Target System	Publish Year
Energy Efficiency on Location Based Applications in Mobile Cloud Computing: A Survey [76]	Energy efficiency on application based on location	From application perspective	Mobile Cloud Computing	2012
Reliability and energy efficiency in cloud computing systems: Survey and taxonomy [77]	Relationship of reliability and energy efficiency	From interaction perspective	Cloud Computing System	2016
Energy and Power Efficiency in Cloud [78]	Power model, energy usage profiles and energy measurement	From energy efficiency related techniques perspective	Cloud Computing	2016
Energy efficient computing, clusters, grids and clouds: A taxonomy and survey [79]	Effect and the side effect of the different energy saving techniques	From comparison among different environment perspective	Clusters, grids and clouds	2017

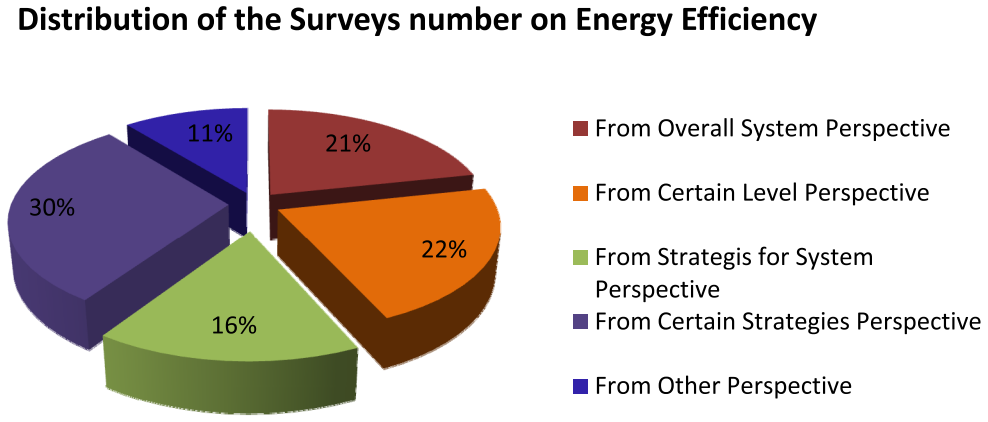

FIGURE 4. Distribution of the surveys number on energy efficiency.

in cloud systems and on other energy efficiency-related problems in cloud-related systems. That is, almost all of the possible energy efficient strategies at different levels of cloud-related systems have been reviewed until now. The architecture of the cloud computing systems and the corresponding energy efficiency-related surveys are shown in Figure 3, which verifies our first observation. Surveys on energy efficient have involved in many aspects of the cloud computing systems.

B. OBERSERVATION 2: SURVEYS ON CERTAIN ENERGY EFFICIENT STRATEGIES AROUSED MOST CONCERN

At present, surveys on the energy efficiency in cloud-related systems are mainly presented from five perspectives, that is, the overall system perspective, a certain level of the cloud system perspective, energy efficient strategies or techniques for the cloud system perspective, a certain energy efficient strategy or method for cloud-related systems and from the other perspective. According to our search, the distribution of the surveys number on energy efficiency in the cloud related system is shown in Figure 4, from which we can find that the surveys on certain energy efficient strategies or techniques have aroused the most concern.

C. OBERSERVATION 3: INTEREST IN THE PROBLEM OF ENERGY EFFICIENCY IS ON-GOING

The energy efficiency problem has aroused a great deal of attention over the past ten years, many techniques, strategies, methods, and algorithms have been designed to improve the energy efficiency of the cloud related system. Since the first survey on the energy efficiency conducted at 2011, apart from not all of the research work been publish in 2017, the interest in the problem of energy efficiency is on-going from 2011 to 2016. The number of surveys on energy efficiency from 2011-2017 is shown in Figure 5.

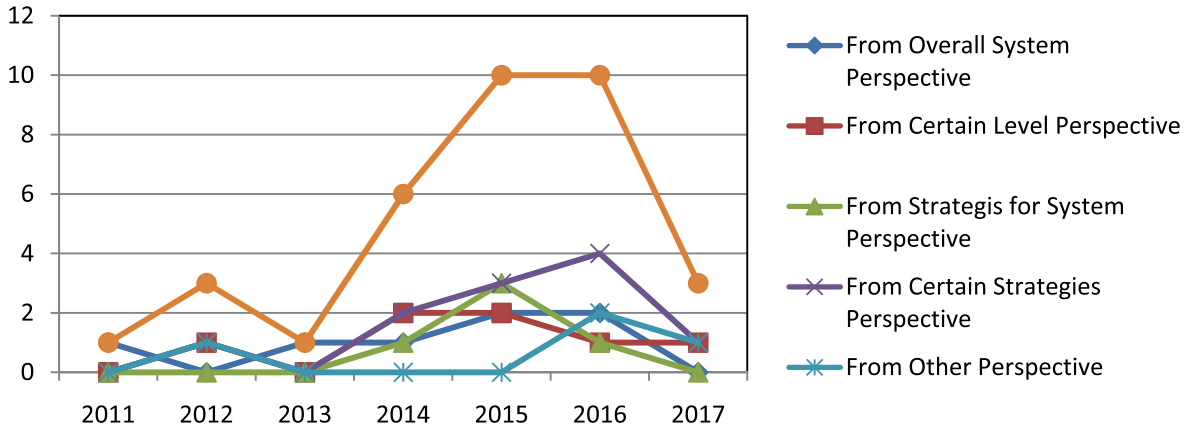

FIGURE 5. The number of surveys on energy efficiency from 2011-2017.

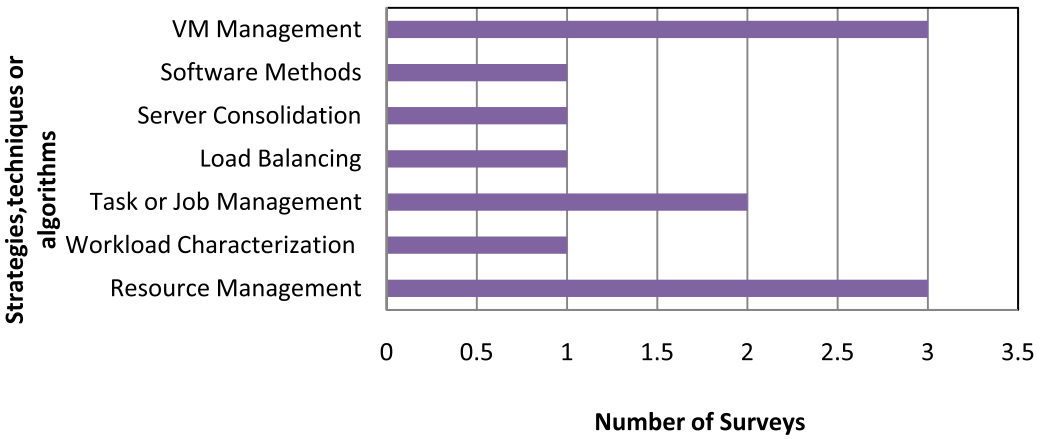

FIGURE 6. Number of surveys on different energy efficiency techniques.

D. OBERSERVATION 4: SURVEYS ON ENERGY-AWARE DATA MANAGEMENT IN CLOUD-RELATED SYSTEMS IS ABSENT

Although there is a considerable number of surveys on certain energy efficiency strategies or techniques, survey on energy-aware data management strategies is absent. Improving energy efficiency through data management strategies is one of the main techniques for Data Center Clouds or data-intensive applications [9]–[12]. We will conduct the survey on the energy-aware data management strategies (data classification, data placement and data replication etc.) in our future work, which will provide a new perspective or more space for improving energy efficiency in cloud-related system. And the number of surveys on different energy efficiency techniques is shown in Figure 6.

IV. CONCLUSION AND FUTURE DIRECTIONS

In this paper, we first investigate surveys on energy consumption savings. We also classify the surveys into five categories, including surveys on the energy efficiency of the whole cloud related system, surveys on the energy efficiency of the certain level or component of the cloud, surveys on energy efficient strategies in the cloud related system, surveys on a certain energy efficiency techniques in the cloud-related systems, and other related surveys on energy efficiency techniques in the cloud-related environments. A taxonomy and the survey on the surveys are conducted from the point of view of focuses, perspective, target system and years. Then observations on the surveys on energy consumption savings techniques are described, which is the baseline of our future work on the energy consumption field.

Based on our investigation of surveys on energy efficiency along with their observations, there may be some research directions of on energy saving techniques for future work.

A. FUTURE DIRECTION 1: REDUCING ENERGY CONSUMPTION THROUGH MULTI-LEVEL COMBINATION

As energy consumption saving strategies in cloud related-environments have been attracted comprehensive

investigations in the past ten years, there is little space to reduce the energy consumption at every level of cloud related systems. Furthermore, the respective energy efficient strategies may conflict with each other when integrating into real cloud system, which makes the designed energy consumption strategies inefficient. Therefore, how to combine the energy efficiency strategies at every level and to form a holistic energy efficient framework is a topic for future research.

B. FUTURE DIRECTION 2: CONDUCTING SURVEYS ON ENERGY-AWARE DATA MANAGEMENT STRATEGIES

Energy-aware data management strategies, such as, data classification algorithms, data layout policies and data replication strategies have attracted attention of a great deal of scholars. It is an important technical means through utilizing the data replication strategies combined with reasonable data layout. There are also many studies been conducted on the energy-aware data management strategies in cloud storage systems. Our future work should conduct survey on energy-aware data management strategies from different perspectives, which may identify more ways of reducing energy consumption in cloud storage systems.

C. FUTURE DIRECTION 3: COMBINING ENERGY-AWARE DATA MANAGEMENT STRATEGIES WITH OTHER TRADITIONAL ENERGY EFFICIENT TECHNIQUES

Data management is an important supplementary technique for energy efficiency in cloud-related environments. Energy-aware data management and the traditional energy efficient strategies have also been thoroughly investigated. Combining data layout policies and data replication with energy-aware scheduling algorithms, DVFS techniques and Energy Gear-shifting mechanisms may be future directions for further energy efficiency in cloud-related systems.

REFERENCES

[1] *Industry Development Trends and Market Scale Prediction of Big Data in China*, accessed on Apr. 29, 2016. [Online]. Available: http://www.cnii.com.cn/Bigdata/2016-04/29/content_1723221.htm

[2] M. Mills, "The cloud begins with Coal: Big data, big networks, big infrastructure, and big power," Energy Policy George C. Marshall Inst., Tech. Rep., 2013.

[3] *New Report Reveals Warehouses Overspend on Energy by $190 m*, Envantage, Aug. 2013.

[4] S. Srikantaiah, A. Kansal, and F. Zhao, "Energy aware consolidation for cloud computing," in *Proc. Workshop Power Aware Comput. Syst. (HotPower)*, San Diego, CA, USA, 2008, p. 10.

[5] G. Prekas *et al.*, "Energy proportionality and workload consolidation for latency-critical application," in *Proc. SoCC*, Kohala Coast, HI, USA, Aug. 2015, pp. 342–355.

[6] Q. Tang, S. K. S. Gupta, and G. Varsamopoulos, "Energy-efficient thermal-aware task scheduling for homogeneous high-performance computing data centers: A cyber-physical approach," *IEEE Trans. Parallel Distrib. Syst.*, vol. 19, no. 11, pp. 1458–1472, Sep. 2008.

[7] T. V. T. Duy, Y. Sato, and Y. Inoguchi, "Performance evaluation of a green scheduling algorithm for energy savings in cloud computing," in *Proc. IEEE Int. Symp. Parallel Distrib. Process. Workshops PhD Forum (IPDPSW)*, Apr. 2010, pp. 1–8.

[8] H. Chen, X. M. Zhu, and H. Guo, "Towards energy-efficient scheduling for real-time tasks under uncertain cloud computing environment," *J. Syst. Softw.*, vol. 99, pp. 20–35, Jan. 2015.

[9] D. K. Lee and K. Koh, "PDC-NH: Popular data concentration on NAND flash and hard disk drive," in *Proc. 10th IEEE/ACM Int. Conf. Grid Comput.*, Oct. 2009, pp. 196–200.

[10] R. Reddy, A. Kthpal, and J. Basak, "Data layout for power efficient archival storage systems," in *Proc. HotPower*, Sep. 2015, pp. 16–20.

[11] S. Iwata and K. Shiozawa, "A simulation result of replicating data with another layout for reducing media exchange of cold storage," in *Proc. 8th USENIX Workshop Hot Topics Storage File Syst.*, Jun. 2016, pp. 10–21.

[12] N. N. Zhao, J. G. Wan, J. Wang, and C. S. Xie, "GreenCHT: A power-proportional replication scheme for consistent hashing based key value storage systems," in *Proc. 31st Int. Conf. Massive Storage Syst. Technol. (MSST)*, 2015, pp. 1–6.

[13] F. Farahanakian, A. Ashraf, and P. Liljeberg, "Energy-aware dynamic VM consolidation in cloud data centers using ant colony system," in *Proc. IEEE 7th Int. Conf. Cloud Comput. (CLOUD)*, Jul. 2014, pp. 104–111.

[14] D. K. Kang, F. Alhazemi, S. H. Kim, and C. H. Youn, "Dynamic virtual machine consolidation for energy efficient cloud data centers," in *Proc. Int. Conf. Cloud Comput. (CloudComp)*, 2015, pp. 70–80.

[15] M. H. Al Shayeji and M. D. Samrajesh, "An energy-aware virtual machine migration algorithm," in *Proc. Int. Conf. Adv. Comput. Commun. (ICACC)*, Aug. 2012, pp. 9–11.

[16] V. R. Reguri, S. Kogatam, and M. Moh, "Energy efficient traffic-aware virtual machine migration in green cloud data centers," in *Proc. IEEE 2nd Int. Conf. Intell. Data Secur. (IDS)*, Apr. 2016, pp. 268–273.

[17] C. Ghribi, M. Hadji, and D. Zeghlache, "Energy efficient VM scheduling for cloud data centers: Exact allocation and migration algorithms," in *Proc. 13th IEEE/ACM Int. Symp. Cluster Cloud Grid Comput. (CCGrid)*, May 2013, pp. 671–678.

[18] Y. Wang and Y. Xia, "Energy optimal VM placement in the cloud," in *Proc. IEEE 9th Int. Conf. Cloud Comput. (CLOUD)*, Jun. 2016, pp. 84–91.

[19] A. Shafiee, A. Naq, and N. Muralimanohar, "ISAAC: A convolutional neural network accelerator with *in-situ* analog arithmetic in crossbars," in *Proc. 43rd Int. Symp. Comput. Archit. (ISCA)*, 2016, pp. 14–26.

[20] M. O. Muhammet *et al.*, "Energy efficient architecture for graph analytics accelerators," in *Proc. ACM/IEEE 43rd Annu. Int. Symp. Comput. Archit. (ISCA)*, Jun. 2016, pp. 166–177. [Online]. Available: https://www.cs.utah.edu/~rajeev/pubs/isca16.pdf

[21] W. Wang and K. Sohraby, "A study of application layer paradigm for lower layer energy saving potentials in cloud-edge social user wireless image sharing," in *Proc. 8th Int. Conf. Mobile Multimedia Commun. (MobiMedia)*, May 2015, pp. 54–59.

[22] L. Zhou *et al.*, "High availability green gear-shifting mechanism in cloud storage system," *Int. J. Grid Distrib. Comput.*, vol. 8, no. 5, pp. 303–314, 2015. [Online]. Available: http://dx.doi.org/10.14257/IJgdc.2015.8.5.30

[23] Q. Wu *et al.*, "Dynamo: Facebook's data center-wide power management system," in *Proc. ACM/IEEE 43rd Annu. Int. Symp. Comput. Archit. (ISCA)*. Jun. 2016, pp. 469–480.

[24] J. Leverich and C. Kozyrakis, "On the energy (in)efficiency of hadoop clusters," *ACM SIGOPS Oper. Syst. Rev. Arch.*, vol. 44, no. 1, pp. 61–65, Jan. 2010.

[25] V. Vasudevan, D. Andersen, M. Kaminsky, L. Tan, J. Franklin, and I. Moraru, "Energy-efficient cluster computing with FAWN: Workloads and implications," in *Proc. 1st Int. Conf. Energy-Efficient Comput. Netw. (e-Energy)*, Apr. 2010, pp. 195–204.

[26] C. Weddle *et al.*, "PARAID: A gear-shifting power-aware RAID," in *Proc. 5th USENIX Conf. File Storage Technol. (FAST)*. Berkeley, CA, USA, 2007, pp. 245–260.

[27] E. Li and J. Wang, "EERAID: Energy efficient redundant and inexpensive disk array," in *Proc. 11th ACM SIGOPS Eur. Workshop*, New York, NY, USA, 2004, Art. no. 29.

[28] J. Kim and D. Rotem, "Energy proportionality for disk storage using replication," in *Proc. 14th Int. Conf. Extending Database Technol. (EDBT/ICDT)*, New York, NY, USA, 2011, pp. 81–92.

[29] J. Stoess, C. Lang, and F. Bellosa, "Energy management for hypervisor-based virtual machines," in *Proc. USENIX Annu. Tech. Conf.*, Santa Clara, CA, USA, 2007, pp. 1–14.

[30] B. Riskhan, K. Zhou, and R. Muhammad, "Energy management of the system: An empirical investigation of virtualization approaches in static and dynamic modes," *Inf. Technol. J.*, vol. 12, no. 1, pp. 1–10, 2017.

[31] G. Y. Jia, J. J. Wan, X. Li, C. F. Jiang, and D. Dai, "Memory power optimization policy of coordinating page allocation and group scheduling," (in Chinese), *Ruan Jian Xue Bao/J. Softw.*, vol. 25, no. 7, pp. 1403–1415, 2014.

[32] C. H. Hsu and U. Kremer, "The design, implementation, and evaluation of a compiler algorithm for CPU energy reduction," in *Proc. ACM SIGPLAN Conf. Programm. Lang. Design Implement. (PLDI)*, Jun. 2003, pp. 38–48.
[33] K. Ma, X. Li, W. Chen, C. Zhang, and X. Wang, "GreenGPU: A holistic approach to energy efficiency in GPU-CPU heterogeneous architectures," in *Proc. 41st Int. Conf. Parallel Process. (ICPP)*, Sep. 2012, pp. 48–57.
[34] S. Gurumurthi, A. Sivasubramaniam, M. Kandemir, and H. Franke, "DRPM: Dynamic speed control for power management in server class disks," in *Proc. Int. Symp. Comput. Archit. (ISCA)*, New York, NY, USA, Jun. 2003, pp. 169–181.
[35] E. A. Papathanasiou and M. L. Scott, "Energy efficient prefetching and caching," in *Proc. USENIX Annu. Tech. Conf. (USENIX)*, Berkeley, CA, USA, 2004, pp. 255–268.
[36] M. E. Tolentino, J. Turner, and K. W. Cameron, "Memory MISER: Improving main memory energy efficiency in servers," *IEEE Trans. Comput.*, vol. 58, no. 3, pp. 336–350, Mar. 2009.
[37] J. S. Vetter and S. Mittal, "Opportunities for nonvolatile memory systems in extreme-scale high-performance computing," *Comput. Sci. Eng.*, vol. 17, no. 2, p. 73, 2015.
[38] K. Cengiz and T. Dag, "A review on the recent energy-efficient approaches for the Internet protocol stack," *EURASIP J. Wireless Commun. Netw.*, vol. 2015, no. 1, pp. 1–22, Dec. 2015.
[39] C. Eyupoglu and M. A. Aydin, "Energy efficiency in backbone networks," *Procedia-Social Behavioral Sci.*, vol. 195, pp. 1966–1970, Jul. 2015.
[40] A. Beloglazov, R. Buyya, Y. C. Lee, and A. Zomaya, "A taxonomy and survey of energy-efficient data centers and cloud computing systems," *Adv. Comput.*, vol. 82, no. 2, pp. 47–111, 2011.
[41] G. L. Valentini *et al.*, "An overview of energy efficiency techniques in cluster computing systems," *Cluster Comput.*, vol. 16, no. 1, pp. 3–15, 2013.
[42] A. C. Orgerie, M. D. D. Asuncao, and L. Lefeve, "A survey on techniques for improving the energy efficiency of large scale distributed system," *ACM Comput. Surveys*, vol. 46, no. 4, p. 47, Apr. 2014.
[43] T. Kaur and I. Chana, "Energy efficiency techniques in cloud computing: A survey and taxonomy," *ACM Comput. Surveys*, vol. 48, no. 2, p. 22, 2015.
[44] S. Sohrabi and I. Moser, "A survey on energy-aware cloud," *Eur. J. Adv. Eng. Technol.*, vol. 2, no. 2, pp. 80–91, 2015.
[45] D. Kliazovich, P. Bouvry, and S. U. Khan, "GreenCloud: A packet-level simulator of energy-aware cloud computing data centers," *J. Supercomput.*, vol. 62, no. 3, pp. 1263–1283, 2012.
[46] S. H. Lim, B. Sharma, G. Nam, E. K. Kim, and C. R. Das, "MDCSim: A multi-tier data center simulation, platform," in *Proc. IEEE Int. Conf. Cluster Comput. Workshops (CLUSTER)*, Apr. 2009, pp. 1–9.
[47] R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. De Rose, and R. Buyya, "CloudSim: A toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms," *Softw. Pract. Exp.*, vol. 41, no. 1, pp. 23–50, 2011.
[48] S. Bkak, M. Krystek, K. Kurowski, A. Oleksiak, W. Pikatek, and J. Wkaglarz, "GSSIM—A tool for distributedcomputing experiments," *Sci. Program*, vol. 19, no. 4, pp. 231–251, 2011.
[49] X. Jin, F. Zhang, A. V. Vasilakos, and Z. Liu, "Green data centers: A survey, perspectives, and future directions," to be published.
[50] J. Shuja *et al.*, "Survey of techniques and architectures for designing energy-efficient data centers," *IEEE Syst. J.*, vol. 10, no. 2, pp. 507–519, Jun. 2016.
[51] K. Bilal, S. U. Khnan, and S. A. Mahdni, "A survey on Green communications using adaptive link rate," *Cluster Comput.*, vol. 16, no. 3, pp. 575–589, Jul. 2013.
[52] K. Bilal *et al.*, "A taxonomy and survey on Green data center networks," *Future Generat. Comput. Syst.*, vol. 36, pp. 189–208, Jul. 2014.
[53] A. Hammadi and L. Mhamdi, "A survey on architectures and energy efficiency in data center networks," *Comput. Commun.*, vol. 40, pp. 1–21, Mar. 2014.
[54] F. A. Moghaddam, P. Lago, and P. Grosso, "Energy-efficient networking solutions in cloud-based environments: A systematic literature review," *ACM Comput. Surveys*, vol. 47, no. 4, p. 64, Jul. 2015.
[55] F. Idzikowski, L. Chiaraviglio, A. Cianfrani, J. L. VizcaÃno, M. Polverini, and Y. Ye, "A survey on energy-aware design and operation of core networks," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 2, pp. 1453–1499, 2nd Quart., 2016.
[56] F. Dabaghi, Z. Movahedi, and R. Langar, "A survey on green routing protocols using sleep-scheduling in wired network," *J. Netw. Comput. Appl.*, vol. 77, pp. 106–122, Jan. 2017.
[57] A. P. Bianzino, C. Chaudet, D. Rossi, and J. L. Rougier, "A survey of Green networking research," *IEEE Commun. Surveys Tuts.*, vol. 14, no. 1, pp. 3–20, 1st Quart., 2012.
[58] S. Y. Jiang, S. Ali, K. She, and Y. Zhong, "State-of-the-art research study for green cloud computing," *J. Supercomput.*, vol. 65, no. 1, pp. 445–468, 2013.
[59] T. Mastelic, A. Oleksiak, H. Claussen, and I. Brandic, "Cloud computing: Survey on energy efficiency," *ACM Comput. Surv.*, vol. 47, no. 2, p. 33, Dec. 2014.
[60] K. Tejaswini and H. S. Guruprasad, "Energy efficiency in cloud computing: A review," *Int. J. Sci. Res. Manage. Stud.*, vol. 2, no. 5, pp. 253–259, 2015.
[61] A. Majeed and M. A. Shah, "Energy efficiency in big data complex systems: A comprehensive survey of modern energy saving techniques," *Complex Adapt. Syst. Model.*, vol. 3, p. 6, Dec. 2015.
[62] F. Kong and X. Liu, "A survey on green-energy-aware power management for datacenters," *ACM Comput. Surv.*, vol. 47, no. 2, p. 30, Jan. 2015.
[63] S. P. Ahuja and K. Muthiah, "Survey of state-of-art in green cloud computing," *Int. J. Green Comput.*, vol. 7, no. 1, p. 12, 2016.
[64] J. Sekhar, G. Jeba, and S. Durga, "A survey on energy efficient server consolidation through VM live migration," *Int. J. Adv. Eng. Technol.*, vol. 5, no. 1, pp. 515–525, Nov. 2012.
[65] E. S. Mkoba and M. A. A. Saif, "A survey on energy efficient with task consolidation in the virtualized cloud computing environment," *Int. J. Res. Eng. Technol.*, vol. 3, no. 3, pp. 70–73, 2014.
[66] E. C. Inacio and M. A. R. Dantas, "A survey into performance and energy efficiency in HPC, cloud and big data environments," *Int. J. Netw. Virtual Org.*, vol. 14, no. 4, pp. 299–318, 2014.
[67] B. Pavithra and R. Ranjana, "A survey on energy aware resource allocation techniques in cloud," *Int. J. Sci., Eng. Technol. Res.*, vol. 4, no. 11, pp. 3751–3755, Nov. 2015.
[68] G. Poonacha C, K. Priya, K. P. Sheelvanthmath, and P. Ashwini, "A survey on energy aware scheduling of VMs in cloud data centers," *Int. J. Comput. Sci. Mobile Comput.*, vol. 4, no. 3, pp. 226–229, Mar. 2015.
[69] S. Bose and J. Kumar, "A survey on energy aware load balancing techniques in cloud computing," *Int. J. Adv. Res. Comput. Commun. Eng.*, vol. 4, no. 5, pp. 397–402, May 2015.
[70] P. Matre, S. Silakari, and U. Chourasia, "A survey on energy aware resource allocation for cloud computing," *Int. J. Eng. Res. Technol.*, vol. 5, no. 2, pp. 21–31, Feb. 2016.
[71] M. A. Khoshkholghi, A. Abdullah, S. Subramaniam, M. Othman, and M. N. Derahman, "A taxonomy and survey of power management strategies in cloud data centers," *Int. J. Commun. Antenna Propag.*, vol. 6, no. 5, pp. 305–317, 2016.
[72] S. Naseera and P. Jyotheeswai, "A survey on energy aware job scheduling algorithms in cloud environment," *J. Cloud Comput.*, vol. 3, p. 30, Jan. 2016.
[73] C. Jin *et al.*, "A survey on software methods to improve the energy efficiency of parallel computing," *Int. J. High Perform. Comput. Appl.*, vol. 5, no. 2, pp. 10–16, Sep. 2016.
[74] S. F. Piraghaj, R. N. Calheiros, A. V. Dastjerdi, and R. Buyya, "A survey and taxonomy of energy efficient resource management techniques in platform as a service cloud," in *Handbook of Research on End-to-End Cloud Computing Architecture Design*. Hershey, PA, USA: IGI Global, 2017, pp. 410–454.
[75] M. Splieth, F. Kramer, and K. Turowski, "Classification of techniques for energy efficient load distribution algorithms in clouds—A systematic literature review," in *Proc. 28th EnviroInfo Conf.*, Oldenburg, Germany, Sep. 2014, pp. 1–8.
[76] X. Ma, Y. Cui, and I. Stojmenovic, "Energy efficiency on location based applications in mobile cloud computing: A survey," *Procedia Comput. Sci.*, vol. 96, no. 7, pp. 569–585, 2014.
[77] Y. Sharma, B. Javadi, W. Si, and D. Sun, "Reliability and energy efficiency in cloud computing systems: Survey and taxonomy," *J. Netw. Comput. Appl.*, vol. 74, pp. 66–85, Oct. 2016.
[78] M. Karpowicz, E. Niewiadomska-Szynkiewicz, P. Arabas, and A. Sikora, "Energy and power efficiency in cloud," in *Resource Management for Big Data Platforms* (Computer Communications and Networks). Springer, Oct. 2016, pp. 97–127.
[79] M. Zakarya and L. Gillam, "Energy efficient computing, clusters, grids and clouds: A taxonomy and survey," *Sustain. Comput., Inform. Syst.*, vol. 14, pp. 13–33, Jun. 2017.

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