IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Date of current version June 23, 2020.

*Digital Object Identifier 10.1109/ACCESS.2020.3001770*

EDITORIAL

# IEEE ACCESS SPECIAL SECTION EDITORIAL: EMERGING TRENDS, ISSUES, AND CHALLANGES IN ENERGY-EFFICIENT CLOUD COMPUTING

Cloud computing is one of the most successful business models for providing a simple pay-as-you-go, and therefore is gaining much popularity in the industry. Customers and enterprises can maintain or scale-up a business easily while cutting down on their budget. However, energy consumption is one of the biggest problems in current cloud computing. It is both essential and urgent for governmental and industrial institutions to address this, to achieve rapid growth. The development of energy-efficient cloud computing has to be taken into consideration, which relies on the development of several key technologies: More energy-efficient mediums can be used in cloud computing at the platform level; energy-efficient scheduling algorithms, memory systems, storage systems, resource management policies, etc., can be adopted at the hypervisor level; energy-efficient scheduling, communications, and applications can be applied at the virtual machine level; and energy-efficient mobile cloud computing will be developed, involving green networking and wireless communications, cloud-based mobile applications, and limited resources management.

This Special Section of IEEE ACCESS on emerging trends, issues, and challenges in energy-efficient cloud computing aims at bringing together researchers to disseminate their findings in the field of energy-efficient cloud computing, pushing the theoretical and practical boundary forward for a deeper understanding of fundamental algorithms, modeling, and analysis techniques from academics and industry viewpoints.

Cloud manufacturing (CMfg) is a new service-oriented production paradigm from the wide application of cloud computing for the manufacturing industry. Traditional resource allocation approaches in CMfg mainly focus on the optimal resource selection process, but the energy consumption for manufacturing resources is rarely considered. In the article by Zheng *et al.*, "A hybrid energy-aware resource allocation approach in cloud manufacturing environment," the authors propose a hybrid energy-aware resource allocation approach to help requestors acquire energy-efficient and satisfied manufacturing services. In general, energy-aware resource allocation in CMfg can be classified into the following process: QoS-aware services selection and energy-aware resource composition. A local selection strategy based on fuzzy similarity degree is used to obtain appropriate candidate services from vast cloud space. Furthermore, an energy-aware multi-objective optimization model is established, and a NSGA-II algorithm is introduced to acquire a Pareto set. Finally, a TOPSIS-based decision-making approach is adopted to select an optimal solution.

In the article by Zuo *et al.*, "A multi-objective hybrid cloud resource scheduling method based on deadline and cost constraints," the authors propose a task-oriented multi-objective scheduling method based on ant colony optimization (MOSACO) to optimize the finite pool of public and private computing resources in a hybrid cloud computing environment, according to deadline and cost constraints. They address resource utilization in hybrid cloud computing with multiple considerations of cost, task completion time, user QoS, and resource provider interests, and develop the MOSACO algorithm to optimize resource utilization according to deadline and cost constraints. MOSACO is employed to minimize task completion times and cost using time-first and cost-first single-objective optimization strategies, respectively, and to maximize user quality of service and the profit of resource providers using an entropy optimization model. Compared with other similar resource scheduling methods, MOSACO demonstrates the highest optimality according to considerations of task completion time, cost, number of deadline violations, and the degree of private cloud resource utilization based on simulation and three application examples.

Cloud data centers are acknowledged as being massive energy consumers, which may have significant environment impacts. Service providers have an ethical responsibility to reduce the environmental impact of server resources and a simultaneously and complementary commercial desire to reduce energy costs. Zombie servers in the data centers are one of the primary sources of undesirable energy expenditures by incurring idle resources during task execution. The article by Panneerselvam *et al.*, "Analysis, modelling and characterisation of zombie servers in large-scale cloud datacenters," investigates the cause, impact and energy-related implications of zombie servers. Three such server profiles have been used as examples to determine power consumption incurred by the presence of idle CPU and memory resource times. Empirical analysis demonstrates that CPU resources

account for the highest proportion of idle resource time at 75.6%, with memory resources exhibiting 25.5% of idleness. They further present the environmental implications of idle resource time in terms of $CO_2$ emissions in order to highlight the demand for energy efficient computing. Idle resource time is the result of not fully realizing the complete compute potentials of IT resources; the idle resource time has the scope of being utilized to process a greater number of useful workloads in the same time period.

Cloud data centers are faced with the serious problem of increasing energy consumption. Thus, the problem of virtual machine placement for energy saving is becoming a critical issue. Considering various requirements of cloud providers and users, a many-objective virtual machine placement model is built to minimize energy consumption and maximize load balance, resource utilization, and robustness. The article by Ye *et al.*, ''Energy-efficient many-objective virtual machine placement optimization in a cloud computing environment,'' proposes an energy-efficient KnEA (EEKnEA) algorithm to address the virtual machine placement problem. In EEKnEA, Energy-Efficient-oriented Population Initialization is proposed and used to obtain a higher quality initial population. The proposed model and algorithm are evaluated through experiments comparing KnEA and other algorithms. The results demonstrate that the proposed model and EEKnEA are competitive. EEKnEA performs better than other algorithms in reducing energy consumption and load balancing. Therefore, the proposed model and EEKnEA can achieve a more robust placement scheme.

The article by Wen *et al.*, ''Energy-efficient virtual resource dynamic integration method in cloud computing,'' proposes an energy-efficient virtual resource dynamic integration (VRDI) method to minimize the energy consumption of a data center. The method is based on the live migration technology for VMs, which can reduce the energy consumption of a data center by integrating the virtual resources. The proposed VRDI method consists of three parts: (1) Based on the resource utilization and the corresponding predefined thresholds of the PMs, determine the integration timing and the PMs set that need to be integrated; (2) based on the load pattern of the VM, and the Euclidean distance between the VM and a PM, select a minimal set of VMs which need to be migrated; (3) using the IGAVP to find an effective VM placement solution to solve the bin-packing problem. Further, they present experimental results to compare the proposed the VRDI method with the existing solutions. The results show that the VRDI method has a significant advantage in terms of reducing the energy consumption of a data center. Therefore, the proposed VRDI method can reduce the energy consumption of data center and ensure the quality of service of the cloud applications developed on the VMs.

Large data centers providing basic resources to hosted tasks, such as CPU, RAM, storage, and bandwidth, also consume a huge amount of energy, which leads to higher operating costs and $CO_2$ traces. Therefore, the research community felt the need to provide energy-efficient solutions that reduce the impact of the aforementioned issues. In the article by Mustafa *et al.*, ''SLA-aware energy efficient resource management for cloud environments,'' the authors use the same workload consolidation concept and present two techniques that reduce energy consumption while ensuring the negotiated quality-of-service. Moreover, they enhance two existing techniques by improving the energy efficiency and introducing service level agreement (SLA) awareness to minimize the overall SLA violations. The results show that SLA violations are reduced significantly. Furthermore, the proposed resource management techniques reduce energy consumption and SLA violations by considering the real-time states of energy and CPU capacity of servers.

In the cloud computing environment, the source-level energy consumption (EC) estimation is employed to approximately measure the EC of a cloud computing task before it is executed. The EC of two tasks consisting of the same statements with different structures is unequal, therefore, the code structure should be highlighted in source-level EC estimation. The article by Liu *et al.*, ''Source-level energy consumption estimation for cloud computing tasks,'' proposes an abstract energy consumption (AEC) model, which is static and runtime-independent. For the model, the two quantitative measurements, ''cross-degree'' and ''reuse-degree,'' are proposed as the code structure features, and the quantitative relationships between AEC and the cross-degree as well as the reuse-degree are derived, and an estimation function of AEC is given. Experimental results show that the ratios between the EC and AEC with 50 test cases are stable; the standard deviation is 0.0002; and the mean value is 0.005. Through AEC, it is easier to schedule the cloud computing tasks properly and reduce the consumed energy.

Recently, Hadoop enhanced its homogeneous storage function to heterogeneous storage, storing data sets into multiple storage media, i.e., SSD, RAM, and DISK. This evolution increases the consumption of computing capacity and memory usage over MapReduce job scheduling. The scheduler processes MapReduce jobs into homogeneous containers having configuration of CPU, memory, DISK volume, and network I/O, and accesses, processes, and stores data sets over heterogeneous storage media. This produces a processing latency of locating and pairing source data set to MapReduce tasks, and results in abnormally high consumption of computing capacity and memory usage in a Data node. In the article by Qureshi *et al.*, ''Storage-tag-aware scheduler for Hadoop cluster,'' the authors present Storage-Tag-Aware Scheduler (STAS) that reduces processing latency by scheduling MapReduce jobs into heterogeneous storage containers, i.e., SSD, DISK, and RAM container. STAS endorses job with a tag of storage media, such as Job-SSD, JobDISK, and JobRAM, parsing them into heterogeneous shared-queues, which assign processing configuration to enlist jobs. Then, STAS manager schedules shared-queue jobs into heterogeneous MapReduce containers and generates an output into storage media of the cluster. The experimental evaluation shows that STAS optimizes the consumption of

computing capacity and memory usage more efficiently than available schedulers in a Hadoop cluster.

Mobile receivers are increasingly used to collect data in sensor networks, but their data sources are actively transmitting data based on their location in the network, which generates a lot of overhead and unnecessary energy consumption. To reduce overhead and balance energy consumption in the network, the article by Yang *et al.*, ''A clue based data collection routing protocol for mobile sensor networks,'' proposes a clue-based data collection routing (CBDCR) protocol. The mobile receiver in the CBDCR randomly moves and broadcasts its location message only through limited hops instead of the entire network. As the number of nodes receiving the broadcast message increases, the location information stored by the node is more detailed and the location of the receiver is more explicit. Thus, the sensed data can be effectively forwarded to the receiver. A large number of simulation experiments using mobile receivers in the network show that CBDCR can significantly reduce redundant transmission messages and balance network energy consumption, which proves that the protocol is effective.

Mobile Edge Computing (MEC) is a promising technology for enhancing user equipment (UE) capabilities. MEC Service Providers (SPs) are equipped with limited wireless and computing resources. However, most of the existing research work does not consider the UE's demand for heterogeneity and resource constraints, and limited resources may limit the number of UEs accessed. Therefore, in the article by Zhang *et al.*, ''Combinational auction-based service provider selection in mobile edge computing networks,'' the authors study the matching problem between MEC SP and UE in multi-MEC and multi-UE scenarios, and propose the auction model and multi-wheel seal sequential combined auction (MSSCA) mechanism. The auction theory is used to simulate the matching relationship between the MEC SP and the UE as a commodity transaction. SPs and UEs are considered sellers and buyers, and SP resources are considered commodities. When the SP has sufficient resources and the UE can successfully purchase resources from the SP, the UE can obtain the service from the SP. The auction process follows a multi-round sealed sequential combined auction (MSSCA) mechanism. The mechanism includes the user's bid strategy, the winner determination and pricing process. The user's bidding strategy is based on multiple rounds of priority rules, the winner determination process is formulated as a two-dimensional knapsack problem, and the pricing process is modeled according to the UE's resource requirements. At the end of the article, simulation experiments show that the proposed method has better system performance than the existing algorithms.

Slope damage and debris flow cause a large number of casualties and property damage. Early warning systems for slope collapse and debris flow are critical to ensuring the safety of humans and assets. Based on the fiber-optic sensing technology and the Internet of Things, in the article by Xu *et al.*, ''Early-warning system with quasi-distributed fiber optic sensor networks and cloud computing for soil slopes,'' a new soil pressure sensor inside the soil slope is proposed, and the on-site soil slope is tested with the developed fiber sensor and other sensors. The main findings are as follows: 1) In the sensing layer, the optical sensor detects the slope of the field; 2) The wireless network and the optical fiber can be used to connect the sensing layer to the data acquisition system. The Internet of Things is then used to upload slope deformation information to the cloud computing layer. 3) The cloud computing layer performs data analysis and finds that rainfall infiltration strongly affects slope stability, especially on the slope surface. And when the rainfall is greater than 0.5mm/h, and the rainfall duration is greater than 100h, the slope will collapse. These analysis results provide a basis for early warning monitoring systems.

Wireless Information and Power Transmission (SWIPT) is an innovative way to provide power to mobile devices. The research work in this mode mainly focuses on energy harvesting in a relatively narrow frequency range, but users collect less energy, and actual implementations are often limited to low-power devices. In this article written by Zhao *et al.*, ''Energy-efficient sub-carrier and power allocation in cloud-based cellular network with ambient RF energy harvesting,'' an energy-saving sub-object is proposed in a cloud-based cellular network with ambient radio frequency (RF) energy harvesting. In order to obtain sufficient energy, a broadband antenna is provided at the user equipment to simultaneously collect ambient RF energy over six frequency bands. From the perspective of the service reaching the environmental transmitter, a new energy arrival model is proposed. The joint problem of subcarrier and power allocation is expressed as a mixed-integer nonlinear programming problem. The goal is to maximize energy efficiency while meeting energy constraints and total data rate requirements. In order to reduce the computational complexity, the suboptimal solution of the optimization problem is derived by using the quantum behavior particle swarm optimization (QPSO) algorithm. The simulation results show that compared with the narrowband SWIFT system, the user equipment can obtain more energy, and the QPSO method achieves higher energy efficiency than the traditional particle swarm optimization method.

For energy-efficient resource management, empty node avoidance is one of the key objectives of energy-constrained underwater wireless sensor networks (UWSN). In this article by Javaid *et al.*, ''Establishing a cooperation-based and void node avoiding energy-efficient underwater WSN for a cloud,'' the authors propose two new underwater wireless sensor network (UWSN) schemes: Avoiding node-based adaptive hop-by-hop vector forwarding (AVN-AHH-VBF) and collaboration-based CoAVN-AHH-VBF. In both scenarios, the sensor node forwards the data packet in a multi-hop manner within the virtual pipeline. Nodes outside the pipe do not forward packets to avoid flooding in the network. At each hop, forwarding to an empty area of the network is avoided by utilizing two-hop information. This article contributes in three areas: The energy-efficient freight forwarder chooses

to avoid blank areas in the network, and the proper hold time calculation and bit error rate BER are minimized. Our freight forwarder selection technology enables high delivery rates (DR) even under sparse network conditions. By using our formulated Eq., the retention time of each successful package is minimized. A large number of simulation results show that the proposed scheme significantly improves network performance in terms of delivery rate, energy consumption and delay compared to the selected existing solution (AHH-VBF).

Receiver mobility improves the energy efficiency and data acquisition performance of wireless sensor networks. However, in some applications it may be possible to limit the mobility of the sink, and optimizing the network performance of the random and hierarchical topology becomes a challenge. In order to solve this problem, Wu *et al.*, propose a data acquisition scheme called Double Optimization Energy Efficiency (DOEE) based on graph theory in the article ''Graph-based data gathering scheme in WSNs with a mobility-constrained mobile sink.'' That is, the energy efficiency of the subreceiver defined according to the movement path. At the same time, they also specialize in routing discovery protocols and their corresponding dynamic gateway protocols to balance the energy consumption between sensor nodes. They first use the concept of graphics to describe the monitored area to simplify the description of the network area and reduce the complexity of the algorithm. Then, they assign the sensor node grid to the child sink grid based on the map inspired by the heuristic algorithm. The simulation results performed in NS-3 show that technology is superior to MASP, SPT and RANDOM schemes in terms of network life cycle and indicators. The energy consumption of all sensor nodes becomes more efficient for applications with mobility-limited receivers and correspondingly increases network life.

Wireless sensor networks (WSNs) have been widely used in many fields such as military and environmental monitoring. How to make full use of the energy of the sensor and prolong the life of the network is a challenge that has attracted the attention of researchers in recent years. In this article by Zhang *et al.*, ''Graph-based mechanism for scheduling mobile sensors in time-sensitive WSNs applications,'' the authors arrange motion sensors by applying techniques from ant colony optimization and genetic algorithms to balance the energy consumption of the motion sensors. First, they divide the area into many small cells. Then they abstract the area into a graph. Each cell is treated as a vertex and the motion sensor will collect data from each vertex. They use heuristic algorithm-inspired techniques to account for the energy consumption of movement and data collection to arrange each mobile sensor. Experimental results show that this technology can balance the energy consumption of each mobile sensor and extend the service life of the network.

Network Function Virtualization (NFV) is a new network architecture framework that implements network functions in software running on shared commercial server pools. NFV can provide the infrastructure flexibility and flexibility needed to successfully compete in today's evolving communications arena. This article by Eramo *et al.*, ''Migration energy aware reconfigurations of virtual network function instances in NFV architectures,'' discusses the VNFI migration issues required to shut down a server during low-traffic periods, thereby saving energy consumption. While integration allows for energy savings, it also has a negative impact as service quality declines or the energy consumption required to move memory migration associated with VNFI. They focus on cold migration where virtual machines are redundant and suspended before performing the migration. They propose a migration strategy to determine when and where to migrate VNFI in response to changes in SFC request strength. The goal is to minimize the total energy consumption given by the sum of the merge and migration energies. They have developed an energy-aware VNFI migration problem, and after proving that it is NP-hard, the article proposes a heuristic algorithm based on the Viterbi algorithm to determine the migration strategy with low computational complexity. The results obtained by the proposed heuristics show how the introduced strategy allows for the reduction of the migration energy and thus reduces the total energy consumption relative to conventional strategies. Energy savings can be about 40% relative to strategies that do not perform the migration.

The Internet of Things (IoT) is expanding its reach to almost every aspect of our daily lives. By using network coding in the Internet of Things, IoT energy consumption can be reduced. Therefore, it is worthwhile to research and improve the application in the Internet of Things, including network coding. In the article ''Towards green IoT networking: Performance optimization of network coding based communication and reliable storage,'' Li *et al.*, optimize the performance of network-coded communication and reliable storage in two important components of the Internet of Things, including. the IoT core network, where data is sensed and transmitted, and the distributed cloud storage, where the data generated is stored. First, they propose an adaptive network coding scheme in the core network of the Internet of Things to improve transmission efficiency. They demonstrate the effectiveness of the solution and the performance advantages over the existing solutions through simulation. The simulation results show that the ANC scheme can achieve higher transmission efficiency than the existing scheme. Secondly, they introduce the optimal storage allocation problem in distributed cloud storage based on network coding, the purpose of which is to search for the most reliable allocation that distributes the N data components to N data centers, given the failure probability P of each data center. Finally, the article proposes a polynomial-time optimal storage allocation(OSA) scheme to solve this problem. Simulation experiments show that OSA solution can greatly improve storage reliability.

In the field of cloud computing, energy consumption has been a concern. Energy efficiency issues of different dimensions are constantly being proposed, and researchers have proposed different energy efficiency algorithms and strategies. Based on different perspectives, many scholars classify

and summarize different energy efficiency strategies, but most of the classification and summary work lacks consistent and unified standards. In this article, ''A survey and taxonomy of energy efficiency relevant surveys in cloud-related environments,'' You *et al.*, have conducted a detailed investigation of cloud computing energy consumption problems and strategies and proposed independent classification standards. Based on the above observations, the future direction of energy consumption research is obtained. The classification mainly includes surveys of energy efficiency of the entire cloud-related system, energy efficiency surveys at a certain level or component of the cloud, surveys of all energy efficiency strategies, surveys of certain energy efficiency technologies, and other energy efficiency related surveys. After the analysis, the final direction of the future is given. The three directions include: Reduce energy consumption through multiple levels of integration, investigate energy-aware data management strategies, and integrate energy-aware data management strategies with other traditional energy efficiency technologies.

With the development and popularization of cloud computing, the cloud of enterprise services has become a trend, and the failure to adopt cloud services has become a potential risk. In large data centers, processor trends have shifted from traditional CPUs to dedicated chips, similar to the AI implementation process. In this article by He *et al.*, ''A survey to predict the trend of AI-able server evolution in the cloud,'' the authors have made a detailed investigation and research on the development process and design of the cloud computing center processor. At the same time, based on the analysis results, a hybrid new architecture for AI applications is conceived, by combining proprietary chips such as FPGA and ASIC with traditional CPUs to handle different categories of tasks. The survey expands the research horizon and provides researchers with a comprehensive tutorial on cloud service architecture to provide direction for future AI server design.

In cloud computing mode, the data center carries a large amount of computing and storage requirements. Since the data center usually uses a many-to-one communication mode, the arrival of a large number of server requests is likely to cause excessive congestion and data loss of the local server, which is inherently caused by the TCP protocol. In academia, many researchers have given many solutions, including the recently proposed software-defined networking approach. SDN provides a centralized platform for stream-level global visibility of all network traffic and the ability to perform accurate traffic engineering in the data center. The main work of this article, ''Detection and mitigation of congestion in SDN enabled data center networks: A survey,'' by Hafeez *et al.*, is to introduce the research of SDN to solve the congestion of data center networks, propose the classification of all solutions, and give the advantages and disadvantages of each type. The final analysis conclusions of this article determine the future research direction of this field.

In location-based services, the shortest path query problem has been widely understood and put into use. Due to the high overhead of querying the underlying road network, accessing map data through external requests is unaffordable, and how to access data efficiently and efficiently becomes a challenge. In this article, ''Efficient path query processing through cloud-based mapping services,'' Zhang *et al.*, propose two optimization methods to reduce the number of requests, thereby reducing the user query response time. The two methods are path sharing and path caching respectively. The basic idea of path sharing optimization is that if the origin and destination of the q value are located on the path, the path information of the query can be shared with another query q. The path cache is an extension of path sharing, which allows the LBS provider to answer path queries directly from the cache path. Through experiments, the optimized method can effectively reduce the number of requests by more than 35%.

With the development of network technologies, multiple network types coexist in the form of wireless networks. For most users, effective switching decisions can help users continue to get network services. However, traditional switching decisions are not suitable for drones that move and communicate in 3D space. In the article by Lee *et al.*, ''Intelligent handover scheme for drone using fuzzy inference systems,'' the authors define the parameters that represent the communication characteristics of three-dimensional space drones, and then propose a fuzzy reasoning method for handover decision. The fuzzy inference system consists of four steps. 1) Analyze terminal related information to select factors that can affect the drone switching decision. 2) The input data values are converted to membership functions. 3) The inference rules for handover decisions are designed and applied. 4) The switch is determined by considering the current information of the drone. The authors have proved the rationality of the proposed method through experiments.

With the development of cloud computing, energy conservation has become an important factor in cloud computing considerations. Users can share information with low overhead in different communities. However, as the number of users increases and the size of the network increases, it is a challenge to share information with low energy consumption. In this article by Xu *et al.*, ''Optimal control theory-based epidemic information spreading scheme for mobile social users with energy constraint,'' the authors propose an energy-constrained optimal control theory for epidemiological information dissemination of mobile users. In the method, the social relationship of mobile users is divided into four types based on blood, geography, work and interest relationships. At the same time, the authors develop an analytical model to assess the impact of social relations on information dissemination, and propose an information dissemination scheme based on control theory. The experimental data proves that the scheme can save energy and improve the quality of experience in the process of mobile user information dissemination.

The tailings dam is a dangerous source of artificially generated debris flows with high potential energy and is a necessary facility to maintain the normal operation of mining companies. The instability of the tailings dam requires real-time warning, which is of great significance for ensuring the safety of human life and property. The main work of this article by Dong *et al.*, ''Pre-alarm system based on real-time monitoring and numerical simulation using Internet of Things and cloud computing for tailings dam in mines,'' is based on the Internet of Things and wireless network, using sensors to build a key information system for the tailings dam. The system parameters include diving line, water level, deformation degree of the tailings dam and other indicators. The cloud platform can predict the state of the dive line based on real-time data, limit the balance state parameters, reservoir water level and rainfall, etc., and then establish a numerical simulation model. Through a series of mathematical methods for statistical calculations, the probability of the warning signal is finally obtained and notified. The article proves through practice that the early warning system is relatively stable and has the ability to integrate and verify key information.

Integrating the protection of medical information systems in cloud computing has become the norm, and the healthcare and public health industries are adopting a variety of cloud models. Because the data of the protection medical system, such as HIS, is essentially shared with other systems, with the participation of cloud computing, the data security risks of the system also increase, and the system risk is increased. In the article by Abrar *et al.*, ''Risk analysis of cloud sourcing in healthcare and public health industry,'' the authors adopt a method to timely evaluate the risk of the HIS cloud computing model, and analyze the impact and applicability of cloud computing on the HIS system by identifying HIS assets. Further experiments and analysis show that using a cloud computing environment can reduce the vulnerability and mitigate the threat to HIS integrity.

Because cloud computing has the characteristics of massive storage and computing resources, it is also commonly used to simulate the generation of various models such as the surface model LSM. And the Chinese Academy of Sciences' science cloud is based on data clouds and high-performance computing clouds, which are used to support LSM simulation. In this article, ''System for land surface model applications based on cloud computing,'' Luo *et al.*, used the Science Cloud software and hardware to build a prototype system for LSM. An integrated software package is designed for pre-processing and post-processing; the LSM Web portal is developed and statistical and visual. The final experiment indicates that the prototype system functions as expected.

In the development of cloud computing, location-based services (LBS) have always been a research hotspot. How to ensure the hidden protection of LBS services, both point-to-point and centralized architecture models, have their own shortcomings and defects. Therefore, in this article, ''Trajectory privacy preservation based on a fog structure for cloud location services,'' Wang *et al.*, propose a fog computing structure that uses virtual anonymity techniques to store important data to ensure physical control. Some of the important information of mobile users can be stored on the fog server to ensure better management. The authors consider the principles of similarity, intersection, practicability and relevance, and design a virtual rotation algorithm with multiple attributes. Based on the simulation experimental results, the proposed method can effectively provide enhanced privacy protection.

With the concept and development of the Internet of Things, cloud computing is improving. Among them, fog calculation is considered to be the most suitable calculation model for the Internet of Things. However, the following problems include the inevitable replacement of hardware and firmware, the uncertainty of operators, unclear infrastructure operation procedures, and unclear resource allocation. In ''User-participatory fog computing architecture and its management schemes for improving feasibility,'' Kim *et al.,* propose a user-involved fog computing architecture management solution to solve the above problem, in which the fog service instance placement optimization is performed based on the service usage of the participating users, which is formulated as a mixed-integer nonlinear programming problem and then linearized. Through simulation evaluation, this scheme can effectively optimize the fog calculation PRR when providing the same service to more users at the same time.

The popularity of cloud computing and high-performance computing creates serious challenges in energy consumption. Dynamic voltage and frequency scaling (DVFS) is an effective technique for energy saving. Many previous works addressed energy-officiate task scheduling based on DVFS. However, these works need to know the total workload of tasks, which is difficult for some real-time tasks requests. In the article by Wang *et al.*, ''A DVFS based energy-efficient tasks scheduling in a data center,'' the authors propose a new task model that describes the QoS requirements of tasks with the minimum frequency. In addition, energy consumption ratio (ECR) is defined to evaluate the efficiency of different frequencies and it is possible to convert the energy-efficient task scheduling problem into minimizing the total ECR. The proposed methods dispatch the coming tasks to the active servers by using servers as little as possible and adjusting the execution frequencies of relative cores to save energy. When a task is finished, a processor-level migration algorithm is adopted to reschedule remaining tasks among processors on an individual server and dynamically balance the workloads to lower the total ECR on this server. The experiments in the real test-bed system and simulation show that the proposed strategy outperforms others, which verifies the energy-saving benefits of this strategy.

In cloud computing, data owners host their data on cloud servers, and users (data consumers) can access the data from the cloud servers. This new paradigm of data hosting service

also introduces new security challenges that require an independent auditing service to check the integrity of the data in the cloud. Some existing methods for checking the integrity of the data cannot handle this problem efficiently and they cannot deal with the error condition. Thus, a secure and efficient dynamic auditing protocol should reject requests that are made with improper authentication. In addition, an excellent remote data authentication method should be able to collect information for statistical analysis, such as validation results. In the article by Feng *et al.*, ''An efficient protocol with bidirectional verification for storage security in cloud computing,'' the authors design an auditing framework for cloud storage systems and propose an efficient and privacy-preserving auditing protocol. Then, the auditing protocol is extended to support dynamic data operations, bidirectional authentication and statistical analysis. In addition, a better load distribution strategy is adopted, which greatly reduces the computational overhead of the client. Last, an error response scheme is also provided. Experiments show that the solution has the good error-handling ability and offers lower overhead expenses for computation and communication than other approaches.

Hybrid object storage systems provide opportunities to achieve high performance and energy efficiency with low cost for enterprise data centers. Existing object storage systems, however, distribute data objects in the system without considering the heterogeneity of the underlying devices and the asymmetric data access patterns. Therefore, the system performance and energy efficiency may degrade as data are placed on improper storage devices. Various real enterprise workloads are analyzed and found that read and write requests are not uniformly distributed to data objects. Based on these observations, in the article by Wu *et al.*, ''BOSS: An efficient data distribution strategy for object storage systems with hybrid devices,'' the authors propose a novel strategy, biased object storage strategy (BOSS), to reduce writes to SSDs and improve system performance for hybrid object storage systems. Different from conventional uniform and fixed data distribution strategies, the BOSS can distribute and migrate data objects to various types of devices dynamically, according to the data access patterns collected online. The experimental results show that the BOSS can reduce 64% of writes on SSDs and improve system performance by 29.51% on average, while maintaining a high level of load balance.

In the article by Ahn *et al.*, ''Competitive partial computation offloading for maximizing energy efficiency in mobile cloud computing,'' the authors newly model computation offloading competition when multiple clients compete with each other, so as to reduce energy cost and improve computational performance. Two types of destination of offloading request are considered, such as a cloudlet and a remote cloud. Here, the cloudlet consists of locally connected mobile terminals with low-latency and high bandwidth but suffering from task overload due to its limited computational capacity. On the other hand, the remote cloud has a high and stable capacity but high latency. To facilitate the competition model, on the destination sides, the authors have designed an energy-oriented task scheduling scheme, which aims to maximize the welfare of clients in terms of energy efficiency. Under this proposed job scheduling, as a joint consideration of the destination and client sides, competition behavior among multiple clients for optimal computation offloading is modeled and analyzed as a non-cooperative game by considering a trade-off between different types of destinations. Based on this game-theoretical analysis, the authors propose a novel energy-oriented weight assignment scheme in the mobile terminal side to maximize mobile terminal energy efficiency. Finally, the proposed scheme converges well to a unique equilibrium and maximizes the payoff of all participating clients.

Provisioning fault-tolerant scheduling in computational grid is a challenging task. Most of the existing fault tolerant scheduling schemes are either proactive or reactive. The emphasis for proactive schemes is on the reasons responsible for generating faults, whereas reactive mechanisms come into effect after failure detection. Unlike most existing mechanisms, in the article by Haider *et al.*, ''Dynamic and adaptive fault tolerant scheduling With QoS consideration in computational grid,'' the authors present a novel, dynamic, adaptive, and hybrid fault-tolerant scheduling scheme based on proactive and reactive approaches. In the proactive approach, the resource filtration algorithm picks resources based on resource location, availability, and reliability. Unlike most existing schemes, which rely on remotely connected resources, the proposed algorithm prefers to employ locally available resources as they might have less failure tendencies. To cope with the frequent turnover problem, the proposed scheme calculates resource availability time based on various newly identified parameters (e.g., mean time between availability) and picks highly available nodes for task execution. Resource reliability is an indispensable consideration in the proposed scheme and is calculated based on parameters such as jobs success or failure ratio and the types of failures encountered. An optimal resource identification algorithm is employed to determine and select optimal resources for job execution. The performance of the proposed scheme is validated through the GridSim toolkit. Compared with contemporary approaches, experimental results demonstrate the effectiveness and efficiency of the proposed scheme in terms of various performance metrics, such as wall clock time, throughput, waiting and turnaround time, number of checkpoints, and energy consumption.

In delay tolerant networks (DTNs), the delivery rate and delivery speed are restricted by node selfishness. To promote the delivery rate and reduce the delivery delay in DTNs, in the article by He *et al.*, ''HITM: A hybrid incentive trade model for data forwarding in DTNs,'' the authors propose a hybrid incentive trade model (HITM), which uses reputation compensation to stimulate nodes to give up

their temporary benefits and transfer their forwarding missions to other more qualified nodes. Furthermore, HITM gives credit payment and reputation promotion to nodes whose mission transferring behaviors are capable of reducing delivery delay or promoting delivery reliability, and conversely punishes nodes whose mission transferring behaviors could prolong the delivery delay or impair the delivery reliability. Trace-driven experiments are performed to compare HITM with previous representative incentive schemes. The experimental results demonstrate that the HITM can effectively limit node selfishness, thereby promoting the delivery rate as well as reducing the delivery delay.

With the tremendous growth of cloud computing and Internet-scale online services, massive geographically distributed infrastructures have been deployed to meet the increasing demand, resulting in significant monetary expenditure and environmental pollution caused by energy consumption. In the article by Zhao *et al.*, ''On minimizing energy cost in internet-scale systems with dynamic data,'' the authors investigate how to minimize the long-term energy cost of dynamic Internet-scale systems by fully exploiting the energy efficiency in geographic diversity and variation over time. To this end, the authors formulate a stochastic optimization problem by considering the fundamental uncertainties of Internet-scale systems, such as the dynamic data. A dynamic request mapping algorithm is developed to solve the formulated problem, which balances the tradeoff between energy cost and delay performance. The designed algorithm makes real-time decisions based on current queue backlogs and system states, and does not require any knowledge of stochastic job arrivals and service rates caused by dynamic data queries. The authors formally prove the optimality of the approach. Extensive trace-driven simulations verify the theoretical analysis and demonstrate that the proposed algorithm outperforms the baseline strategies with respect to system cost, queue backlogs, and delay.

NAND flash memory has many advantages, including a small form factor, non-volatility, and high reliability. However, problems caused by physical limitations, such as asymmetric I/O latencies and out-of-place updates, still need to be resolved. By using a probability of reference (PR) to select a candidate page as the victim page, in the article by Yuan *et al.*, ''PR-LRU: A novel buffer replacement algorithm based on the probability of reference for flash memory,'' the authors propose a novel buffer replacement algorithm called PR least recently used to enhance the flash memory performance. To predict whether a page may be referenced in the future, three variables are used to calculate a page's PR. In addition, the performance overhead of the number of write operations, the hit ratio, and the runtime are improved by using a novel PR strategy. The algorithm is implemented and tested on the flash simulation platform Flash-DBSim. The results indicate that the proposed algorithm provides improvements of up to 7% for the hit ratio with an improvement of up to 36.7% for the overall runtime compared with other approaches.

As capacity and complexity of on-chip cache memory hierarchy increases, the service cost to the critical loads from last level cache (LLC), which are frequently repeated, has become a major concern. The processor may stall for a considerable interval while waiting to access the data stored in the cache blocks in LLC, if there are no independent instructions to execute. To provide accelerated service to the critical loads requests from LLC, in the article by Khoshavi *et al.*, ''Read-tuned STT-RAM and eDRAM cache hierarchies for throughput and energy optimization,'' the authors concentrate on leveraging the additional capacity offered by replacing SRAM-based L2 with spin-transfer torque random access memory (STT-MRAM) to accommodate frequently accessed cache blocks in exclusive read mode in favor of reducing the overall read service time. The proposed technique improves the temporal locality while preventing cache thrashing via sufficient accommodation of the frequently read reused fraction of working set that may exhibit distant re-reference interval in L2. Experimental results show that the proposed technique can reduce the L2 read miss ratio by 51.7% on average compared to conventional STT-MRAM L2 design across PARSEC and SPEC2006 workloads while significantly decreasing the L2 dynamic energy consumption.

In conclusion, we would like to thank the authors who submitted their high-quality manuscripts to this Special Section. We would like to acknowledge the contribution of the reviewers who have participated in the review process, and provided helpful comments and suggestions to the authors to improve their manuscripts. We especially thank Professor Derek Abbott, the Editor-in-Chief of IEEE ACCESS, for his advice and strong support during the process of putting together this Special Section. We also hope that the readers will enjoy reading the articles included in this Special Section.

**GUANGJIE HAN,** *Guest Editor*
*Department of Information and Communication System*
*Hohai University*
*Nanjing 211100, China*

**GANGYONG JIA,** *Guest Editor*
*Department of Computer Science*
*Hangzhou Dianzi University*
*Hangzhou 310018, China*

**JAIME LLORET,** *Guest Editor*
*Department of Communications*
*Polytechnic University of Valencia*
*46022 Valencia, Spain*

***YUANGUO BI,*** *Guest Editor*
*Department of Electrical and Computer Engineering*
*University of Waterloo*
*Waterloo, ON N2L 3G1, Canada*

**GUANGJIE HAN** (Senior Member, IEEE) received the Ph.D. degree from Northeastern University, Shenyang, China, in 2004.

In February 2008, he finished his work as a Postdoctoral Researcher with the Department of Computer Science, Chonnam National University, Gwangju, South Korea. From October 2010 to October 2011, he was a Visiting Research Scholar with Osaka University, Suita, Japan. From January 2017 to February 2017, he was a Visiting Professor with the City University of Hong Kong, China. He is currently a Professor with the Department of Information and Communication System, Hohai University, Changzhou, China, and a Distinguished Professor with the Dalian University of Technology, Dalian, China. He has over 400 peer-reviewed journal and conference papers, in addition to 140 granted and pending patents. His H-index is 41 and i10-index is 135 in Google Citation (Google Scholar). The total citation of his articles by other people is more than 6500 times. His current research interests include the Internet of Things, the industrial Internet, machine learning and artificial intelligence, mobile computing, and security and privacy.

Dr. Han is a Fellow of the U.K. Institution of Engineering and Technology (FIET). He had been awarded the 2020 IEEE Systems Journal Annual Best Paper Award and the 2017–2019 IEEE Access Outstanding Associate Editor Award. He has served as the Chair of organizing and technical committees of many international conferences. He has also served on the Editorial Board for up to ten international journals, including the IEEE NETWORK, the IEEE SYSTEMS, the IEEE/CCA JOURNAL OF AUTOMATICA SINICA (JAS), IEEE ACCESS, and *Telecommunication Systems*. He has a Guest Edited a number of special issues in the IEEE journals and magazines, including the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS (JSAC), *IEEE COMMUNICATIONS*, the IEEE WIRELESS COMMUNICATIONS, the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, *Computer Networks*, and so on.

**GANGYONG JIA** (Member, IEEE) received the Ph.D. degree from the Department of Computer Science, University of Science and Technology of China, Hefei, China, in 2013.

He is currently an Associate Professor with the Department of Computer Science, Hangzhou Dianzi University, China. He has published over 50 articles in related international conferences and journals, such as the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, the IEEE TRANSACTIONS ON CLOUD COMPUTING, the IEEE INTERNET OF THINGS, the *Journal of Network and Computer Application*, the IEEE SYSTEM JOURNAL, *Enterprise Information Systems*, *Sensors*, *Personal and Ubiquitous Computing*, IEEE ACCESS, and so on. He has served as a Reviewer for the IEEE TRANSACTIONS ON COMPUTER, the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, *IEEE COMMUNICATIONS MAGAZINE*, the IEEE TRANSACTIONS ON MODELING AND PERFORMANCE EVALUATION OF COMPUTING SYSTEMS, the IEEE TRANSACTIONS ON SUSTAINABLE COMPUTING, *Applied Soft Computing*, the *International Journal of Parallel Programming*, and *Microprocessors and Microsystems*. His current research interests are the IoT, cloud computing, edge computing, power management, and operating systems.

Dr. Jia is a member of CCF.

**JAIME LLORET** (Senior Member, IEEE) received the B.Sc. and M.Sc. degrees in physics, in 1997, the B.Sc. and M.Sc. degrees in electronic engineering, in 2003, and the Ph.D. degree in telecommunication engineering (Dr. Ing.), in 2006.

He worked as a network designer and an administrator in several enterprises. He is currently a Cisco Certified Network Professional Instructor. He is also an Associate Professor with the Polytechnic University of Valencia. He is also the Chair of the Integrated Management Coastal Research Institute (IGIC). He is also the Head of the Active and Collaborative Techniques and use of Technologic Resources in the Education (EITACURTE) Innovation Group. He is also the Director of the University Diploma Redes y Comunicaciones de Ordenadores. He was the Director of the University Master Digital Post Production for the term 2012–2016. He has authored 22 book chapters and has more than 450 research articles published in national and international conferences, international journals (more than 200 with ISI Thomson JCR). He has been the co-editor of 40 conference proceedings and a guest editor of several international books and journals. Since 2016, he has been the Spanish Researcher with highest H-index in the *Telecommunications* journal list according to Clarivate Analytics Ranking. He has been involved in more than 450 Program committees of international conferences, and more than 150 organizations and steering committees. He has led many local, regional, national, and European projects.

Dr. Lloret is an IEEE Senior, an ACM Senior, and an IARIA Fellow. He was the Vice-Chair for the Europe/Africa Region of Cognitive Networks Technical Committee (IEEE Communications Society) for the term 2010–2012, and the Internet Technical Committee (IEEE Communications Society and Internet society) for the term 2011–2013. He was the Internet Technical Committee Chair (IEEE Communications Society and Internet society) for the term 2013–2015. He is the IARIA Journals Board Chair (eight journals). He is also the Chair of the Working Group of the Standard IEEE 1907.1. He has been the General Chair (or Co-Chair) of 45 International workshops and conferences, such as the Chairman of SENSORCOMM 2007, UBICOMM 2008, ICNS 2009, ICWMC 2010, eKNOW 2012, SERVICE COMPUTATION 2013, COGNITIVE 2013, ADAPTIVE 2013, 12th AICT 2016, 11th ICIMP 2016, 3rd GREENETS 2016, 13th IWCMC 2017, 10th WMNC 2017, 18th ICN 2019, 14th ICDT 2019, 12th CTRQ 2019, and GC-ElecEng 2019; the Co-Chairman of ICAS 2009, INTERNET 2010, MARSS 2011, IEEE MASS 2011, SCPA 2011, ICDS 2012, 2nd IEEE SCPA 2012, GreeNets 2012, 3rd IEEE SCPA 2013, SSPA 2013, AdHocNow 2014, MARSS 2014, SSPA 2014, IEEE CCAN 2015, 4th IEEE SCPA 2015, IEEE SCAN 2015, ICACCI 2015, SDRANCAN 2015, FMEC 2016, 2nd FMEC 2017, 5th SCPA 2017, XIII JITEL 2017, 3rd SDS 2018, 5th IoTSMS 2018, 4th FMEC 2019, 10th International Symposium on Ambient Intelligence, and 6th SNAMS 2019; and the Local Chair of MIC-WCMC 2013 and IEEE Sensors 2014. He is the Editor-in-Chief of the *Ad Hoc and Sensor Wireless Networks* (with ISI Thomson Impact Factor), the international journal *Networks Protocols and Algorithms*, and the *International Journal of Multimedia Communications*. He is also an Associate Editor-in-Chief of *Sensors* in the Section Sensor Networks, he is an Advisory Board Member of the *International Journal of Distributed Sensor Networks* (both with ISI Thomson Impact factor). He is (or has been) an Associate Editor of 46 international journals (16 of them with ISI Thomson Impact Factor).

**YUANGUO BI** (Member, IEEE) received the B.Sc. degree from Liaoning University, Shenyang, China, in 2003, and the M.Sc. and Ph.D. degrees in computer science from Northeastern University, Shenyang, in 2006 and 2010, respectively.

He was a Visiting Ph.D. Student with the Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, Canada, from 2007 to 2009. He joined the School of Computer Science and Engineering, Northeastern University, China, as an Associate Professor, in 2010. He was a Professor with the School of Computer Science and Engineering, Northeastern University. He has authored or coauthored 30 journal/conference papers, including high-quality journal articles, such as those appearing in the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, *IEEE COMMUNICATIONS MAGAZINE*, and the IEEE Wireless Communications and mainstream conferences, such as IEEE Globecom and IEEE ICC. His current research interests include medium access control, QoS routing, multi-hop broadcast, mobility management in vehicular networks, and software defined networking.

Dr. Bi has served as a TPC member for many IEEE conferences, e.g., IEEE ICC, IEEE Globecom, and IEEE VTC. He has served an Editor/Guest Editor for *IEEE COMMUNICATIONS MAGAZINE*, the IEEE WIRELESS COMMUNICATIONS, IEEE ACCESS, and *SpringerPlus*.