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Special Issue on Computational Sustainability

THE growing field of sustainability science and technology focuses on the design of products, processes, and services to meet economic and societal needs with minimal impact on the global ecosystem. An important emerging area of sustainability science is to develop computational models, methods and tools for decision making for a broad range of sustainability related applications such as conservation of natural resources and ecosystem, enhancing human health and well-being, minimizing impact of human activities on the environment, intelligent management and conservation of scarce resources, reducing impact of disasters, managing stress on urban infrastructures, etc. Solutions to these sustainability problems often depend on advances in computational areas, including optimization, modeling, data management and analytics, advanced sensing techniques, human computer interaction, and intelligent systems. The sustainability of computing itself is an important topic of concern and relates to effective management of energy consumption, operation under energy constraints, and dealing with environmental impact of rapid obsolescence of electronic devices and systems. The computational sustainability is woven into many areas, including system design, computer architecture, programming language, compilers, networking, etc.

Motivated by these considerations, papers were solicited on all aspects of computing and communications technologies for enhancing sustainability. In particular, the specified areas included computational models, energy issues in large scale computing or monitoring systems, data management and analytics for sustainability applications, management and optimization of smart infrastructures, health and wellness monitoring and management, disaster response and management, lifecycle of technology design and use, and case studies.

We received a total of 17 papers, of which we eventually selected 10. These papers cover a wide range of subjects relating to sustainability.

A. SUSTAINABILITY OF COMPUTING SYSTEMS

Maryline Chetto (University of Nantes, France) studies a scheduling problem in which every job is associated with a release time, deadline, required computation time, and required energy. A semi-online Earliest Deadline First based scheduling algorithm is proposed for jobs executing on a uniprocessor system that is supplied by a renewable energy source and uses a rechargeable storage unit with limited capacity. The algorithm uses notions of energy demand and slack energy besides the processor demand and slack time.

Yan Wang, Kenli Li, Hao Chen (Hunan University, China), Ligang He (University of Warwick, U.K.), and Kegin Li (State University of New York) present an integer linear programming (ILP) method to address the problem of energy-aware heterogeneous data allocation and task scheduling on heterogeneous multiprocessor systems for real-time applications. In a heterogeneous distributed shared-memory multiprocessor system, an important problem is how to assign processors to real-time application tasks, allocate data to local memories, and generate an efficient schedule in such a way that a time constraint can be met and the total system energy consumption can be minimized. The proposed algorithms exhibit excellent performance in evaluation on two heterogeneous multiprocessor systems.

Nidhi Singh and Shrisha Rao (International Institute of Information Technology, Bangalore) demonstrate two online ensemble learning methods for workload prediction in large scale server systems. These methods guide in identifying servers, time intervals, and other parameters that are needed for building solutions based on techniques like virtualization and server consolidation for server systems. The goal is to reduce server energy consumption, cooling requirements, carbon footprint, and so forth, thereby leading to improved sustainability of the holistic server infrastructure. The effectiveness of these algorithms was demonstrated using real and synthetic data sets.

Peter Garraghan, Ismael Solis Moreno, Paul Townend, and Jie Xu (University of Leeds, U.K.) present a comprehensive analysis of the impact of failures on energy consumption in a real-world large-scale Cloud system (comprising over 12,500 servers), including the study of failure and energy trends of the spatial and temporal environmental characteristics. Their results show that 88% of task failure events occur in lower priority tasks producing 13% of total energy waste, and 1% of failure events occur in higher priority tasks due to server failures producing 8% of total energy waste. These results highlight an unintuitive but significant impact on energy consumption due to failures, providing a strong foundation for research into dependable energy-aware Cloud computing.

B. SUSTAINABILITY OF WIRELESS SENSOR NETWORKS

Roy Hsu, Cheng-Ting Liu, and Hao-Li Wang (National Chiayi University, Taiwan) introduce a reinforcement learning-based throughput on demand (ToD) provisioning

of dynamic power for sustaining perpetual operation and satisfying the ToD requirements for today's energy harvesting wireless sensor nodes. The mechanism monitors the environmental state of such nodes and adjusts their operational duty cycle under criteria of energy neutrality to meet the demanded throughput. Outcomes of these observation-adjustment interactions are then evaluated by feedback/reward that represents how well the throughput on demand requests are met; subsequently, the observation-adjustment-evaluation process, so-called reinforcement learning, continues. The authors show 10.7% throughput improvement under the most stringent ToD requirement.

Shiva Shankar (AIT, Bangalore), Varaprasad Prasad (BMSCE, Bangalore), Suresh H. N. (BIT, Bangalore), and Jayanthi G (AIT, Bangalore), develop a power aware routing protocol that increases the lifetime of mobile ad hoc networks (MANETs). The proposed method identifies the capacity of a node not just by its residual battery power, but also by the expected energy spent in reliably forwarding data packets over a specific link. Using a mini-max formulation, the method selects the path that has the largest packet capacity at the smallest residual packet transmission capacity. They report more than 20% reduction in energy consumption along with decrease in the mean delay especially for high load networks while achieving a good packet delivery ratio.

Yu Luo, Lina Pu, Michael Zuba, Zheng Peng, and Jun-Hong Cui (University of Connecticut) advocate cognitive acoustic (CA) as a promising technique to develop an environment-friendly underwater acoustic network (UAN) with high spectrum utilization. Underwater cognitive acoustic networks (UCANs) are highly challenging due to the unique features of underwater channel and acoustic systems including the fact that they need to accommodate both natural acoustic systems (marine mammals) and man-made systems. The article provides a survey of the challenges and several techniques to address them.

C. SUSTAINABILITY OF ECONOMIC, ENVIRONMENTAL, AND SOCIAL ISSUES

The first paper by Siny Joseph (Kansas State University) and Vinod Namboodiri and Vishnu Dev (Wichita State University) develop an analytical economic framework as it applies to mobile phones by analyzing a market scenario of two firms competing under a differentiated Bertrand duopoly model. The framework and its analysis help verify intuitions about the reasons that affect a firm's decision to offer an environmentally sustainable choice for consumers and consider the feasibility, possible benefits, and challenges in increasing device lifespan, including technical challenges. The results of this paper also provide guidance on the relative impacts of various factors involved on device lifespan, such as user-experience, subsidies, and differences in underlying costs to providers.

The next paper by Iyswarya Narayanan (Pennsylvania State University), Arunchandar Vasan, Venkatesh Sarangan, and Jamsheeda Kadengal (Tata Consultancy Services), and Anand Sivasubramaniam (Pennsylvania State University) considers non-revenue water as a major issue faced by water utilities in developing economies. To address this, a utility would require a permanent metering infrastructure. They present a solution to understand the operations of water network even in absence of hydraulic models. The intuition is that the static part of the network contributes significantly to the network operations. The authors analyze water distribution networks using augmented centrality measures. They use readily available static information about the network elements rather than calibrated dynamic information and model each network element appropriately.

The next article, by Dagiang Zhang (Nanjing Normal University, China), Robert Hsu (Chung Hua University), Min Chen (HUST), Quan Chen (Shanghai Jiao Tong University), Naixue Xiong (Colorado Technical University), and Jaime Lloret (Polytechnic University of Valencia), proposes BiFu – a newly-fashioned scheme for the cold-start problem in social recommender systems based on the Bi-clustering and Fusion techniques. To identify the rating sources for recommendation, it introduces the concepts of popular items and frequent raters. To overcome the data sparseness and the rating diversity, BiFu employs the Bi-clustering and the smoothing technique, respectively. Finally, it makes recommendation by fusing social media suggestions from both item and user clusters. Experimental results demonstrate that BiFu significantly alleviates the cold start problem in terms of accuracy and scalability.

We hope that this special issue would be of considerable interest to the *readership of IEEE TETC* concerned with the role of computing and communications in sustainability, and these articles would spawn further research in this very important and timely subject area.

We would like to thank the authors of the papers for their interesting work and the submission to this special issue and their effort in revising the papers – sometimes multiple times – in response to the reviews. We would also like to thank them for their patience with the review process. We would like to thank the reviewers for doing an excellent job of reviewing the papers. Finally, we would like to thank the *TETC* editor, Dr. Fabrizio Lombardi for his guidance and support during the long process of review and paper selection.

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LEI WANG received the B.S. and M.S. degrees from Tsinghua University, Beijing, China, in 1992 and 1996, respectively, and the Ph.D. degree from the University of Illinois at Urbana-Champaign, Champaign, IL, USA, in 2001.

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