Guest Editors’ Introduction: Special Issue on Cyber-Physical Systems (CPS)

Symeon Papavassiliou, Senior Member, IEEE, Nei Kato, Yunhao Liu, Cheng-Zhong Xu, Senior Member, IEEE, and Xinbing Wang

C YBER-PHYSICAL systems refer to the tight link between computational, virtual, and physical resources that drive the potential of having a pervasive effect in the citizens everyday life. Cyber-physical systems find direct applicability in a wide range of areas and disciplines, and promise to transform our world with systems that will far exceed those of today in terms of: effectiveness, adaptability, energy efficiency, precision, reliability, safety, usability, scalability, and stability. Moreover, recently, the Sensor Web concept came into the foreground, aiming at combining distributed sensing with the ubiquitous connectivity and accessibility of the web, therefore facilitating the close interaction of the digital world with the physical world. Toward merging the two main and different features of those systems, those of information-centric character and node-centric physical world connectivity, well-defined analytical models, methodologies, and experimental validations are required of how to build such systems capable of coping with the entire chain of operations and orchestrating the various parts together in a flexible, efficient, and economic way. This special issue of the IEEE Transactions on Parallel and Distributed Systems (TPDS) highlights some of the emerging issues in cyber-physical systems, along with their applicability, in an innovative and insightful way.

The papers in this special issue are organized into four thematic groups. The first set of six papers focuses on the communication, scheduling, and efficiency of smart grids. Specifically, in “Reducing Electricity Cost of Smart Appliances via Energy Buffering Framework in Smart Grid,” a novel energy buffering framework to intelligently schedule the distributed energy storage for the cost reduction of smart appliances is proposed. In “A Statistical Analysis on Operation Scheduling for an Energy Network Project,” the authors statistically analyze suboptimal operation schedules that are computed for a demonstrative project of regional power grids with various new energies. In “Optimal Power Management of Residential Customers in the Smart Grid,” the focus is placed on minimizing the expected electricity cost with real-time electricity pricing from the perspective of residential customers.

The next three papers in the smart grid thematic area deal with communication issues in smart grids. Specifically, in “Alleviating Solar Energy Congestion in the Distribution Grid via Smart Metering Communications,” the congestion caused by power surpluses produced from households’ solar units is considered and a model for the disconnection process via smart metering communications between smart meters and the utility control center is proposed. In “EPPA: An Efficient and Privacy-Preserving Aggregation Scheme for Secure Smart Grid Communications,” a privacy-preserving multidimensional data aggregation methodology is presented which has significantly less computation and communication overhead than existing approaches in smart grid communications. In “Scalable Distributed Communication Architectures to Support Advanced Metering Infrastructure in Smart Grid,” the benefits of the adoption of distributed communication architectures over traditional centralized ones are argued and quantified via appropriate metrics and costs.

A key focus of cyber-physical systems is the appropriate use of sensor networks and data. The next set of four papers all deal with techniques related to issues associated with coverage, sensing, and query processing in sensor networks. In “Covering Targets in Sensor Networks: From Time Domain to Space Domain,” the problem of scheduling energy-limited sensors to monitor physical targets is considered by optimizing network lifetime while satisfying coverage requirements of the physical targets. In “Maintaining Quality of Sensing with Actors in Wireless Sensor Networks,” the authors, aiming at maintaining the quality of sensing in a wireless sensor network, present a methodology where actors are used to allocate spare sensors to sensor-deficient regions (sensor allocation) or to relocate sensors from sensor-abundant regions to sensor-deficient regions (sensor relocation). In “A General Framework for Efficient Continuous Multidimensional Top-k Query Processing in Sensor Networks,” a sensor network query framework is presented where the sensor network maintains an efficient dominant graph data structure for data readings, while a simple top-k extraction algorithm is used for user query processing. Finally, in “COSE: A Query-Centric Framework of Collaborative Heterogeneous Sensor Networks,” an optimal strategy of query processing with respect to energy efficiency is presented in an environment where multiple heterogeneous sensor networks collaborate with each other for effective and efficient processing of queries.

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Published by the IEEE Computer Society
The next set of six papers covers important operational aspects of various cyber-physical systems, such as security, robustness, control, and effective resource sharing. In “Security and Discoverability of Spread Dynamics in Cyber-Physical Networks,” the authors develop graph theoretic characterizations of security and discoverability for a canonical model that can represent spread dynamics of numerous cyber-physical networks of interest. In “Optimal Allocation of Interlinking Flows to Interconnected Cyber-Physical Systems: Interdependence, Cascade Failures and Robustness,” the optimum interlink allocation strategy against random attacks in a cyber-physical system consisting of two interacting networks, i.e., a cyber-network overlaying a physical-network, is studied and characterized. In “Dependability Analysis of Control Center Networks in Smart Grid Using Stochastic Petri Nets,” stochastic Petri nets (SPNs) are used to model, analyze, and measure the reliability and availability of control center networks in smart grids through analyzing both the transient and steady-state probabilities. In “Quantitative Analysis of Load Redistribution Attacks in Power Systems,” the authors deal with the modeling and identification of load redistribution attacks in electric grid toward deploying specific protection strategies to avoid the most damaging effect. In “Fidelity-Aware Utilization Control for Cyber-Physical Surveillance Systems,” a novel approach to holistically address the fidelity and timeliness requirements of wireless cyber-physical surveillance systems is proposed. Finally, in “Radio Resource Management for QoS Guarantees in Cyber-Physical Systems,” a framework for sharing radio resources efficiently in a large-scale distributed CPS comprised of numerous machines with the existing wireless networks while maintaining sufficient quality-of-service for machine-to-machine communications is described and evaluated.

Finally, the last set of three papers deals with application of different aspects of cyber-physical systems in vehicular and avionics systems. In “Sensor Data Fusion Algorithms for Vehicular Cyber-Physical Systems,” the focus is placed on the development of efficient sensor data fusion algorithms to be combined with a probe data service intended for use in vehicular on-board units (OBU) in order to transmit the data collected by in-vehicle sensors in real time via wireless communication links to road-side units. In “Toward Effective Service Scheduling for Human Drivers in Vehicular Cyber-Physical Systems,” a novel service scheduling approach in a vehicular cyber-physical system is presented where the goal is to deliver up to a certain number of services, each having a time dependent and possibly decreasing utility to a subset of intended drivers by taking a human factors standpoint. Finally, in “Scheduling Heterogeneous Flows with Delay-Aware Deduplication for Avionics Applications,” the authors present a low complexity and easy to implement scheduling scheme for avionics networks in order to achieve flexibility in handling burst flows and efficiently save bandwidth, while at the same time providing required delay guarantee.

The guest editorial team would like to express their appreciation to the authors of all the submissions, which were impressive, both in quantity and quality. We are also grateful to all the reviewers for their high quality and timely expert reviews that provided many valuable suggestions to the authors. We would like to further thank Professor Ivan Stoimenov, Editor-in-Chief of IEEE Transactions on Parallel and Distributed Systems, for his support. Finally, we owe a debt of gratitude to the whole editorial team of IEEE TPDS who provided us assistance and continuous support throughout the whole process.

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Guest Editors

Symeon Papavassiliou received the diploma in electrical engineering from the National Technical University of Athens (NTUA), Greece, in 1990 and the MSc and PhD degrees in electrical engineering from Polytechnic University, Brooklyn, New York in 1992 and 1995, respectively. He is an associate professor in the School of Electrical and Computer Engineering, NTUA, Greece. Before joining NTUA, he was an assistant professor at the New Jersey Institute of Technology (NJIT), while from 1995 to 1999, he was a senior technical staff member at AT&T Laboratories in New Jersey. He was awarded the Best Paper Award at IEEE INFOCOM ’94, the AT&T Division Recognition and Achievement Award in 1997, the US National Science Foundation (NSF) CAREER Award in 2004, and the Best Paper Award at IEEE WCNC ’12. He has also been a founding member and associate director of the New Jersey Center for Wireless Networking and Internet Security. Dr. Papavassiliou has an established record of publications in the field of computer and communication networks, with more than 170 technical journal and conference published papers. He is a senior member of the IEEE, an associate editor for the IEEE Transactions on Parallel and Distributed Systems, and a technical editor for IEEE Wireless Communications.

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