Guest Editorial: Smart Grid Communications Systems

WELCOME to this Special Issue of the IEEE SYSTEMS JOURNAL. This Special Issue is devoted to the topic of the latest research and development on smart grid communications systems. The future-generation smart grid is a modernized grid that proactively uses state-of-the-art information technology in the areas of sensing, communications, control, and computing to improve efficiency, sustainability, reliability, stability, and security. The success of the smart power grid is highly dependent on the communication technologies and architectures that support efficient and reliable end-to-end two-way information flows. In addition to delivering a large amount of metered power data, the communication architecture is required to support market- and business-related issues, including active demand management, load balancing, self-healing and operation in islanded mode, and seamless integration of renewable energy sources. Due to its inherent advantage of low-cost deployment, wireless solutions play a crucial role in the smart grid architecture.

The aim of this Special Issue is to present a collection of high-quality research papers that report the latest research advances in smart grid communication systems. In this Special Issue, we selected 24 papers. The selected papers covered the following important topics in the field of smart grid: communications quality-of-service (QoS), optimization and control, demand response management, security and privacy, node placement, scheduling, economic approaches, and medium-access control. A detailed overview of the selected works is given below.

The first paper, *Event-Driven and Hybrid Communication between Meters in Smart Grid*, uses the internal metering data to elicit the new information categories, characterizing the variations of power flows in time dimension. The capability to recognize the events and their sequences originates from the new information flows in smart grids. The author also discusses how to exploit the process knowledge in grid's control. The proposed scheme enables the detection, understanding, and management of energy dynamics.

The second paper, *Adaptive Quickest Estimation Algorithm for Smart Grid Network Topology Error*, proposes a quickest estimation scheme to determine the network topology as quickly as possible with given accuracy constraints from the dispersive environment. A Markov-chain-based analytical model is also constructed to systematically analyze the proposed scheme for the online estimation. The work configures the system parameters for the guaranteed performance in terms of the false-alarm rate and missed detection ratio under a detection delay constraint. Results show that the proposed scheme achieves the minimum average stopping time, but retains the comparable estimation accuracy and false-alarm rate.

The third paper, *Privacy-Preserving Power Request in Smart Grid Networks*, proposes a privacy-preserving power request (PPP) scheme to fulfill the security requirements. In particular, when requesting for the power with the authentication guarantee, the source smart meter (SM) will not leak the identity to the power generator and substations of the smart grid. In addition, the proposed PPP scheme is efficient in terms of communication and computation overhead.

The fourth paper, *Multi-appliance Recognition System with Hybrid SVM/GMM Classifier in Ubiquitous Smart Home*, proposes a set of multiappliance recognition system. The system designs a single SM using a current sensor and a voltage sensor in combination with a microprocessor to meter multiappliances. After fuzzy processing of the power information read through the SM and extraction of the power features, electric appliances are classified using the hybrid support vector machine/Gaussian mixture model (SVM/GMM) classification model. The proposed system is able to determine the power features extracted through the waveform by extracting the operation waveform of electric appliances, then the household appliances that are in use can be recognized with the household power supply terminal, and their information can be reported to users to achieve ubiquitous recognition services.

The fifth paper, *Smart Grid Network Optimization: Data-Quality-Aware Volume Reduction*, investigates data traffic management in smart grid networks, in which huge volumes of data produced by advanced meters cannot be fully delivered to utility data centers due to limited bandwidth. To develop a solution for optimizing traffic flow, the authors exploit a particular characteristic of this network—power-related applications can benefit from different levels of data quality along the path to the final destination. The formulated optimization problem is that of computing for each flow the amount of volume reductions in different locations, so as to maximize overall revenue. For the offline case, the work proposes an efficient near-optimal solution, whereas for the online case, the work derives almost tight polylogarithmic upper and lower bounds on the competitive ratio.

The sixth paper, *A Beamforming Approach to Smart Grid Systems based on Cloud Cognitive Radio*, uses cognitive radio (CR) channels for communication among a wireless network of SMs. The authors show a beamforming approach that effectively mitigates the self-interference effects of the SM channel. The beamforming approach is based upon the minimum-mean-square-error method in SM systems. The authors propose novel channel estimation and noise-plus-interference power estimation methodologies that efficiently exploit the preamble feature of the IEEE 802.22 WRAN. The framework is premised upon the utilization of a cloud computing smart grid infrastructure that hosts the IEEE 802.22 WRAN CR standard.

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The seventh paper, *Network Virtualization for Smart Grid Communications*, proposes a network virtualization-based framework for smart grid communications. In the framework, real-time services are supported by virtual networks that are mapped to two physical networks simultaneously, i.e., WMN and PLC network. The WMN for network virtualization is designed to adopt orthogonal frequency-division multiple access as the multiple-access scheme. This way, different virtual networks are allocated distinct subcarriers to be separated gracefully. Concurrent transmission in multiple subcarriers brings about diversity improvement, which is another benefit of the framework. Since the mapping and subcarrier assignment problem is NP-hard, a heuristic solution is developed to solve the problem efficiently and effectively. Simulation results reveal the effectiveness of our proposed framework.

The eighth paper, *Optimal Placement of PMUs and Communication Links in a Power System with Constraint on Data Availability*, presents a solution to placing a minimum number of phasor measurement units (PMUs) and communication links in a power system so that the steady-state availability of synchrophasor data at each bus meets a prescribed level. For this purpose, a Markov model suitable for the evaluation of synchrophasor availability is built. A five-bus power system is used to demonstrate the problem formulation, and placement results are presented. A method to treat a large power system as interconnected smaller power systems with common boundary buses is proposed to address the curse of dimensionality encountered. Each smaller power system formulates an independent optimal placement problem with constraints on matching boundary placement. The steps involved are illustrated through a 14-bus system. The complexity and optimality of a divided problem are compared with that of the original problem.

The ninth paper, *Achieving Accountability in Smart Grids*, argues that accountability mechanisms should be involved in smart grid designs. A feasible architectural framework for the smart grid is provided based on the U.S. National Institute of Standards and Technology smart grid interoperability standards. The authors design two separate accountable communication protocols using the proposed architecture with certain reasonable assumptions: One represents home area network (HAN), and the other represents neighborhood area network (NAN). Analysis and simulation results indicate that the design works well, and it may cause all power loads in HAN and NAN to become accountable.

The tenth paper, *Towards a Secure, Wireless-Based, Home Area Network for Metering in Smart Grids*, takes a comprehensive look at wireless security in the SM-based HAN scenario. Subsequently, some countermeasures are developed that can be used by both the utility company and the customer, and are integrated into a common framework called SecureHAN that can be agreed to by both. Additionally, the experience from implementing the SecureHAN framework using COTS hardware is described including possible challenges.

The 11th paper, *On the Capacity of a Wireless Backhaul for the Distribution Level of the Smart Grid*, proposes a linear chain multihop wireless communication architecture to meet application requirements of the communication backhaul. Based on capacity limitations first seen in the simulation results, a theoretical analysis is done to understand the data carrying capacity of using linear chain wireless technologies for the communication backhaul. The AMI application scenario is also used as a case study to understand the implications of any limitations imposed by the proposed communication architecture.

The 12th paper, *Effects of Communication Network Performance on Dynamic Pricing in Smart Power Grid*, studies the effects of network delay and transmission error on achieving a desired power load through dynamic pricing. The study finds that these communication network impairments may impose a lower bound on price update interval and an upper bound on price update step size. Based on the findings, the author further proposes a heuristics algorithm to determine the price update interval and price update step size, for a given requirement of maximum deviation in power load from a desired level. Results confirm that, in the presence of network delay and transmission error, deviation from the desired power load can be limited for a range of number of users and price sensitivity of users.

The 13th paper, *Data Traffic Scheduling for Cyber Physical Systems with Application in Voltage Control of Distributed Generations: A Hybrid System Framework*, investigates the scheduling problem in CPS, which is fitted into the framework of the hybrid, and different selections of links correspond to different dynamics modes. Both centralized and distributed scheduling algorithms are designed. The proposed algorithms are also applied in the background of voltage control of distributed generations. Numerical simulations show that the proposed framework and algorithms achieve good performances.

The 14th paper, *Distributed Algorithm for Tree-Structured Data Aggregation Service Placement in Smart Grid*, proposes a minimum-cost forwarding-based asynchronous distributed algorithm to find the optimal placement for data aggregation service tree with optimal cost of in-network processing. It is shown that minimum-cost forwarding can dramatically reduce message overheads of an asynchronous algorithm. It is also shown that the proposed algorithm has less message overheads than a synchronous algorithm by both mathematical analysis and simulation-based evaluation.

The 15th paper, *Optimal Energy Scheduling for Residential Smart Grid with Centralized Renewable Energy Source*, considers a cost-efficient energy scheduling for residential smart grid equipped with a centralized renewable energy source. The scheduling problem aims at 1) quantifying the optimal utilization of renewable energy that achieves the tradeoff between the system-wide benefit from exploiting the renewable energy and the associated cost due to its volatility and 2) evaluating how the volatility of renewable energy influences its optimal exploitation. The authors also propose computationally efficient and distributed algorithms to determine the optimal exploitation of renewable energy as well as the associated energy scheduling decisions.

The 16th paper, *Hybrid Spectrum Access in Cognitive Radio Based Smart Grid Communications Systems*, considers the spectrum resource management in cognitive-radio-based smart grid networks. A new spectrum access paradigm called hybrid spectrum access is proposed, in which both licensed and unlicensed spectrum bands are intelligently scheduled for the transmission of smart grid services. Furthermore, the impact of spectrum sensing error on the performance of hybrid spectrum access is analyzed by using a multidimension Markov chain. Results indicate that the hybrid spectrum access strategy is able to significantly improve the QoS of the smart grid services,

save the cost in spectrum leasing and also maintain the system interference at a sufficiently low range.

The 17th paper, *GTES: An Optimized Game-Theoretic Demand Side Management Scheme for Smart Grid*, investigates how energy consumption may be optimized by taking into consideration the interaction between both parties. The authors propose a new objective function, which optimizes the difference between the value and cost of energy. The interaction between the power company and its consumers is modeled through a two-step centralized game, the objective of which is to reduce the peak-to-average power ratio by simultaneously optimizing users' energy schedules and lowering the overall energy consumption in the system. The performance of the proposed game-theoretic demand-side management approach is evaluated through computer-based simulations.

The 18th paper, *Human-factor-aware Privacy Preserving Aggregation in Smart Grid*, identifies and formalizes a new attack, in which the attacker could exploit the information about the presence or absence of a specific person to infer his meter readings. This attack is coined as human-factor-aware differential aggregation (HDA) attack in the paper. The authors give a formal definition on it and propose two novel protocols, including a basic scheme and an advanced scheme, to achieve privacy-preserving smart metering data aggregation and resist the HDA attack. The performance and utility analysis shows that our protocol is simple, efficient, and practical.

The 19th paper, *Priority and Delay Aware Medium Access for Wireless Sensor Networks in the Smart Grid*, introduces two medium-access approaches, namely, delay-responsive cross-layer (DRX) data transmission and fair and delay-aware cross-layer (FDRX) data transmission that aim to address delay and service requirements of the smart grid. The authors outline the tradeoffs regarding those approaches and draw future research directions for robust communication protocols for smart grid monitoring applications.

The 20th paper, *On Quality of Usage Provisioning for Electricity Scheduling in Microgrids*, investigates the grid stability problem from an admission control perspective, while guaranteeing the quality-of-usage (QoU) of local residents in a microgrid under both electricity supply and demand randomness. The problem is formulated as a queue stability problem by introducing the concept of a QoU blocking virtual queue. Lyapunov optimization is then applied to derive an adaptive QoU scheduling algorithm. Results demonstrate the efficacy and robustness of the proposed QoU scheduling algorithm.

The 21st paper, *Efficient Authentication and Key Management Mechanisms for Smart Grid Communications*, proposes an efficient scheme that mutually authenticates an SM of a HAN and an authentication server in SG by utilizing an initial password, by decreasing the number of steps in the secure remote password protocol from five to three and the number of exchanged packets from four to three. The improved efficiency for key management is realized by periodically refreshing all public/private key pairs as well as any multicast keys in all the nodes using only one newly generated function broadcasted by the key generator entity. Security and performance analyses are presented to demonstrate these desirable attributes.

The 22nd paper, *An Efficient Merkle Tree Based Authentication Scheme for Smart Grid*, proposes an efficient authentication scheme that employs the Merkle hash tree technique to secure smart gird communication. Security analysis indicates its security strength, namely, resilience to the replay attack, the message injection attack, the message analysis attack, and the message modification attack. In addition, extensive performance evaluation demonstrates its efficiency in terms of computation complexity and communication overhead.

The 23rd paper, *Toward Unified Security and Privacy Protection (USaPP) for Smart Meter Networks*, explores a unified approach for addressing security and privacy of smart metering systems. In the process, the authors present a unified framework that entails the analysis and synthesis of security solutions associated with closely interrelated components of a typical smart metering system. Ultimately, the proposed framework can be used as a guideline for embedding cross-domain security and privacy solutions into smart grid communication systems.

The 24th paper, *A New intelligent Neuro-Fuzzy paradigm for Energy Efficient Homes*, presents a new intelligent EMS (iEMS) in a smart house. It consists of two parts: fuzzy subsystem and intelligent lookup table. Fuzzy subsystem is based on its fuzzy rules and inputs, which produces the proper output for an intelligent lookup table. The second part, whose core is a new model of an associative neural network, is able to map inputs to desired outputs. This system is able to find the best energy efficiency scenario in different situations.

In conclusion, this Special Issue of the IEEE SYSTEMS JOURNAL offers a groundbreaking view into the recent advances in smart grid communication systems. We believe that this issue offers both academic and industry appeal—the former as a basis toward future research directions and the latter toward viable commercial applications.

Finally, we would like to express our gratitude to the Editor-in-Chief of the IEEE SYSTEMS JOURNAL, Prof. Mo Jamshidi, and Prof. Vincenzo Piuri for their advice and encouragement from the beginning until the final stage. We thank Siu Ying Shaneyfelt for the hard work and patience during the production of this Special Issue. We thank all anonymous reviewers who spent much of their precious time reviewing all the papers. Their timely reviews and comments greatly helped us select the best papers in this Special Issue.

We hope you will enjoy reading the great selection of papers in this issue.

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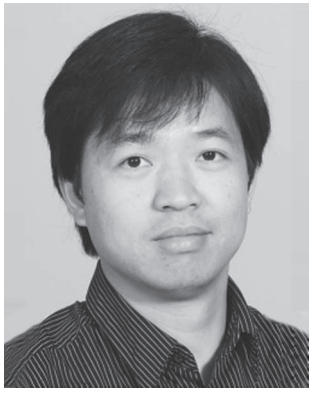

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