# EDITORIAL

# IEEE ACCESS SPECIAL SECTION EDITORIAL: CLOUD-FOG-EDGE COMPUTING IN CYBER–PHYSICAL–SOCIAL SYSTEMS (CPSS)

Cyber–Physical–Social Systems (CPSS) integrate the cyber, physical, and social spaces together. One of the ultimate goals of cyber–physical–social systems is to make our lives more convenient and intelligent by providing prospective and personalized services for users. To achieve this goal, a wide range of data in CPSS are employed as the starting point for research, since the data contain the users' historical behavior trajectory and the users' demand preference. Generated and collected from social and physical spaces and integrated into the cyberspace, CPSS data are complex and heterogeneous, recording all aspects of users' lives in the forms of image, audio, video, and text. Generally, the collected or generated data in CPSS satisfy the 4Vs (volume, variety, velocity, and veracity) of big data. Thus, knowing how to deal with CPSS big data efficiently is the key to providing services for users. From another perspective, CPSS big data are specified as the global historical data and the local real-time data. Cloud computing, as a powerful paradigm for implementing the data-intensive applications, has an irreplaceable role in processing global historical data. On the other hand, with the increasing computing capacity and communication capabilities of mobile terminal devices, fog-edge computing, as an important and effective supplement of cloud computing, has been widely used to process local real-time data. Therefore, the question of how to systematically and efficiently process CPSS big data (including both the global historical data and the local real-time data) in CPSS has become the key for providing services. The goal of this Special Section is therefore to provide insights and views into the area of Cloud-Fog-Edge Computing in CPSS, as well as to provide directions for research in the field.

The Call for Papers was published in early December 2019 and attracted many submissions. After an extensive peer-review process, we have selected 38 high-quality articles for final publication.

In the article ''Dynamic computation offloading based on graph partitioning in mobile edge computing,'' by Li *et al.*, a multiuser computation offloading problem for mobile-edge computing is studied. The authors propose a set of strategies to satisfy the requirement of task scheduling and offloading in a multiuser MEC system where a server partitioning algorithm based on clustering as well as a multiuser game are applied, respectively.

In the article titled ''Cross-modal retrieval for CPSS data,'' by Zhong *et al.*, a nonlinear discrete cross-modal hashing method based on concise binary classification, called NDCMH, is proposed to fully investigate the nonlinear relationship embedding discrete optimization as well as the hashing functions learning for CPSS data. Moreover, a cross-modal retrieval service at cloud and fog is developed to show that the proposed NDCMH method could achieve better performance compared with state-of-the-art methods.

In the article ''A survey of online data-driven proactive 5G network optimization using machine learning,'' by Ma *et al.*, the state-of-the-art works for 5G network optimization are reviewed from two perspectives: 1) the existing methods to mine and infer CPSS context from heterogeneous data sources and 2) a range of proactive optimization techniques, including the key aspects of load balancing, mobile edge caching, and interference management.

In the article titled ''A fast alternating direction method of multipliers algorithm for big data applications,'' by Wang and Chen, the authors propose a strategy to improve the efficiency for distributed big data processing. In particular, they adopt the Alternating Direction Method of Multipliers with Adaptive Local Update (ADMM-ALU) to accelerate the speed of convergence by automatically determining the number of inner iterations of local update in each outer iteration.

The article titled ''Public-key encryption secure against related randomness attacks for improved end-to-end security of cloud/edge computing,'' by Liu, proposes two methods for constructing secure public-key encryption schemes against related randomness attacks: 1) an RRA-CPA secure PKE scheme with an efficient decryption algorithm and short ciphertexts size and 2) standard IND-CCA PKE scheme with hardcore function for arbitrarily correlated inputs to get an RRA-CCA secure public-key encryption scheme against arbitrary function.

In the article ''Dynamical propagation model of malware for cloud computing security,'' by Gan *et al.*, the issue of malware propagation among VMs under the infrastructure as a service (IaaS) architecture is studied. First, a dynamical propagation model is proposed to explore the important factors affecting the spread of malware, especially the impact of installing antivirus software in VMs. On this basis, a theoretical analysis for this model is investigated by means of

differential dynamics, from which we could to understand the dissemination behavior of malware under an infected cloud environment.

In the article "A data-driven vulnerability evaluation method in grid edge based on random matrix theory indicators," by Ding *et al.*, a data-driven method based on random matrix theory is proposed to address the problem of vulnerability assessment of complex power systems facing complex structures and large sizes. With the full utilization of phasor measurement unit (PMU) big data, the model-free method provides more accurate and comprehensive results by simulation on an IEEE 39-bus test system and a real-world power grid in China.

The article titled "Stability and Hopf Bifurcation of a Stochastic Cournot Duopoly game in a blockchain cloud services market driven by Brownian motion," by Xin and Wang, explores the potential and uncertainties in adopting blockchain technology in cloud service markets. The authors propose a Cournot duopoly game to model a blockchain cloud services market and analyze the stochastic stability as well as the stochastic Hopf bifurcation of the Cournot duopoly game to illustrate the complex behaviors of the stochastic Cournot duopoly game in the blockchain cloud services market.

The article titled "A data storage and sharing scheme for cyber–physical–social systems," by Huang *et al.*, proposes a data storage and sharing scheme for CPSS with the help of cloud storage service. The authors adopt the technology of public auditing and bilinear map to construct a secure and efficient data storage scheme. A lightweight access model to access the final data is designed as well.

In the article "A cloud-fog-edge closed-loop feedback security risk prediction method," by Li *et al.*, a set of security risk prediction strategies against multi-task compound attacks for Cloud-Fog-Edge applications is designed. The offensive and defensive ideas of intelligent games, classified deep Boltzmann machines, as well as Markov time-varying models are adopted to realize security prediction with modularity, interoperability, open interfaces, and compliance with open standards.

The article titled "Targeted influence maximization based on cloud computing over big data in social networks," by Chen *et al.*, proposes a targeted influence maximization solution for social network applications. A tag-aware IC model is designed to find a seed set to maximize the expected influence spread over target users, so as to speed up the calculation and save storage overhead.

The article titled "Smart contract privacy protection using AI in cyber–physical systems: Tools, techniques, and challenges," by Gupta *et al.*, investigates various artificial intelligence (AI) techniques and tools for smart contract (SC) privacy protection. Open issues and challenges for AI-based SC are analyzed. Moreover, a case study of retail marketing is presented to prove the feasibility of the proposal, which uses AI and SC to preserve its security and privacy.

The article titled "Large-scale synthetic urban dataset for aerial scene understanding," by Gao *et al.*, studies how to generate synthetic large-scale data sets for geometric and semantic urban scene understanding from a bird's eye view. The evaluation of the proposal shows that the performance is improved significantly in both pure and combined modes.

The article titled "Reviewer credibility and sentiment analysis based user profile modeling for online product recommendation," by Hu *et al.*, proposes an online product recommendation model called the credibility, interest, and sentiment enhanced recommendation (CISER) model. The model could harness not only numeric ratings but also sentiment expressions associated with features, customer preference profiles, and reviewer credibility, which greatly improves the recommendation precision compared with state-of-the-art methods.

The article titled "Statistical behavior guided block allocation in hybrid cache-based edge computing for cyber–physical–social systems," by Shen *et al.*, proposes a statistical behavior guided block allocation (SBOA) scheme to process CPSS data so as to enhance the performance of hybrid cache.

In the article "A choreography analysis approach for microservice composition in cyber–physical–social systems," by Dai *et al.*, an approach for choreography analysis is discussed, by taking advantage of Labeled Transition Systems, as well as projection and $\varepsilon$-remove techniques.

In the article "Dynamic resource allocation for scalable video streaming in OFDMA wireless networks," by Jiao *et al.*, the dynamic resource allocation problem for scalable video streaming over cache-enabled wireless networks with time-varying channel conditions is discussed in detail.

In the article "An improved authentication scheme for remote data access and sharing over cloud storage in cyber–physical–social–systems," by Ghaffar *et al.*, an enhanced, secure, and convenient protocol for data access in cloud storage services is proposed. The protocol adopts proxy re-encryption key for cloud server and generates the credential token during decryption for the data users. Performance analysis shows that their protocol has practical computation, communication, and storage costs as compared to various related protocols.

In the article "An efficient CNN to realize speckle correlation imaging based on cloud-edge for cyber–physical–social–system," by Xu *et al.*, an efficient CNN to do speckle image reconstruction is proposed via two stages of training. Experiments show that the method can reach a high resolution even with a small sample input for training.

In the article "Local codes with cooperative repair in distributed storage of cyber–physical–social systems," by Wang *et al.*, fault tolerance scheme for distributed storage systems of CPSS is studied, and a framework that can recover multiple failed nodes simultaneously is proposed so as to enhance the reliability of storage nodes in distributed storage systems.

In the article "A distributed storage and computation $k$-nearest neighbor algorithm based cloud-edge computing for cyber–physical–social systems," by Zhang *et al.*, a distributed $k$-nearest neighbor (D-kNN) algorithm is discussed

for distributed data storage and computation in cloud computing applications. $k$-nearest neighbor boundaries and $k$-nearest neighbor search are proposed to reduce the time complexity of typical kNN algorithms.

In the article "A low-complexity equalizer for video broadcasting in cyber–physical social systems through handheld mobile devices," by Solyman *et al.*, a least-squares minimal residual (LSMR) algorithm is proposed to reduce the complexity of matrix inversion computation for video broadcasting problems in social network applications. The LSMR equalizer has significant performance and reduced complexity over the classical MMSE equalizer and other low complexity equalizers.

The article titled "MATT: A mobile assisted tense tool for flexible *m*-grammar learning based on cloud-fog-edge collaborative networking," by Refat *et al.*, proposes a Mobile-Assisted Tense Tool that encapsulates an *m*-grammar instructional design leveraging upon cloud-fog-edge collaborative networking. The Cognitive Theory of Multimedia Learning principles is adopted to minimize the extraneous cognitive load, while a motivational model is designed to increase motivation and learning effectiveness.

In the article titled "Astronomical data preprocessing implementation based on FPGA and data transformation strategy for the FAST telescope as a Giant CPS," by Song *et al.*, the authors implement the Bitshuffle preprocessing algorithm on field programmable gate array (FPGA) and present a unique data transformation strategy to turn raw FAST data in classic FITS format into another format to support huge file sizes, i.e., Hierarchical Data Format (HDF5). Their proposal could satisfy the performance requirement and power budget requirement for CPS systems simultaneously.

In the article "Accurate position estimation of mobile robot based on cyber–physical–social systems (CPSS)," by Zhu *et al.*, an improved particle filter algorithm is proposed for the position estimation of mobile robot dynamic systems. The proposed method is effective in solving the measurements with gross errors, which could realize accurate position estimation of the mobile robot as a result.

In the article "A new cloudlet placement method based on affinity propagation for cyber–physical–social systems in wireless metropolitan area networks," by Peng *et al.*, a novel cloudlet placement method based on improved Affinity Propagation (AP) algorithm is proposed to solve the load-balancing problem for mobile edge computing applications. The improved AP algorithm can obtain the least number of cloudlets while covering the largest number of MDs simultaneously.

In the article "Cloud-based k-closest pairs discovery in dynamic cyber–physical–social systems," by Lu *et al.*, the temporal multiple constraints $k$ closets pairs (i.e., TMC-k-CP) problem in dynamic CPSS is studied. The TMC-k-CP problem is NP-Complete, and a divide-and-conquer cloud-based algorithm called DC is proposed to solve the TMC-k-CP problem efficiently and effectively.

The article titled "CPSS LR-DDoS detection and defense in edge computing utilizing DCNN Q-learning," by Liu *et al.*, explores and enhances the Mirai botnet to a sophisticated, multitarget, low-rate TCP attack network, which makes the edge LR-DDoS more powerful and obfuscates their activity. Moreover, a novel intrusion detection and defense hybrid method for the above CPSS LR-DDoS scenario is proposed to work as the powerful decision maker to defend the attacks by taking advantage of the locality-sensitive feature extraction and the deep convolution neural network (DCNN).

The article titled "An aggregative high-order singular value decomposition method in edge computing," by Chen *et al.*, proposes an aggregative high-order singular value decomposition (HOSVD) method by reusing intermediate results of subtensor HOSVD in ECNs to reduce the HOSVD computing cost of the merged tensor in the cloud server. The proposed HOSVD algorithm could reduce repeated calculations and improve the efficiency and accuracy as a result.

In the article "Privacy-aware secure anonymous communication protocol in CPSS cloud computing," by Li *et al.*, the problem of how to ensure the security of data transmission and data storage in CPSS is discussed. Moreover, an anonymous communication protocol is designed to protect the identity privacy of communicating units in CPSS.

In the article "Self-layer and cross-layer bilinear aggregation for fine-grained recognition in cyber–physical–social systems," by Peng *et al.*, a novel approach of self-layer and cross-layer bilinear aggregation (SCBA) is proposed for fine-grained visual recognition. The proposed approach can not only learn the correlations among different layers but also the same layer, which makes it efficient to achieve state-of-the-art accuracy on three common fine-grained image datasets.

In the article "Task offloading and resource allocation for mobile edge computing by deep reinforcement learning based on SARSA," by Alfakih *et al.*, a reinforcement learning-based state–action–reward–state–action (i.e., RL-SARSA) algorithm is proposed to resolve the resource management problem in edge servers. More specifically, an optimal offloading strategy, called OD-SARSA, is designed for minimizing system cost in terms of energy consumption and computing time delay.

The article titled "Smart routing management framework exploiting dynamic data resources of cross-layer design and machine learning approaches for mobile cognitive radio networks: A survey," by Salih *et al.*, reviews the numerous routing protocols in MCRNs. At the same time, a cross-layer framework for smart routing protocol in MCRNs is proposed by exploiting multiple machine learning mechanisms. Moreover, the open research issues of the routing protocol in MCRNs are summed up as well.

In the article "Dynamics of complex networks: Malware propagation modeling and analysis in industrial Internet of Things," by Li *et al.*, a dynamic malware propagation model, called DDSEIR, is proposed to study the propagation characteristics of malware. The Live Journal data set is adopted

to verify the effectiveness of DDSEIR, with the findings that intelligent device's dissemination capacity and discriminant ability have significant influences on malware propagation.

In the article "Blockchain-based dynamic spectrum access of non-real-time data in cyber–physical–social systems," by Fan and Huo, a general framework based on blockchain technologies and smart contracts is designed for license-free spectrum resource management in CPSSs, which also enables non-real-time data sharing for edge computing applications. Moreover, a virtual currency called Xcoin is introduced as the intermediate for spectrum trading.

In the article "Validity evaluation of transformer DGA online monitoring data in grid edge systems," by Jia *et al.*, a method to evaluate the validity of online dissolved gas analysis (DGA) monitoring data based on B-EMD and DBN is proposed. The optimization for the corresponding calibration plan is presented as well. The proposed method could effectively diagnose faults and improve the reliability of DGA online monitoring devices.

In the article "A blockchain-based access control framework for cyber–physical–social system big data," by Tan *et al.*, a blockchain-based access control scheme called BacCPSS for CPSS big data is proposed. The BacCPSS scheme takes advantage of blockchain technology to store access control permission information, which could achieve secure access in CPSS while protecting privacy.

Finally, the invited article "Trust and reputation in the Internet of Things: State-of-the-art and research challenges," by Fortino *et al.*, deals with the principal aspects emerging from the application of trust techniques to the IoT domains with respect to the particular viewpoint of an IoT environment. Their work provides a comparative study of the main current architectures for modeling trust in IoT environments. Moreover, both advantages and limitations of existing approaches are discussed in detail, as well as the emerging research challenges.

In conclusion, the articles presented in this Special Section demonstrate the breadth and diversity of research in the field of cloud-fog-edge computing in CPSS. The Lead Guest Editor, along with the Guest Editors, would like to thank all the authors who submitted their research articles to the Special Section. They highly appreciate the contributions of the reviewers for their constructive comments and suggestions. They would also like to acknowledge the guidance from IEEE ACCESS Editor-in-Chief and staff members.

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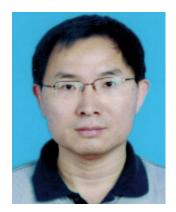
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