Guest Editorial
Special Issue on Fog Computing in the Internet of Things

FOG COMPUTING (FC) is an emerging research area that targets on providing services and satisfying customers' needs in the space between "Ground" and "Cloud." In the current cloud-based Internet of Things (IoT) model, smart devices (such as sensors and smartphones) exchange information through the Internet (routers and/or servers on cloud) to cooperate and provide services to users, which could be citizens, smart home systems, and industrial applications. The cloud-based IoT model describes a uniform, concise, and scalable solution for supporting IoT applications. The deployments of IoT applications on cloud, however, are facing the challenges originated from economic considerations, social concerns, technical limitations, and administrative issues.

There is no doubt that the big data generated by things are surprisingly useful. Fog consists of all the smart computing/sensing systems that are around us and tied together. Typically, it includes a small data center that is placed close to the things in IoT. FC is probably the most promising technology to support IoT applications while simultaneously and successfully addressing all the aforementioned challenges and issues. It adds a new dimension to the IoT model for meeting the customers' needs such as fast connection, strong security, easy management, infrastructure reuse, off load core network traffic, and quick scaling. FC is expected to support a wide range of IoT applications, including device-to-device data sharing, wearable cognitive assistance, video editing and sharing, vehicular systems, etc. To address the arising new challenges and opportunities, we have planned this feature topic issue to help both industry and academia research communities better understand the recent advances and potential research directions on the converging paths of IoT and FC.

The papers in this feature topic issue focus on the state-of-the-art research and the grant challenges in various aspects of FC for IoT. We solicited papers covering various topics of interest, and received a total of 42 submissions. After a rigorous peer review process, ten papers were accepted.

In the paper entitled "LoDPD: A Location Difference-Based Proximity Detection Protocol for Fog Computing," proximity detection is investigated. The authors first perform a theoretical and experimental analysis of the exiting solutions; then they propose a location difference-based proximity detection protocol based on the Paillier cryptosystem, which outperforms the traditional protocols in terms of communication and computation costs.

The survey paper entitled "A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications" conducts a comprehensive overview of IoT from the aspects of system architectures, enabling technologies, and security and privacy issues. It presents the integration of Fog/Edge computing and IoT. The survey begins with exploring the relationship between cyber-physical systems and IoT. Then the Fog/Edge computing-based IoT is introduced. At last, applications such as smart grid, smart transportation, and smart cities, are presented to illustrate how Fog/Edge computing-based IoT can be implemented.

Some security and privacy issues in FC-based face identification are investigated in the paper entitled "Security and Privacy Preservation Scheme of Face Identification and Resolution Framework Using Fog Computing in Internet of Things." A security and privacy preservation scheme is proposed considering authentication and session key agreement, data encryption, and data integrity checking. A prototype system is illustrated. It is shown that the proposed scheme can effectively preserve security and privacy in FC-based face identification.

In the paper entitled "Securing SDN Infrastructure of IoT–Fog Network From MitM Attacks", the authors investigate the potential threats of man-in-the-middle attacks on the OpenFlow control channel in software-defined networking, which can automatically and dynamically manage network flows for IoT. A feasible attack model in an IoT–Fog architecture is first introduced. The severe consequences of the corresponding attacks is shown. Furthermore, the authors propose a lightweight countermeasure using Bloom filters. A prototype for this method is also implemented. The evaluation results demonstrate that the proposed Bloom filter monitoring system is efficient and consumes few resources.

The paper entitled "Feasibility Study of 60 GHz Millimeter-Wave Technologies for Hyperconnected Fog Computing Applications" carries out the feasibility study of the interference impacts in advanced FC networks with the 60 GHz millimeter-wave wireless technology. This performance simulation study investigates whether utilizing the 60 GHz millimeter-wave wireless technology for hyperconnected FC networks is feasible or not considering various interference scenarios. As validated by the simulation

Digital Object Identifier 10.1109/JIOT.2017.2750438

results, it is shown that 1.5 Gb/s high rate can be supportable even though more than 1000 edge devices are deployed in the 100 m-by-100 m size small-scale network. Thus, it is confirmed that hyper-connection can be realized with the 60 GHz millimeter-wave technology for FC networks.

The authors of the paper entitled "Fog-Empowered Anomaly Detection in IoT Using Hyperellipsoidal Clustering" study anomaly detection for IoT applications. The traditional anomaly detection methods suffer from significant latency and energy consumption issues. The authors propose a novel anomaly detection method, called Fog-empowered anomaly detection, by harnessing the processing power of the FC platform and using an efficient hyperellipsoidal clustering algorithm. The authors also define three types of anomalies in the Fog architecture. The evaluations toward both synthetic and real datasets demonstrate that the proposed method achieves a significant reduction in latency and energy consumption compared with the traditional methods, while achieving a comparable detection accuracy.

In the paper entitled "QoS-Aware Deployment of IoT Applications Through the Fog," a simple yet general model is proposed to support the QoS-aware deployment of multicomponent IoT applications to Fog infrastructures. In the proposed model, the issues regarding operational systemic qualities of the available infrastructure, interactions among software components and things, and business policies are addressed. Several algorithms that can be used to determine eligible application-to-Fog deployments are also proposed. Furthermore, a prototype Java tool based on the proposed model is introduced.

The paper entitled "Identifying the Most Valuable Workers in Fog-Assisted Spatial Crowdsourcing" focuses on worker selection in spatial crowdsourcing. A spatial crowdsourcing task relies on worker's effort and skill. In order to maximize the long-term platform utility, the paper exploits the Fog platform as a service to identify valuable workers through learning their performance data. The proposed worker selection scheme takes into account balancing exploration and exploitation attempts. An online algorithm is proposed to promote workers who are not fully explored. The proposed algorithm can be used to maximize the long-term platform utility with budget constraint. The authors perform theoretical analysis and derive that the proposed algorithm achieves asymptotically diminishing regret. Extensive simulation results based upon real-world datasets are also presented to demonstrate the advantage of the proposed algorithm.

The paper entitled "Computing Resource Allocation in Three-Tier IoT Fog Networks: A Joint Optimization Approach Combining Stackelberg Game and Matching" considers a specific FC network with a set of data service operators (DSOs), each of which controls a set of fog nodes (FNs) to provide data service to a set of data service subscribers (DSSs). The problem of how to allocate the limited computing resources of FNs to all the DSSs to achieve an optimal and stable performance is investigated. The authors propose a joint optimization framework for all FNs, DSOs, and DSSs to achieve the optimal resource allocation schemes in a distributed manner. In this paper, the pricing problem for the DSOs and the resource allocation problem for the DSSs are addressed through formulating a Stackelberg game. A many-to-many matching game is employed to investigate the pairing problem between DSOs and FNs. Another layer of many-to-many matching between each of the paired FNs and serving DSSs is employed to solve the FNDSS pairing problem within the same DSO. The simulation results are presented to show that the proposed framework can significantly improve the performance of the IoT-based network systems.

A resource allocation strategy for FC based on priced timed Petri nets (PTPNs) is proposed in the paper entitled "Resource Allocation Strategy in Fog Computing Based on Priced Timed Petri Nets." With the proposed strategy, users can choose the satisfying resources autonomously from a group of preallocated resources. The proposed strategy considers the price cost and time cost to complete a task comprehensively. Moreover, it considers the credibility evaluation of both users and fog resources. The PTPN models of tasks in FC are constructed according to the features of fog resources. An algorithm for predicting task completion time is presented. The method of computing the credibility evaluation of fog resource is also proposed. Furthermore, a dynamic fog resource allocation algorithm is presented. The simulation results demonstrate that the proposed algorithms can achieve a higher efficiency than the static allocation strategies in terms of task completion time and price.

We are very grateful to all the authors for their great contributions to this feature topic issue, and to all the reviewers for their excellent job in providing timely and rigorous reviews. Special thanks go to Dr. C. Wang and Dr. X. Shen, the two Editors-in-Chief of the IEEE INTERNET OF THINGS JOURNAL, for their help in the whole publication process. We expect that this feature topic issue can help both industry and academia research communities better understand the recent advances and potential research directions on the converging paths of IoT and FC.

RONG N. CHANG, *Guest Editor*
IBM T. J. Watson Research Center
Yorktown Heights, NY 10598 USA

XIUZHEN CHENG, *Lead Guest Editor*
Department of Computer Science
The George Washington University
Washington, DC 20052 USA

WEI CHENG, *Guest Editor*
Department of Computer Science
Virginia Commonwealth University
Richmond, VA 23284 USA

WONJUN LEE, *Guest Editor*
Department of Cyber Defense
School of Information Security
Korea University
Seoul, South Korea

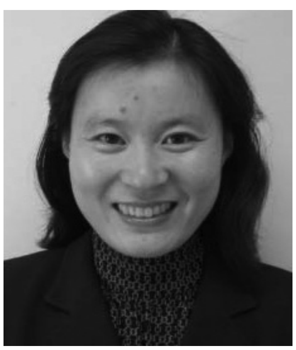
YINGSHU LI, *Guest Editor*
Department of Computer Science
Georgia State University
Atlanta, GA 30302 USA

JIGUO YU, *Guest Editor*
School of Information Science and Engineering
Qufu Normal University
Rizhao, Shandong, China

Rong N. Chang (S'86–M'86–SM'12) received the B.S. (Hons.) degree in computer engineering from National Chiao Tung University, Hsinchu, Taiwan, in 1982, and the Ph.D. degree in computer science and engineering from the University of Michigan, Ann Arbor, MI, USA, in 1990.

He joined the IBM T. J. Watson Research Center, Yorktown Heights, NY, USA, in 1993, where he is a member of the IBM Academy of Technology. He is the Lead Architect and Developer of the IBM PAIRS Services, a scalable REST API offering that provides geospatial big data and analytics capabilities via DevOps, continuous delivery, and cloud-centric microservices. He was with Bellcore performing research on B-ISDN-based personal ubiquitous application services. He has an ITIL Foundation certificate in IT Services Management and one Micro MBA certificate. He has authored or co-authored over 50 refereed technical papers in the areas of Internet-enabled distributed services computing, enterprise clouds, and service level agreement management optimization. He holds over 30 patents.

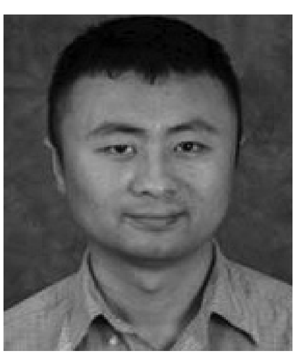
Dr. Chang was a recipient of one IEEE Best Paper Award and five IBM Corporate-Level Outstanding Technical Achievement Awards. He is an Associate Editor-in-Chief of the IEEE TRANSACTIONS ON SERVICES COMPUTING and a Guest Editor of five special issues in international journals. He is the General Chair of the 2017 IEEE World Congress on Services and a Steering Committee member of the 2017 ACM/IEEE Symposium of Edge Computing. He is a Distinguished Member of the ACM. He is the Chair of IEEE-CS Technical Committee on Services Computing.



Xiuzhen Cheng (M'03–SM'12–F'15) received the M.S. and Ph.D. degrees in computer science from the University of Minnesota–Twin Cities, Minneapolis, MN, USA, in 2000 and 2002, respectively.

She is a Professor with the Department of Computer Science, The George Washington University, Washington, DC, USA. She was a Program Director for the U.S. National Science Foundation in 2006 for six months (full time) and from 2008 to 2010 (part time). She has authored or co-authored over 200 peer-reviewed papers. Her current research interests include Fog computing, privacy-aware computing, mobile handset networking systems (mobile health and safety), wireless and mobile security, smart cyber-physical systems, and algorithm design and analysis.

Dr. Cheng is the Founder and the Steering Committee Co-Chair of the International Conference on Wireless Algorithms, Systems, and Applications (WASA, launched in 2006), and the Co-Founder of the IEEE Symposium on Privacy-Aware Computing (PAC, launched in 2017). She has served on the Editorial Boards of several technical journals such as the IEEE TRANSACTIONS ON PARALLEL AND DISTRIBUTED SYSTEMS and IEEE WIRELESS COMMUNICATIONS and on the Technical Program Committees of various professional conferences/workshops such as ACM Mobihoc, ACM Mobisys, IEEE INFOCOM, IEEE ICDCS, IEEE ICC, and IEEE/ACM IWQoS. She also has also chaired several international conferences such as IEEE CNS and WASA.



Wei Cheng received the B.S. degree in applied mathematics and M.S. degree in computer science from the National University of Defense Technology, Changsha, China, in 2002 and 2004, respectively, and the Ph.D. degree in computer science from The George Washington University, Washington, DC, USA, in 2010.

He is currently an Assistant Professor with Virginia Commonwealth University, Richmond, VA, USA. He was a Post-Doctoral Scholar with the University of California at Davis, Davis, CA, USA. His current research interests include wireless networks, cyber-physical networking systems, and algorithm design and analysis. In particular, he is interested in localization, security, Fog computing, and smart cities.

Dr. Cheng is a member of the ACM.

Wonjun Lee (A'00–M'00–SM'06) received the B.S. and M.S. degrees in computer engineering from Seoul National University, Seoul, South Korea, in 1989 and 1991, respectively, the M.S. degree in computer science from the University of Maryland at College Park, College Park, MD, USA, in 1996, and the Ph.D. degree in computer science and engineering from the University of Minnesota, Minneapolis, MN, USA, in 1999.

In 2002, he joined the faculty of Korea University, Seoul, where he is currently a Professor with the Department of Computer Science and Engineering. He has authored or co-authored over 180 papers in refereed international journals and conferences. His research interests include communication and network protocols, optimization techniques in wireless communication and networking, security and privacy in mobile computing, and radio frequency powered computing and networking.

Dr. Lee has served as a Technical Program Committee member for the IEEE International Conference on Computer Communications from 2008 to 2018. He was associated with the Computing Machinery International Symposium on Mobile Ad Hoc Networking and Computing from 2008 to 2009 and the IEEE International Conference on Computer Communications and Networks from 2000 to 2008 and over 118 international conferences.

Yingshu Li (S'03–M'05–SM'10) received the B.S. degree from the Department of Computer Science and Engineering, Beijing Institute of Technology, Beijing, China, and the M.S. and Ph.D. degrees from the Department of Computer Science and Engineering, University of Minnesota–Twin Cities, Minneapolis, MN, USA.

She is currently an Associate Professor with the Department of Computer Science, Georgia State University, Atlanta, GA, USA. Her research has been supported by the National Science Foundation (NSF), the NSF of China, the Electronics and Telecommunications Research Institute of South Korea, and GSU internal grants. Her current research interests include wireless networking, sensor networks, sensory data management, social networks, and optimization.

Dr. Li was a recipient of the NSF CAREER Award.

Jiguo Yu (M'09–SM'17) received the Ph.D. degree from the School of Mathematics, Shandong University, Jinan, China, in 2004.

He became a Full Professor with the School of Computer Science, Qufu Normal University, Rizhao, China, in 2007, where he is currently a Full Professor with the School of Information Science and Engineering. His current research interests include wireless networking, distributed algorithms, privacy-aware computing, peer-to-peer computing, and graph theory. He is particularly interested in designing and analyzing algorithms for computationally hard problems in networks.

Dr. Yu is a member of the ACM and a Senior Member of the China Computer Federation.