

Guest Editorial

Special Issue on Cognitive Internet of Things

COGNITIVE Internet of Things (IoT) is the use of cognitive computing technologies, which is derived from cognitive science and artificial intelligence, in combination with data generated by connected devices and the actions those devices can perform. Cognitive IoT provides high performance of communicating, computing, controlling, and even high degree of machine intelligence. Cognitive IoT redefines the relationship between human and their pervasive digital environment. They may play the role of assistant or coach for the user. Specifically, the IoT generated big data, when used to power predictive analytics algorithms or to develop a corps for a cognitive computing solution, can provide insights that would never be discovered in time to be useful if the departmental silos do not collaborate in data sensing and analysis. It is the integration of this data that enables cognitive computing applications for IoT of the next decade. Therefore, the services of a cognitive IoT could be constructive, prescriptive, or instructive in nature.

Although IoT has emerged with a great potential to change our life, especially with ubiquitous sensing and sensory data, cognitive IoT technologies will make it possible to understand what is happening in the world more deeply. Therefore, cognitive computing is significant for the IoT to meet many technical challenges and problems that need to be addressed to realize this potential, such as big sensory data generation, computing at the edge of IoT, integration of multiple data sources and types, etc. Furthermore, to address the new computing and communication paradigm, the IoT ecosystems have to be upgraded with new capabilities, such as machine learning, IoT sensing, data analytics, and cognitive power for providing human intelligence.

This JOURNAL's Special Issue (SI) aims to explore recent advances and disseminate state-of-the-art research related to IoT on designing, building, and deploying novel cognitive computing, services and technologies, to enable smart IoT services and applications.

The response to our Calls for Papers on this SI was satisfactory, with 28 submissions from around the globe. During the review process, each paper was assigned to and reviewed by at least three experts in the relevant areas, with a rigorous two-round review process. Thanks to the great support of the Editor-in-Chief of this JOURNAL, Dr. Sherman Shen, we are able to accept 15 excellent papers covering various aspects of cognitive IoT.

In the paper "The Future Internet of Things: Secure, Efficient, and Model-Based," the authors propose a solution

modeled on human use of context and cognition, leveraging cloud resources to facilitate IoT on constrained devices units. And it presents an architecture applying process knowledge to provide security through abstraction and privacy through remote data fusion. Specifically, the novel architecture consists of quality of data targets, security and cognitive layers, mathematical-model based data proxies, and an application agent to optimizing sampling costs or minimizing error subject to constraints.

A major challenge in cognitive IoT is the packet transmission efficiency using cognitive networks. To address this challenge, the paper "A New Deep-Q-Learning-Based Transmission Scheduling Mechanism for the Cognitive Internet of Things" proposes a new *Q*-learning-based transmission scheduling mechanism using deep learning to achieve the appropriate strategy to transmit packets of different buffers through multiple channels to maximize the system throughput.

To recover missing data among the massive sensed data of the IoT, the paper "Probabilistic Recovery of Incomplete Sensed Data in IoT" proposes a probabilistic method based on probabilistic matrix factorization (PMF) to recover missing (incomplete) data from IoT sensors by utilizing data from related sensors. Simulation results show that the proposed PMF model with clustering outperforms support vector machine and deep neural network algorithms in terms of accuracy and root mean square error.

The paper entitled "SRSM-Based Adaptive Relay Selection for D2D Communications" proposes an adaptive relay selection method that exploits the social network and establishes a physical domain and social domain-based model named the social-based D2D relay selection model to address relay selection failure caused by the diversity of users cooperation willingness and the instability of communication links due to human mobility.

In the paper "A Knowledge Fusion Approach for Context Awareness in Vehicular Networks," the authors propose a novel logic-based framework enabling a contextual data management and mining in vehicular ad-hoc networks (VANETs). It grounds on a knowledge fusion algorithm based on nonstandard, nonmonotonic inference services in description logics, adopting standard semantic Web languages. The approach has been implemented in a vehicular network simulator and early experimental results proved its effectiveness and feasibility.

The paper "Materializing the Promises of Cognitive IoT: How Cognitive Buildings Are Shaping the Way" devises a cognitive IoT architecture that integrates thousands of sensors present in our buildings in order to learn the buildings' behavior and intuitively assist users in diagnosing and mitigating undesired events. And it presents the potential of cognitive

IoT to create highly scalable, adaptable, and interactive IoT systems functioning for buildings and capable of addressing the challenges encountered in the realm of Homes, Smart Cities, and Industry 4.0. In the paper “Analysis of Information Delivery Dynamics in Cognitive Sensor Networks Using Epidemic Models,” the authors propose a hybrid interference-aware flooding scheme for cognitive radio ad hoc network that utilizes global timeout and antipackets for information dissemination control. The simulation results show that the implementation of the proposed flooding scheme indeed mitigates the buffer occupancy burden while providing statistical data delivery guarantees. Moreover, with the aid of mobility, information dissemination is shown to possess distinct characteristics that facilitates information dissemination.

For advanced material handling, the authors of the paper “Context-Aware Cloud Robotics for Material Handling in Cognitive Industrial Internet of Things” designs a cognitive industrial entity called context-aware cloud robotics (CACR). Compared with the one-time on-demand delivery, CACR is characterized by two features: 1) context-aware services and 2) effective load balancing. Simulations indicate the superiority of cognitive industrial IoT and show that using CACR for material handling can significantly improve energy efficiency and save cost.

In the paper “People-Centric Cognitive Internet of Things for the Quantitative Analysis of Environmental Exposure,” the authors present an architecture for a people-centric and cognitive IoT (PIoT) environmental sensing platform, which involves closed loops of interactions among people nodes and physical devices, as well as servers and recommendations on device connections by cognitive computing. Moreover, a PIoT prototype sensing system is designed and deployed to measure the space-time distribution of particulate matter in air (PM 2.5), and mobility counts, for quantifying personal exposure to air pollution.

The paper “A Microbial Inspired Routing Protocol for VANETs,” is a bio-inspired unicast routing protocol for vehicular ad hoc networks, which uses the cellular attractor selection mechanism to select next hops. The proposed unicast routing protocol based on attractor selecting is an opportunistic routing protocol, which is able to change itself adaptively to the complex and dynamic environment by routing feedback packets.

In the paper “Motor Anomaly Detection for Unmanned Aerial Vehicles Using Reinforcement Learning,” the authors propose a reinforcement learning-based anomaly detection system to prevent the motor of the unmanned aerial vehicles from operating at abnormal temperatures. The experimental results confirmed that the proposed system can safely control the drone using information obtained from temperature sensors attached to the motor.

Considering emotional care, especially for children, elderly, and mentally ill people, the authors of the paper “Emotion-Aware Connected Healthcare Big Data Towards 5G” propose an emotion-aware connected healthcare system using a powerful emotion detection module to capture speech and image signals of a patient in a smart home scenario. It verifies that the proposed framework would greatly contribute personalized and seamless emotion-aware healthcare services toward 5G.

The paper “Narrow Band Internet of Things: Simulation and Modeling” present the narrowband IoT (NB-IoT) development, and main characteristics and design objectives of NB-IoT according to 3GPP R13. The simulation results have verified the performance of NB-IoT, wherein uplink time delay is lower than 10 s, channel utilization is higher than that of Long Term Evolution (LTE) network, and coverage area is larger than LTE network.

The authors of paper “Fusion of Nonintrusive Environmental Sensors for Occupancy Detection in Smart Homes” present an approach to detect and count occupants using a fusion of environmental sensors from an indoor air quality measurement system. Furthermore, a method is proposed to greatly reduce time and effort of collecting training data in residential buildings. The results indicated that the predictive power of volatile organic compound sensing is comparable to that of carbon dioxide. With a simple naïve Bayes classifier, the approach detected occupancy and estimated the number of occupants with an accuracy of 81.1% and 64.7%, respectively.

To improve the cognitive ability of IoT, the authors of the paper “Device Clustering Algorithm Based on Multimodal Data Correlation in Cognitive Internet of Things” design a device level multimodal data correlation mining model to transform the data feature into a subspace and analyze the data correlation. Extensive simulations are carried out and show that the proposed scheme can effectively improve the quality of data transmission and the intelligent service.

We express our gratitude to the authors for their excellent contributions to this SI. We are also thankful for all reviewers dedicating their efforts in reviewing these papers, and for their valuable comments and suggestions that significantly improve the quality of them. We hope that this SI will serve as a good reference for researchers, scientists, engineers, and academicians in the field of cognitive IoT.

YIN ZHANG, *Guest Editor*

School of Information and Safety Engineering
Zhongnan University of Economics and Law
Wuhan 430073, China
e-mail: yin.zhang.cn@ieee.org

MIN CHEN, *Guest Editor*

School of Computer Science and Technology
Huazhong University of Science and Technology
Wuhan 430074, China

VICTOR C. M. LEUNG, *Guest Editor*

Department of Electrical and Computer Engineering
The University of British Columbia
Vancouver, BC V6T 1Z4, Canada

TIANYI XING, *Guest Editor*

WalmartLabs
Sunnyvale, CA 94086 USA

GIANCARLO FORTINO, *Guest Editor*

Department of Informatics, Modeling, Electronics and
Systems
University of Calabria
87036 Rende, Italy



Yin Zhang (SM'16) is an Associate Professor with the School of Information and Safety Engineering, Zhongnan University of Economics and Law (ZUEL), Wuhan, China. He is a Wenlan Distinguished Scholar with ZUEL and a Chutian Distinguished Scholar in Hubei, China. He has been published in over 80 prestigious conference and journal papers, including eight ESI Highly Cited Papers. His current research interests include intelligent service computing, big data, and social network.

Dr. Zhang was a recipient of the IEEE SYSTEMS JOURNAL Best Paper Award of the IEEE Systems Council in 2018. He is the Vice-Chair of the IEEE Computer Society Big Data STC. He serves as an Editor or an Associate Editor for *IEEE Network*, *IEEE ACCESS*, and the *Journal of Information Processing Systems*. He is a Guest Editor for *Future Generation Computer Systems*, the IEEE INTERNET OF THINGS JOURNAL, *Mobile Networks and Applications*, *Sensors*, *Multimedia Tools and Applications*, *Wireless Communications and Mobile Computing*, *Electronic*

Markets, the *Journal of Medical Systems*, and *New Review of Hypermedia and Multimedia*. He also served as the Track Chair of IEEE CSCN 2017 and the TPC Co-Chair of CloudComp 2015 and TRIDENTCOM 2017.



Min Chen (SM'09) has been a Full Professor with the School of Computer Science and Technology, Huazhong University of Science and Technology (HUST), Wuhan, China, since 2012, where he is the Director of Embedded and Pervasive Computing Lab. He was an Assistant Professor with the School of Computer Science and Engineering, Seoul National University, Seoul, South Korea, where he was a Post-Doctoral Fellow for one and half years. He was a Post-Doctoral Fellow with the Department of Electrical and Computer Engineering, University of British Columbia, Vancouver, BC, Canada, for three years. He has authored or co-authored over 300 paper publications, including over 200 SCI papers, over 80 IEEE TRANSACTIONS/Journal papers, 23 ESI highly cited papers, and 9 ESI hot papers. He has authored or co-authored *OPNET IoT Simulation* (HUST Press, 2015), *Big Data Inspiration* (HUST Press, 2015), *5G Software Defined Networks* (HUST Press, 2016), *Introduction to Cognitive Computing* (HUST Press, 2017), *Big Data: Related Technologies, Challenges, and Future Prospects* (Springer, 2014), *Cloud Based*

5G Wireless Networks (Springer, 2016), *Cognitive Computing and Deep Learning* (China Machine Press, 2018), and *Big Data Analytics for Cloud/IoT and Cognitive Computing* (Wiley, 2017). He has over 12 600 Google Scholars Citations with an H-index of 55. His top paper was cited over 1300 times. His current research interests include cyber-physical systems, IoT sensing, 5G networks, mobile cloud computing, SDN, healthcare big data, media cloud privacy and security, body area networks, emotion communications, and robotics.

Dr. Chen was a recipient of the Best Paper Award of QShine 2008, IEEE ICC 2012, ICST Industrial IoT 2016, and IEEE IWCMC 2016 and the IEEE Communications Society Fred W. Ellersick Prize in 2017. He serves as an Editor or an Associate Editor for *Information Sciences*, *Information Fusion*, and *IEEE ACCESS*. He is a Guest Editor for *IEEE Network*, *IEEE Wireless Communications*, and the IEEE TRANSACTIONS ON SERVICES COMPUTING. He was the Co-Chair of the IEEE ICC 2012-Communications Theory Symposium and IEEE ICC 2013-Wireless Networks Symposium. He was the General Co-Chair of IEEE CIT-2012, Tridentcom 2014, Mobimedia 2015, and Tridentcom 2017. He was the Chair of the IEEE Computer Society Special Technical Communities on Big Data. He was a Keynote Speaker of CyberC 2012, Mobiquitous 2012, Cloudcomp 2015, IndustrialIoT 2016, Tridentcom 2017, and the 7th Brainstorming Workshop on 5G Wireless.



Victor C. M. Leung (F'03) is a Professor of electrical and computer engineering and Holder of the TELUS Mobility Research Chair with the University of British Columbia (UBC), Vancouver, BC, Canada. He has contributed to 700 technical papers, 27 book chapters, and 6 books in the areas of wireless networks and mobile systems.

Dr. Leung was a recipient of the 2012 UBC Killam Research Prize and the IEEE Vancouver Section Centennial Award. He is serving on the Editorial Boards of IEEE WIRELESS COMMUNICATIONS LETTERS and several other journals, and has contributed to the Organizing and Technical Program Committees of numerous conferences. He served on the Editorial Boards of the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, and the IEEE TRANSACTIONS ON COMPUTERS. He was a Distinguished Lecturer of the IEEE Communications Society. He is a Fellow of the Royal Society of Canada, the Canadian Academy

of Engineering, and the Engineering Institute of Canada.



Tianyi Xing received the B.E. degree in telecommunications engineering from Xidian University, Xi'an, China, in 2007, the M.E. degree in electronic engineering from the Beijing University of Posts and Telecommunications, Beijing, China, in 2010, and the Ph.D. degree from the School of Computing Informatics and Decision Systems Engineering, Arizona State University, Tempe, AZ, USA, in 2014.

He is currently a Senior Software Engineer with WalmartLabs, Mountain View, CA, USA. In 2009, he was a Research Intern with Microsoft Research Asia, Beijing, for five months. His current research interests include secure networking design and implementation, software-defined networking, and cloud computing.



Giancarlo Fortino (M'02–SM'12) received the Laurea (B.Sc. and M.Sc.) and Ph.D. degrees in computer engineering from the University of Calabria (Unical), Rende, Italy.

Since 2006, he has been a Professor of computer engineering with the Department of Informatics, Modeling, Electronics, and Systems, Unical. He holds the Italian Scientific National Habilitation for Full Professorship and is a High-End Foreign Expert of China, an Adjunct Professor with the Wuhan University of Technology, Wuhan, China, a Senior Research Fellow with the Italian National Research Council ICAR Institute, and High-End Expert with the Huazhong University of Science and Technology, Wuhan. He has also been a Visiting Researcher and a Professor with the International Computer Science Institute, Berkeley, CA, USA, and the Queensland University of Technology, Brisbane, QLD, Australia. He has participated in many local, national, and international research projects and is currently the Vice Coordinator and STPM of the EU-funded H2020 INTER-IoT project. He is the co-founder and the CEO of SenSysCal

S.r.l., Rende, a spin-off of Unical, developing innovative IoT-based systems for e-health and domotics. He has authored over 350 publications in journals, conferences, and books. He is on the the list of Top Italian Scientists by the VIA-academy. He has over 4300 Google Scholar citations with an *H*-index of 35. His current research interests include agent-based computing, body area networks, wireless sensor networks, pervasive and cloud computing, multimedia networks, and Internet of Things technology.

Dr. Fortino was a recipient of the 2014 Andrew P. Sage SMC Transactions Paper Award. He has chaired over 85 international conferences/workshops as the Co-Chair, organized approximately 40 special issues in well-known ISI-impacted international journals, and participated on the Technical Program Committee of over 400 conferences. He is the Founding Editor of the Springer Book Series on “Internet of Things: Technology, Communications, and Computing,” and currently serves (as an Associate Editor) on the Editorial Board of the IEEE TRANSACTIONS ON AFFECTIVE COMPUTING, the IEEE TRANSACTIONS ON HUMAN–MACHINE SYSTEMS, the IEEE SENSORS JOURNAL, IEEE ACCESS, the *Journal of Networks and Computer Applications*, *Engineering Applications of Artificial Intelligence*, and *Information Fusion*. He is a member of the IEEE SMCS Board of Governors, the Chair of the IEEE SMC Italian Chapter, and the Founding Chair of the IEEE SMC Technical Committee on “Interactive and Wearable Computing and Devices.”